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Nuclear Power Generation in New Zealand

Report of the Royal Commission of Inquiry

April 1978

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Nuclear Power Generation in New Zealand

REPORT OF THE ROYAL COMMISSION OF INQUIRY

Presented to the House of Representatives by Command of His Excellency the Governor-General

BY AUTHORITY:
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THE ROYAL COMMISSION ON NUCLEAR POWER GENERATION IN NEW ZEALAND

Chairman

The Right Honourable Sir THADDEUS PEARCEY MCCARTHY, K.B.E.

Members

IAN D. BLAIR, M.B.E.
VIVIENNE M. BOYD
BRUCE S. LILEY
LINDSAY A. RANDERSON

Staff

Secretary: L. T. Heath
Research Officer: J. F. de Lisle
Editorial Officer: H. W. Orsman

Secretariat

R. E. Beeby
Mrs M. M. E. McDonald

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Royal Commission on Nuclear Power Generation

ELIZABETH THE SECOND, by the Grace of God, Queen of New Zealand and Her Other Realms and Territories, Head of the Commonwealth, Defender of the Faith:

To Our Trusty and Well-beloved the Right Honourable Sir THADDEUS PEARCEY MCCARTHY, Knight Commander of the Most Excellent Order of the British Empire, of Wellington, Doctor IAN DOUGLAS BLAIR, Member of the Most Excellent Order of the British Empire, of Christchurch, VIVIENNE MYRA BOYD, of Lower Hutt, Professor BRUCE SWEEN LILEY, of Hamilton, and LINDSAY AITKEN RANDERSON, of Wellington:

GREETING:

KNOW YE that We, reposing trust and confidence in your integrity, knowledge, and ability, do hereby nominate, constitute, and appoint you, the said the Right Honourable Sir THADDEUS PEARCEY MCCARTHY, IAN DOUGLAS BLAIR, VIVIENNE MYRA BOYD, BRUCE SWEEN LILEY, and LINDSAY AITKEN RANDERSON to be a Commission to inquire into and report upon the likely consequences of a nuclear power programme and, in so doing, to consider such matters as siting, licensing, environmental effects, safety factors, transport of fuel and waste, disposal of waste, and any other matters which the Commission decides should be brought to the attention of His Excellency the Governor-General.

And We hereby appoint you the said the Right Honourable Sir THADDEUS PEARCEY MCCARTHY to be the Chairman of the said Commission:

And for better enabling you to carry these presents into effect you are hereby authorised and empowered to make and conduct any inquiry or investigation under these presents in such manner and at such time and place as you think expedient, with power to adjourn from time to time and place to place as you think fit, and so that these presents shall continue in force and any such inquiry may at any time and place be resumed although not regularly adjourned from time to time or from place to place:

And you are hereby strictly charged and directed that you shall not at any time publish or otherwise disclose, save to His Excellency the Governor-General, in pursuance of these presents or by His Excellency's direction, the contents of any report so made or to be made by you, or any evidence or information obtained by you in the exercise of the powers hereby conferred on you, except such evidence or information as is received in the course of a sitting open to the public:

And it is hereby declared that the powers hereby conferred shall be exercisable notwithstanding the absence at any time of any one or any two of the members hereby appointed so long as the Chairman or a member deputed by the Chairman to act in his stead, and two other members, are present and concur in the exercise of the powers:

And We do further ordain that you have liberty to report your proceedings and findings under this Our Commission from time to time if you shall judge it expedient to do so.

And using all due diligence you are required to report to His Excellency the Governor-General in writing under your hands, not later than the 31st day of December 1977 your findings and opinions on the matters aforesaid:

And, lastly, it is hereby declared that these presents are issued under the authority of the letters patent of His Late Majesty King George the Fifth, dated the 11th day of May 1917, and under the authority of and subject to the provisions of the Commissions of Inquiry Act 1908, and with the advice and consent of the Executive Council of New Zealand.

In witness whereof We have caused this Our Commission to be issued and the Seal of New Zealand to be hereunto affixed at Wellington this 13th day of September 1976.

Witness Our Right Trusty and Well-beloved Sir Edward Denis Blundell, Knight Grand Cross of Our Most Distinguished Order of Saint Michael and Saint George, Knight Grand Cross of Our Royal Victorian Order, Knight Commander of Our Most Excellent Order of the British Empire, Governor-General and Commander-in-Chief in and over New Zealand.

DENIS BLUNDELL, Governor-General.

By His Excellency's Command—

R. D. MULDOON, Prime Minister.

Approved in Council—

P. G. MILLEN, Clerk of the Executive Council.

Extending the Time Within Which the Royal Commission on Nuclear Power Generation May Report

ELIZABETH THE SECOND, By the Grace of God, Queen of New Zealand and Her Other Realms and Territories, Head of the Commonwealth, Defender of the Faith:

To Our Trusty and Well-beloved the Right Honourable Sir THADDEUS PEARCEY MCCARTHY, Knight Commander of the Most Excellent Order of the British Empire, of Wellington, Doctor IAN DOUGLAS BLAIR, Member of the Most Excellent Order of the British Empire, of Christchurch, VIVIENNE MYRA BOYD, of Lower Hutt, Professor BRUCE SWEEN LILEY, of Hamilton, and LINDSAY AITKEN RANDERSON, of Wellington:

GREETING:

WHEREAS by Our Warrant dated the 13th day of September 1976 We nominated, constituted, and appointed you, the said the Right Honourable Sir THADDEUS PEARCEY MCCARTHY, IAN DOUGLAS BLAIR, VIVIENNE MYRA BOYD, BRUCE SWEEN LILEY, and LINDSAY AITKEN RANDERSON to be a Commission to inquire into and report upon the likely consequences of a nuclear power programme:

And whereas by Our said Warrant you were required to report to His Excellency the Governor-General, not later than the 31st day of December 1977, your findings and opinions on the matters aforesaid:

And whereas it is expedient that the time for so reporting should be extended as hereinafter provided:

Now, therefore, We do hereby extend until the 30th day of April 1978, the time within which you are so required to report, without prejudice to the liberty conferred on you by Our said Warrant to report your proceedings and findings from time to time if you should judge it expedient so to do:

And We do hereby confirm Our said Warrant and the Commission thereby constituted save as modified by these presents:

And, lastly, it is hereby declared that these presents are issued under the authority of the Letters Patent of His Late Majesty King George the Fifth, dated the 11th day of May 1917, and under the authority of and subject to the provisions of the Commissions of Inquiry Act 1908, and with the advice and consent of the Executive Council of New Zealand.

In witness whereof We have caused these presents to be issued and the Seal of New Zealand to be hereunto affixed at Wellington this 28th day of November 1977.

Witness The Right Honourable Sir Keith Jacka Holyoake, Knight Grand Cross of the Most Distinguished Order of Saint Michael and Saint George, Member of the Order of the Companions of Honour, Principal Companion of the Queen's Service Order, Governor-General and Commander-in-Chief in and over New Zealand.

KEITH HOLYOAKE, Governor-General.

By His Excellency's Command—

B. E. TALBOYS, Acting for Prime Minister.

Approved in Council—

P. G. MILLEN, Clerk of the Executive Council.

Letter of Transmittal

To His Excellency The Right Honourable Sir Keith Jacka Holyoake, Knight Grand Cross of the Most Distinguished Order of Saint Michael and Saint George, Member of the Order of the Companions of Honour, Principal Companion of the Queen's Service Order, Governor-General and Commander-in-Chief in and over New Zealand.

MAY IT PLEASE YOUR EXCELLENCY

Your Excellency's predecessor by Warrant dated 13 September 1976 appointed us the undersigned THADDEUS PEARCEY MCCARTHY, IAN DOUGLAS BLAIR, VIVIENNE MYRA BOYD, BRUCE SWEEN LILEY, and LINDSAY AITKEN RANDERSON, to report under the terms of reference stated in that Warrant.

We were originally requested to present our report by 31 December 1977, but this date was extended by your Excellency to 30 April 1978.

We now humbly submit our report for Your Excellency's consideration.

We have the honour to be

Your Excellency's most obedient servants,

THADDEUS MCCARTHY, Chairman.
IAN D. BLAIR, Member.
VIVIENNE M. BOYD, Member.
BRUCE S. LILEY, Member.
LINDSAY A. RANDERSON, Member.

Dated at Wellington this 30th day of April 1978.

We can learn from science and technology how to build a bridge. We may, perhaps, learn from social science what some of the social, political, and economic consequences of building the bridge will be. But whether those consequences are good or bad is not a question in either physical or social science.

And so it is of all the most important questions of human existence. What is the good life? What is a good society? What is the nature and destiny of man? . . . These questions do not yield to scientific inquiry. Nor do they become nonsense, as the logical positivists would have us believe, because they are not scientific. . . . Unfortunately, the question whether there is knowledge other than scientific knowledge is one that science can never answer. It is a philosophical question.

Robert M. Hutchins *The Conflict of Education,* 1953.

PART I

Chapter 1. THE NATURE AND SCOPE OF THE INQUIRY

INTRODUCTION

1. The terms of the Warrant of Your Excellency's predecessor are on first sight specific and confining, limiting us, it might appear, to a mere description of the likely consequences of a nuclear power programme. But such consequences must be seen in the special context of New Zealand and its needs, in a time of world-wide public debate about nuclear power. For this, among other reasons, we have felt justified in placing a broad rather than a narrow legal interpretation upon the language of the Warrant given us. Such an interpretation has affected the form and content of our report. Instead of being fashioned by the terms of its Warrant (as many such reports most aptly are, with each Warrant item dealt with specifically in a separate chapter) our report demands a different structure. We see it falling into four parts, which we now describe.

2. *Part I* contains an explanatory introduction to the inquiry, and an "overview" which is a general discussion of the whole energy scene and a summary of our views about the case for nuclear power in New Zealand now and in the future. *Part II* seeks to gather in much more detail the information we have gained on the whole energy question both in New Zealand and overseas about the present state of, and probable developments in, nuclear physics and engineering, and their expected employment in the future. We also discuss the public acceptability of nuclear power today, especially in the New Zealand context. *Part III* takes up the proposals of the New Zealand Electricity Department (NZED) relating to the introduction of a nuclear power programme as they appeared when we began, and as they now appear; the present and projected generation of electricity in New Zealand; and the different projections of the country's future electricity consumption and the ability of the likely available resources to meet them. *Part IV* discusses at length the consequences for New Zealand of adopting a nuclear programme—those specifically mentioned in our Warrant, and others.

3. This report is not the work of any one person. All members of the Royal Commission, aided greatly by our staff, have taken part in drafting it, with the result that there are perhaps some variations in style. Be that as it may, the report conveys the consensus of us all. It is, we think, the kind of report Your Excellency would require of us. We acknowledge, too, that we have drawn extensively from submissions, and in areas of detailed material especially, from those of State departments. It has not always been possible without interfering unduly with the flow of discussion to acknowledge each and every one of these borrowings, but we have done so where it seemed most desirable.

FACTORS SHAPING OUR THINKING AND REPORT

4. Though we aim at an acceptable standard of scientific accuracy, we have not sought to compile a textbook on any of the areas touched on by our inquiry. We are not nuclear physicists, indeed most of us are not physicists at all. We believe, moreover, that Your Excellency's predecessor's intentions were that we should conduct an inquiry and reach our conclusions rather as informed non-scientists, allowing ourselves to be influenced by all considerations which properly and reasonably affect our community. Such considerations are not exclusively scientific or technical. They introduce philosophical and moral values.

5. Change, someone has written, is the only constant in the field of nuclear power. We have been impressed with its inevitability and speed. It has added to our difficulties—for example, in producing a report which does not seem almost out of date by the time it is released. Even in the short time of our inquiry, administrative structures have altered considerably here and overseas. Nuclear technology is still quite new. As recently as 1956 the first commercial reactor, Britain's Calder Hall, fed electricity into a national grid. Though technology has developed rapidly since then, and many countries are now designing and making nuclear plant, the industry is still in its infancy. The large rises in oil prices in 1973–74 have led to intensified research (and development) not only into producing energy by nuclear fission in ways now well understood, but also into the more complex fast-breeder reactors, and into the possibility of producing electricity from nuclear fusion. Thus the timing of any decision to introduce nuclear power to New Zealand, if that step is to be taken, is of prime importance. We have therefore given it a prominent place in our considerations.

6. Coincident with the rise of nuclear technology, there has been a growing realisation that the world's reserves of fossil fuels are quickly being depleted, and could become critically scarce before the end of the century. The rises in oil prices in the 1970s brought this home. One result is a spate of reports and documentary material from various official commissions and boards of inquiry in New Zealand and overseas, from manufacturers of nuclear hardware, from scientists who favour or oppose nuclear programmes, and from a very articulate opposition in environmental and anti-nuclear organisations. We have found all these a most fertile and varied source of information. Indeed, we have had the greatest difficulty in assimilating the wealth of material given us as well as that which we gathered during our investigations overseas. This information has added to our sense of the inevitability and rapidity of change in nuclear power development, and in the development of alternative resources. It has fortified our belief that this climate of change and discovery is a most important factor to be considered when the question is asked whether a final decision to introduce, or to reject, nuclear power can best be made now or later.

7. There can be no doubt that in New Zealand and elsewhere many citizens fear the consequences of nuclear power generation. Their motivations are numerous, complex, and sometimes emotionally-based rather than informed. Radiation is, and has always been, perhaps the most common external influence to which human beings are exposed by nature. But the memory of the first major use of nuclear power as a devastating weapon has coloured the whole subject. This, with a growing awareness of the health and genetic consequences of escapes of man-made radiation,

and an increasing dissatisfaction with modern industrialised communities, has created a climate in which it would be inappropriate for us to regard our inquiry as calling for scientifically-based approaches only. As we have said, we accept that philosophical and moral issues affect the judgments of men and women on the nuclear question (as on all questions about the quality of life we should seek), and are therefore most important in any decisions which are to be made about nuclear power generation, especially for New Zealand where this technology has not yet been used.

8. But it is not only nuclear power that has problems. All large power plants can have their undesirable consequences. Hydro-electric installations can destroy the beauty of valleys, lakes, and rivers, and have disastrous effects on natural habitats. Coal-fired and oil-fired thermal stations are usually ugly, and poison the atmosphere; and there are many eminent scientists who believe that the changes in the atmosphere produced by accumulations of carbon dioxide from burning fossil fuels could ultimately prove more worrying for mankind than the products of nuclear fission. Oil has its own acute pollution risk, especially when carried by sea. So does the transportation of natural gas. Moreover, serious moral questions are inherent in the consumption of oil, gas, and, in some countries, coal in ways which deprive future generations of those valuable fossil deposits for uses perhaps more advantageous than the production of power. It was this ferment of conflicting considerations, values, and community divisions which led Sir John Hill, the Chairman of the United Kingdom Atomic Energy Authority (UKAEA), to say recently that the principal problems of nuclear power are now not engineering nor technical but those of political will and public acceptability.

BACKGROUND TO THE INQUIRY

9. From the seemingly inexhaustible colonial resources of wood and coal, New Zealand passed for its energy needs to hydro-electricity, again apparently inexhaustible. But the rate of growth of electric power outstripped that of all other forms of energy, so much so that from the Second World War to March 1976, the major hydro resources of the North Island and the most suitable remaining bodies of water in the South (including the present Upper Waitaki and the projected Clutha schemes) were committed. In 1977 hydro-generation produced about 80 percent of the national electricity supply, geothermal 8 percent, and fossil fuels, including highly expensive imported oil, the remaining 12 percent.

10. The Planning Committee on Electric Power Development (PCEPD) presents a power plan to the Government each year, and recommends how future needs can be met. It first introduced nuclear power in the 1968 Power Plan as being necessary to meet forecasted demand. The discovery of the Kapuni and Maui gas fields, and a recent slacking-off in electricity consumption, allowed the timing of the proposed introduction of nuclear power to be somewhat postponed. But the 1976 Power Plan still saw nuclear power as one of the main options for thermal generation beyond 1990, and maintained (because of the long "lead-time" needed to introduce the complex nuclear technology) that a Government "decision in principle" to introduce it would be needed in 1977 or shortly thereafter.

11. Nuclear power was first considered in New Zealand's electricity planning in a period of optimism when nuclear power programmes spread in the western world accompanied by confident estimates of safe, cheap,

and almost unlimited electrical energy. But later, as doubts grew, nuclear power was strenuously questioned on counts of safety, cost, and reliability; first in the United States, then in other countries. In New Zealand there has been widespread, articulate questioning and protest, with demands for public debate and public inquiry. It is against this background that our inquiry was set up.

12. Politically, the interest reflected a bipartisan approach. In late 1975, the Labour Government set up an independent fact-finding group of scientists and other informed people to examine the possible environmental consequences of nuclear power production compared with those of possible alternatives. This Fact Finding Group on Nuclear Power (FFGNP) was chaired by Sir Malcolm Burns, K.B.E., formerly Principal of Lincoln College and at the time President of the Royal Society of New Zealand. Later in the same year, the National Party, then in opposition, presented an election manifesto in which it undertook not "to introduce nuclear power generation in New Zealand until a public inquiry into all aspects of this source of energy has taken place and until it is convinced that the technological aspects have been satisfactorily resolved". In November 1976 a petition was presented to Parliament containing 333 088 signatures advocating an entirely non-nuclear future for New Zealand.

13. Finally, in September 1976, the present National Government set up this Royal Commission. Its purposes, which at first sight would seem very similar to those for which the FFGNP was established, were to inquire into and report upon the likely consequences of nuclear power, and in so doing, to give special consideration to a number of specified areas. But the character of the inquiry was obviously to be different from that made by the FFGNP which was to operate as a scientifically qualified investigating group. Though it did initially intend to invite submissions from the public, the setting-up of this Royal Commission led to a change of mind, public involvement appearing then to be no longer necessary. In contrast, our inquiry was, we thought, intended as a less scientific review; one at which the public could be heard and to which it could bring its needs, its doubts, its fears. We would have to give attention and weight to these. All this we discuss again in this chapter when we explain why we deliberately placed a broad reading on the language of the Warrant defining the extent of our inquiry.

14. Meanwhile, independently, the New Zealand Energy Research and Development Committee (NZERDC), under the chairmanship of Dr C. J. Maiden, had established an energy research group led by Dr Garth Harris, Executive Officer of the Committee, to explore a range of energy choices open to New Zealand, and to identify policies which would match those choices. It decided to construct three scenarios based on different forms of industrial, economic, and population growths to show how our energy needs would be affected by these different assumptions of growth. These were not designed as a forecast but as a feasibility study, and, as their authors emphasised, imply an unlikely degree of consensus by the whole community. They outline ways in which their three objectives might be reached. They are described in detail in chapter 3.

15. The activity in New Zealand was in line with what was going on overseas. Many investigations were under way, and many reports have come to our notice. We mention the more important. First, the sixth report of the Royal Commission on Environmental Pollution in Britain, chaired by Sir Brian Flowers (the Flowers report) became available to us

shortly after we began. Next came the First Report of the Ranger Uranium Environmental Inquiry in Australia, chaired by the Hon. Mr Justice R. W. Fox (the Fox report). Third were the three Maiden scenarios which we have just mentioned. Fourth were the preliminary papers of the Royal Commission on Electric Power Planning in Ontario, chaired by Dr Arthur Porter. Fifth was the report of the Nuclear Energy Policy Study Group sponsored by the Ford Foundation and administered by the MITRE Corporation in the United States (Ford Foundation - MITRE report), a discussion on nuclear power issues and choices by a committee of individuals with a wide variety of expertise, experience, and viewpoints, none of whom had taken a strong position for or against nuclear power. It was issued in January 1977. Sixth was the report of the FFGNP. These reports added greatly to the material available to us and were relied upon by participants in our inquiry to buttress their various arguments. We shall refer to them from time to time, and in far more detail in their particular areas of relevance.

16. During our inquiry governmental and scientific sources made many statements indicating that a decision on nuclear power was not now nearly as urgent as was previously thought. The Maiden scenarios and the FFGNP report (both in March 1977) suggested that if appropriate steps were taken there would be at least some delay before a decision to introduce nuclear power must be made. The Minister of Energy Resources shortly afterwards stated his opinion that this was possibly so. On 1 June 1977, the general manager of the NZED, Mr P. W. Blakeley, was reported as saying that the fall-off in demand had reached the point where even the official 1976 projection that two 600 MW nuclear reactors would be needed by 1991 was "a thing of the past".

17. Next, in July 1977, the Budget gave prominence and support to energy research, to the ascertainment and development of indigenous resources, and to incentives for energy conservation of various kinds. Later in the year the Minister of Energy Resources repeated his belief that there was "no need for a decision [about nuclear power] at present or probably for a few years". This was followed by the tabling in Parliament of the report of the PCEPD which reduced its earlier predictions of future demands for electricity, and dropped nuclear power as an alternative possibly needed within the next 15 years.

18. These manifest changes of opinion, coupled with the statutory creation of a Ministry of Energy designed to bring the departments primarily associated with energy under one central control and to promote greater efficiency in research, investigation, and development, caused the question to be asked in the later months of 1977: had not this Royal Commission already sufficiently fulfilled its purpose by influencing considerably the turn of these very events? It was also suggested that little further was to be gained by our preparing and publishing a report. But for reasons given in the overview in chapter 2, we have felt obliged to complete the work we undertook, though necessarily events have influenced greatly the form which our report now takes as well as reducing the tensions surrounding our inquiry, and making our task easier and more pleasant.

INTERPRETATION OF WARRANT AND RANGE OF INQUIRY

19. In interpreting the wording of our Warrant, we thought it essential to bear in mind the environment which we have sought to explain in the preceding section, and to be influenced by what we saw as the general purpose of the inquiry. The text of the direction of our Warrant reads:

> . . . to inquire into and report upon the likely consequences of a nuclear power programme and, in so doing, to consider such matters as siting, licensing, environmental effects, safety factors, transport of fuel and waste, disposal of waste, and any other matters which the Commission decides should be brought to the attention of His Excellency the Governor-General.

But we could not possibly see our task as being limited to a scientifically-based exposition of the consequences specified in the above and similar quotations. Therefore, we have rejected a strict literal interpretation and adopted a broad liberal one. Moreover, the Government through the then Minister of Energy Resources, the Hon. E. S. F. Holland, in answer to criticism of the limitations thought to be imposed by the Warrant, expressed the hope that the Royal Commission would take a wide view of its powers, a hope that was repeated by his successor, the Hon. G. F. Gair. So in the course of his directions made at the opening of our sittings in November 1976, the Chairman said:

> The matter upon which many await a statement from us, is the interpretation which we intend to place upon the definition of our task as it is set out in His Excellency's Warrant. The definitive words in that Warrant are "to inquire into and report upon the likely consequences of a nuclear power programme and, in so doing, to consider such matters as siting, licensing, environmental effects, safety factors, transport of fuel and waste, disposal of waste, and any other matters which the Commission decides should be brought to the attention of His Excellency the Governor-General". It will be seen that the dominant phrases in that citation are "the likely consequences" and "in so doing". This definition of our function or task has been drawn in a way which patently limits the inquiry to the likely consequences of a nuclear programme. That is not to imply that the Government has decided upon such a programme, but it appears that it does wish to know, in the event of its having to make a decision one way or the other, what are likely to be the consequences of the adoption of a nuclear programme. After asking us to report upon such likely consequences, the Warrant lists a class of matters to which we can turn our attention when examining consequences. I have read the description of that class. In that relation, the words "in so doing" are most important. It could be argued from the phraseology of the description of the class of matters that notwithstanding the general words at the end of that description, the class is of a quite restricted technical nature, that is, it is limited to the class of matter specifically stated. Nevertheless, we hope to take as broad as possible an approach to our task, and we do not propose to exclude any matter which on a fair interpretation of our Order can be said to relate to consequences. Of course, our Order does not permit us to say whether nuclear power should or should not be introduced; but it is for us to draw attention to likely consequences favourable and unfavourable which a Government would have to take into account in determining that ultimate question. In this regard it should be noted that although we are not explicitly asked to consider alternatives, it may be that a fair measure of the consequences of one particular course of action can be obtained only by comparison with possibilities. We shall be willing to hear submissions on that proposition.
>
> We recognise that all this is general, and perhaps not as helpful to you as you would wish; but it is impossible for us, at this stage, to be more precise or to list the matters which fairly can be said to bear on matters we are directed to inquire into. That can only be decided from time to time as we hear the submissions or evidence. Let us be clear about this: a Royal Commission has no

jurisdiction whatsoever to go outside the limits of its Warrant no matter what considerations might be said to exist in favour of that course. A Royal Commission does not draw its own Warrant. But we are heartened by the expressed wish of Government that we should interpret our Warrant as liberally as we fairly can. We shall endeavour to do that and, as we have indicated, we will not confine you unnecessarily. But we must be clear and avoid any misleading. Though we shall take as broad as permissible a view of the matters which relate to consequences, we cannot go beyond that area. As we have already said, no Royal Commission is entitled to disregard the directions of its Warrant and, as it were, to redraft the Warrant in a way it may consider it could have been drawn. Therefore, do not expect us to investigate matters which are plainly outside the parameters of the document which defines our task. Only His Excellency the Governor-General, on the advice of his Government, can authorise that.

20. As the inquiry progressed, we became fortified in our belief that whether nuclear power was suitable for and needed in New Zealand (considering alternative available sources) were primary issues in any worthwhile inquiry. Evidence on these and other matters bearing on the possible choices of action open to the Government was freely admitted. We found it hard to draw the boundaries between evidence which could be admitted on our construction of the Warrant and that which must be rejected as relating to matters which could not on any acceptable liberal interpretation be held to be included. We chose to err on the side of liberality of admission rather than on that of rigidity of exclusion.

21. This is not the sort of study which calls for detailed recommendations as an examination of an existing New Zealand structure would, nor do the terms of our Warrant call for them. We have been concerned to study primarily the need for nuclear power in this country now and in the future, to portray the consequences which are apparent in such countries as have adopted that form of electricity generation, and to visualise how these consequences might apply in New Zealand. Most of the conclusions or recommendations made in the course of preparing this report are not of central importance and emerge sufficiently clearly in the text. They do not justify a gathering together. Our most important are summarised at the end of the overview which follows.

22. In short then our task as we have seen it has been to consider the consequences of introducing a nuclear power programme in the light of the country's present and estimated future energy needs, its present and projected indigenous or imported resources, the choices open to those who are responsible for ensuring that energy is available to meet all proper claims for it, and finally, the most appropriate times at which decisions can be made about a commitment to, or rejection of, nuclear energy. To deal with these basic questions at all adequately we have necessarily had to cover a wide field: how wide it is emerges, we believe, from a reading of this report.

THE PROGRESS OF THE INQUIRY

Procedure

23. The Warrant appointing the Royal Commission was published in the *New Zealand Gazette* No. 100 of 16 September 1976. Advertisements inviting submissions were placed in metropolitan and provincial newspapers on 25 September 1976. Further advertisements were placed in local papers at Auckland, Christchurch, and Dunedin as the Commission

was about to move to these cities for hearings. Our first public sitting at Wellington on 3 November 1976 was limited to a roll-call of those organisations and people who would be taking part, and the opening remarks of the Chairman, in which he informed those present of the stand taken by the Royal Commission about the scope of the inquiry and the procedures to be adopted. He explained that he intended to allow cross-examination freely, provided it was conducted in a proper manner and was not unduly repetitive. All taking part in the hearing would be allowed to cross-examine without engaging counsel.

Public Hearings

24. The first submissions were heard in public on 10 December 1976 in Wellington, and hearings continued until 17 November 1977. Sittings were held in Auckland from 2–6 May; Dunedin, 16–18 May; and Christchurch, 13–16 June. A verbatim record of the submissions and cross-examination was kept throughout. At the first hearing in December the main State departments concerned presented background submissions about their role in the energy field. Then in February 1977 the public hearings of general submissions received from departments, organisations, and individuals were begun.

25. Although at first there was some tension between the main groups representing those seeking approval of a nuclear programme and those opposing—the latter groups were plainly somewhat apprehensive of the procedures which would be followed—by the time the hearings were completed there was, obviously, a general feeling of goodwill and of satisfaction with our procedures.

26. At no time did we refuse to allow cross-examination. Indeed, after each submission, those present who had an interest in the matter under consideration were invited to ask questions. These invitations were accepted freely, and although at times some of the cross-examination was rather long and perhaps too detailed, permission to cross-examine was never abused. We fully appreciated the co-operative attitude of those who attended our hearings. The inquiry was, as a result, much more pleasant for all than it might otherwise have been.

27. During 3 November 1976 to 17 November 1977 when public hearings were held, the Commission sat for a total of 52 days, and 141 submissions were presented. Appendix A gives a list of the organisations and individuals who made submissions. No use was made of the provision for submissions to be presented in confidence outside the public hearings. We sat mainly in Wellington with hearings also in Auckland, Christchurch, and Dunedin. At first the intention had been to go only to Auckland and Christchurch, but there was pressure for us to hold a hearing in Dunedin, and this was agreed to. The number of submissions heard at this hearing was only 5, but the visit proved fruitful.

Overseas Visits

28. In addition to hearing submissions in New Zealand, all members of the Royal Commission and the secretary travelled overseas in September and October 1977 interviewing people and organisations and seeing energy installations in the United States, Canada, Britain, France, Sweden, Switzerland, Austria, and South Africa. Before we set out, the chief organisations taking part in our inquiry were asked to submit the names of people whom they thought we should interview, and the places

we should visit. As was to be expected a very large list of names and places was supplied and these had to be culled to those who were given the highest priority by the bodies putting their names forward. We tried to see as many as possible. Over 70 interviews and visits took place. Besides State departments and agencies, we visited utilities and other organisations concerned in the production and distribution of energy. We took opportunities to visit such celebrated laboratories as Lawrence Livermore in California, Oak Ridge in Tennessee, and Harwell and Culham in Britain. We visited many atomic plants, including 6 of the 19 plants operating in Britain at the time. As often as possible we discussed with members of local communities the impact of these plants on them.

29. A check on the priority list provided by Environment and Conservation Organisations of New Zealand (ECO), who collated the requests of most of the organisations opposing nuclear power, shows that 75 percent of the 28 people and organisations recommended were interviewed. This is a high percentage indeed when it is remembered that these were busy people scattered over the different countries, and often not readily available for interview. The arrangements for these interviews and visits fell in the main on overseas staff of the Ministry of Foreign Affairs. The smooth operation of our programme was due in no small measure to the excellent work of the ministry, for which we are grateful.

30. We believe that this overseas exercise was well worthwhile. Though we did not gain any information which was essentially new in the sense that we had not heard of it before, we were able to supplement greatly our information and knowledge about many aspects. We received a great deal of written material from the people and places we visited, and this has been made available to all who have taken part in our inquiry. But of even more importance than this, were the fruitful opportunities to talk to people and to sense their reactions to the presence of nuclear energy in their midst. On the one hand there were those opposed to nuclear power—some implacably opposed, others ready to accept it only should there be no satisfactory alternative. On the other, there were people in and about the industry, those engaged in planning the nuclear programmes, those working with them, and those living in the vicinity of nuclear power plants who took a contrary view. All this brought a measure of realism and insight which until then was inevitably lacking in our experience. No amount of printed matter, be it in books or submissions, can possibly substitute for the experience of seeing nuclear reactors being built or operated, with their extensive control and safety systems, or convey the feelings of those who live within range of the possible effects of an accidental release of radioactive material. The reactions of these people are of special importance, and are discussed in a later chapter of this report.

Comments on the Evidence

31. Copies of submissions were received in advance and distributed to departments, organisations, and interested people as soon as their receipt had been announced at a hearing. This enabled those people and organisations to prepare themselves to cross-examine on the various submissions. A total of 114 submissions were presented in person, and 27 were merely registered and made available to people concerned. A verbatim record of the evidence (submissions and cross-examination) totalling 6335 pages was kept and copies distributed. Copies of all submissions and

cross-examination were sent to the Auckland, Wellington, Christchurch, and Dunedin public libraries, and a copy was maintained for public inspection in our Wellington office. Two copies have been sent to the General Assembly Library.

32. Generally speaking, the submissions received were of a high standard. Some were excellent indeed. Of those supplied by State departments, we would mention especially the background papers submitted by the Department of Scientific and Industrial Research (DSIR). These were of an extraordinarily high quality; we have seen nothing better anywhere, and we would suggest that they deserve publication in a form which ensures greater availability. The submissions of the NZED, the Ministry of Works and Development (MWD), and the Ministry of Energy Resources (MER) also deserve commendation for care in preparation and detail. Indeed, all State departments deserve our thanks for their co-operation and help though we confess that we were somewhat disappointed with the assistance we received from the Treasury. It did not think it necessary to give evidence in the form of a submission and appeared only after it was made clear that the Commission insisted upon an appropriate appearance. Its reasons were basically that, as in its opinion a decision on nuclear power would not be needed for 20 years, it was consequently irrelevant to discuss issues of costs and their impact on the economy at this time. Treasury's attitude was criticised by the Friends of the Earth who described its contribution as being "grossly inadequate". We had expected a more helpful approach to our problems. We also expected but did not receive submissions from the electricity supply authorities, the Manufacturers' Federation, and the Chambers of Commerce—organisations which we would have thought would be sufficiently concerned about the energy situation of this country in the years to come to have made representations to us.

33. Of the non-departmental submissions, we mention especially those supplied by the Friends of the Earth (Dr D. Hocking), The Campaign for Non-Nuclear Futures (Mrs M. Melhuish), and Ecology Action (Otago) Incorporated. We mention too, the submissions of Dr E. Geiringer who attended our hearings constantly in the role of a concerned citizen, and whose contribution to the inquiry was valuable and stimulating.

The News Media

34. We were disappointed at the extent and quality of the coverage given by the news media. We do not underestimate the difficulties of obtaining reporters or news commentators sufficiently conversant with the technical problems of nuclear energy to enable balanced reports of submissions, nor of those of maintaining a continuous attendance at an inquiry of great length. Nevertheless, we felt that with some exceptions the media, in addition to the intermittent character of their participation, were over-inclined to give prominence to the views of some witnesses rather than to the better balanced evidence of more knowledgeable people. As a result the media did not help as fully as we would have wished the Government's objective of promoting an informed public debate by means of our inquiry. We found that this was often the experience of overseas inquiries into nuclear power, though now that this technology is established in North America and Europe, the media there appear to be improving their coverage of developments and unresolved issues.

35. The New Zealand public needs objective information about what nuclear power and technology involves and entails. For that reason, in presenting our report we have aimed to compile a source of information that will assist lay or non-expert understanding of a technology that could, in the foreseeable future, be even more prominent in the world.

Chapter 2. THE OVERVIEW

INTRODUCTION

1. Here we seek to present in short form, and as far as possible in non-technical language, a statement of our views about the desirability and need for nuclear electricity generation in New Zealand, and the consequences of its introduction. This is more than a summary of our report, and in form is somewhat different. It is designed to give the general reader a useful "overview" of our thinking. Those wishing detail and more scientific discussion should turn to later chapters. Inevitably in those chapters we look at specific topics from different viewpoints. This may give an impression of unnecessary duplication—something we have tried to avoid. But some such duplication is unavoidable.

2. In the introductory chapter 1, we have sought to explain a number of significant matters:

- the changing energy scene and the emerging public concern about nuclear power as a form of electricity generation which led the present Government to establish a Royal Commission of Inquiry;
- the seemingly restricted scope of the inquiry as appeared from the terms of our Warrant which, on its face, would confine us to an examination of the consequences of a nuclear power programme in New Zealand;
- how we thought it meaningless and unprofitable to consider consequences without first considering the need for, and advantages of, nuclear power in New Zealand, without weighing its consequences against those of the alternatives, and without taking into account the time scales involved;
- how we felt obliged to take a very broad view of the areas which the Warrant permitted us to survey with the result that during our hearings we allowed discussion to range over almost all aspects of the nuclear debate;

We have also sought to explain the marked changes which have taken place in official thinking since our inquiry began. This is an important matter which must be stressed even at the expense of some repetition.

.*Changes in Official Viewpoints*

3. In 1976 when the Royal Commission was established, the Committee to Review Power Requirements (CRPR) forecast that electricity demand in 1990 could reach 49 774 GWh a year, with up to 80 400 GWh a year being needed at the end of the century. But the more recent CRPR report of 30 May 1977, which was not released until September when we were overseas on our investigatory study, has greatly reduced its earlier

forecast. The majority of the Committee now forecasts a demand of 47 664 GWh a year for the year 1991–1992; the minority arrives at 41 747 GWh a year. More significantly perhaps from our point of view, the PCEPD, which submits to the Government a plan for developing generating capacity to meet the load forecasts of the CRPR, no longer sees nuclear power as a likely need within the Committee's planning period of 15 years though formerly considering it as one of the most important options for electricity generation beyond 1990. To keep that option open an early decision whether it was to be adopted was necessary. The Committee now believes that a nuclear power station will not be needed to satisfy load growth in the next 15 years. This is not intended to mean that nuclear power can be disregarded as a future energy option. The Committee repeatedly stresses that State departments should continue to keep in close touch with developments overseas, and advance their expertise in, and understanding of, nuclear technology so that its value for electricity generation can be kept in perspective. In its view, a decision to proceed with nuclear power no longer needs to be made in the immediate future.

4. Doubtless there are many reasons for these changes in attitude. We think the Committee's present opinions reflect what seems to be a fairly general belief in the community that taking up the nuclear option is at least not as urgent as many officials previously thought. Plainly, the department most closely involved, the NZED, now agrees. It no longer holds to its former view that nuclear power would probably be needed in the early 1990s, and it has reduced its estimates of future demand at the turn of the century to 60 000–70 000 GWh a year. However, it still seeks authority to take necessary steps to ensure that the nuclear option is available after the PCEPD's 15-year survey period. We discuss this later. But the NZED does not claim that nuclear power will definitely be needed at any time before the year 2000—nor even then. No one now makes such a positive assertion.

5. We imagine that the general falling off in the growth of demand over the last 4 years has modified the views of the CRPR and the NZED, though they are well aware that this decrease (for detail see chapter 6) could prove to be, in part at least, merely temporary. In the United States and Canada, for example, where growth rates have fallen substantially in recent years, there are signs that peak demands are rising again, though the earlier high figures have not been attained.

6. The Maiden scenarios and the report of the FFGNP have also influenced the departments most concerned. But we feel entitled to claim that our inquiry probably as much as (if not more than) anything else has led to these substantial changes in viewpoint, as well as achieving a relaxation of the divisions between the two sides to the argument. During our hearings, the forecasts, past and present, of the CRPR and of the NZED were under sustained attack as extravagant and tending to stimulate consumption rather than conservation. Because of this, as well as the present trends in Gross National Product (GNP) and population growths, departmental officers felt obliged to re-examine their earlier estimates of demand and available resources, and to support their estimates under cross-examination. Moreover, it emerged that not all departments involved were completely in agreement, although, as we shall later see, they came to much closer agreement by the time our public hearings were over.

7. At present, as we see it, no one asserts that New Zealand will certainly need nuclear power before the year 2000, or indeed after. This, we repeat, is a striking change from some official attitudes which obtained when the inquiry was set up. Thus it would be unacceptable for us to advocate an early commitment to nuclear power unless we were satisfied that there was no escape from that commitment, or that the advantages of a decision now in favour of nuclear power were overwhelming. We shall later say that we are not so satisfied.

Continuation of the Royal Commission's Task

8. The question may well be asked then whether, after these changed attitudes emerged, there was a sufficient need for this Royal Commission to continue. It would seem reasonable to say that the Royal Commission had already completed the main work given it by aiding the public debate, and by contributing to a consensus that there was no need for an early nuclear commitment. Furthermore, it was said that much of any technical detail we might write would be well out of date by the time a firm decision on a nuclear programme could be necessary. We were ourselves troubled by such thoughts about our duties. To write a report which might seem to do little more than help to postpone a final decision, and which could date rapidly in a fast changing world, is not a stimulating task. But apart from the obligations imposed by our Warrant, from which we have not asked to be relieved, we have felt that we must go on if only to satisfy ourselves whether, in spite of the changes in official thinking about a nuclear commitment, the forecasts and viewpoints of the CRPR and the PCEPD should be accepted as soundly based. Moreover, we hope that what we write may be a helpful foundation for the further reviews which will be necessary from time to time to keep the nuclear option effectively open, as we will say it should be. We hope too that it will prove helpful in educating our community in the general problems of energy, and in those of nuclear energy in particular. However, in all these circumstances, we have thought it justifiable to aim at a somewhat different form of report than we might otherwise have produced.

THE WORLD ENERGY SCENE

9. An obvious basic, indeed pivotal, decision for us is whether we share the view that nuclear power is not likely to be needed in New Zealand in this century. That in turn will depend on our own judgments of what a reasonable and justifiable demand is likely to be, and what means other than nuclear power should be available to meet that demand over the coming 22 years. But electricity is only one form of energy and it cannot be considered in isolation from other forms. We, like most overseas inquiries into electricity generation, have found it necessary to look at the world energy scene, in particular at electricity, before turning to the local, and to consider the different energy strategies which are open to New Zealand.

10. So in chapter 3 we survey briefly the world's energy consumption and resources, and then the New Zealand situation. The "energy crisis" resulting from the substantial rises in oil price in 1973–74 brought home to the world the long warned of dangers of depending unduly on specific forms of energy, especially oil. The world will never run completely out of energy, for its forms are multiple and inexhaustible; but mankind does, at

least in the short term, face a most serious shortage of those forms of energy that can be readily used at an economic price. It is on these forms which the way of life of developed countries has very largely been built. In the long term, new usable forms of energy (such as those relying on fusion) may provide an abundance for everyone. Oil is at present the source of our greatest concern.

11. In 1975 oil supplied 45 percent of the world's primary energy including that used for electricity (Fox report, page 37). The chairman of the UKAEA, Sir John Hill, has said recently that nearly three-quarters of the world's effective energy input comes from oil or gas. These figures may be questioned, but there is little room for doubt now that the world's oil resources are being rapidly depleted, and although at the moment oil is still readily available, it will not be for long. When exactly oil production will peak, and demand overtake supply, is a matter of debate, but the consensus of evidence given to us, and of the information we obtained overseas, points to a probable date of between 1985 and 1990. From then on oil could become increasingly expensive. Fresh discoveries could of course prolong the period of availability, but new fields such as the North Sea or Alaska would need to be discovered every 1 or 2 years to maintain present patterns of consumption through to the eighties and into the nineties. Many oil experts consider that by the year 2000 it will be extremely scarce and will be likely to be used selectively, for example for petrochemicals, rather than lavishly for transport.

12. The impending shortage of the world's conventional transport fuels has led to an intense scientific search for economically priced substitutes; for example, the conversion of coal or biomass into transport fuels, and the like use of hydrogen which is limitless in the oceans. But at present, cost proves the stumbling block, though we were told that South Africa has had for a long time a pilot plant making transport fuel from coal and at present supplying a small percentage of that country's needs at costs reasonably comparable with imported oil. It has been so successful that a decision has been made to build a substantial plant which, it is hoped, will meet 30 percent of South Africa's predicted transport fuel needs in the mid-1980s. South Africa has immense quantities of cheap coal which make this possible. Other countries too have immense coal reserves though possibly the extraction costs are higher. But New Zealand's coal resources are not large and there are no liquid petroleum products yet located, other than a small amount of condensate from the Kapuni and Maui gas fields. Thus, New Zealand has a grave problem with fuel to keep our transport moving in years to come. Many authorities think it the greatest problem for the economies of all countries placed as New Zealand is. The search for oil continues, with some hope of success. But if no substantial field is discovered, New Zealand could be in a most difficult position by the turn of the century. Any oil then available to us is unlikely to be used for generating electricity. Such arguments lend strength to the case for future nuclear generation in New Zealand.

13. The size of the problem is seen in all its seriousness when we know that until very recently 60 percent of the country's total energy needs was supplied by imported oil at an annual cost of close on $550 million. When natural gas becomes more available, the proportion is expected to drop to about 40 percent—still a most substantial and expensive percentage. We add that if some heavy consumers of oil such as the United States and the EEC countries are forced by internal or external pressures to abandon or

delay their nuclear programmes, their demands for oil will most probably grow. New Zealand's position as a relatively small buyer with little economic bargaining power would then be even more precarious. The present Minister of Energy, the Hon. G. F. Gair, has rightly made this point in public statements.

14. The New Zealander, contrary to the beliefs of many, is not a high total energy consumer. Our per capita consumption has been below that of industrialised countries. Precise figures are not easy to come by, and are often out-of-date, but it seems that our per capita consumption is about a quarter of that of the United States, one-third of that of Canada, and not much more than a half of that of Britain, Sweden, Denmark, and Australia. It is lower than that of France, Japan, and Switzerland. It is close to that of Italy. On the other hand, owing no doubt to the hitherto cheap electricity from hydro sources, our per capita electricity consumption has been among the highest in the world, being exceeded only by Canada, Sweden, and the United States.

15. Nevertheless, many witnesses during our inquiry strongly criticised the level of New Zealand's total energy consumption, seeing it as causing much that is objectionable in modern industrial life. They would urge a much simpler life-style. Some advocated a movement towards a "sustainable" society, or a "conserver" rather than a "consumer" society, by more efficient use of non-renewable resources, greater conservation of energy (especially electricity), and more emphasis on developing renewable resources, accompanied by simpler styles of life. They would contrast the so-called "hard" technology unfavourably with the "soft" technology of using renewable energy resources. Though most advocates of such changes are academically qualified, intelligent people, we remain unconvinced that most New Zealanders share their views. Even if it were possible to gain a consensus that simpler life-styles are desirable social aims, we were given little indication of how the aims could be achieved, or of how society could be induced to change its values without prejudicing the personal freedoms which these same witnesses so strongly advocated. Moreover, we strongly believe that economic growth and energy consumption (including electricity) are closely related. Most countries have found that, as they become wealthier, the convenience of electricity has attracted more uses. The United States is an example. An average annual growth of 4 percent in the economy (in real terms) from 1964–74 was accompanied by a 6 percent a year growth in electrical production. The British figures were 2.5 percent and 5 percent respectively, and for the world as a whole, 5 percent and 7 percent. NZED and Treasury figures tend to show that for New Zealand an annual 2.5 percent per annum growth rate in real Gross Domestic Product (GDP) has been accompanied by growth rates of about 5 percent in non-domestic electricity consumption. In general, however, such relationships are complex, and can change with time (see chapter 8)

16. The general pattern of past consumption has been interrupted and perhaps permanently slowed down in many countries by the energy crisis of recent years, which has, besides inhibiting economic growth, led to campaigns to reduce consumption. The long-term effects of these movements are still uncertain, but, as Terence Price in his *The Balance of Uranium Supply and Demand* said in August 1977, "Trends in the cost of nuclear power, relative to fossil-fuelled generation, imply that it will increasingly be the rational economic choice, if judged on the basis of

energy economics. The hope it holds out in the longer term, of greatly reducing the need for fuel-imports, will also make it strategically attractive. But in some countries the desire to utilise indigenous resources, to safeguard employment amongst coal miners, or to maintain diversity of energy supply, may influence the choice—and thus add to the uncertainty of nuclear forecasting".

17. Whether a continuing economic growth will improve the "quality of life" as well as the economic standard of living is a matter of opinion, but we would agree that some growth is necessary "to maintain employment in increasing populations, to improve the conditions of the poor, finance the cleaning up of the environment, and to maintain favourable positions in international relations, particularly with regard to trade, balance of payments, and defence". (*Economic Growth in the Future*, The Edison Electric Institute, 1976).

18. Many of those who oppose economic growth talk about the world, not as it is, but as they want it to be. But in a democracy such as New Zealand, a Government has to face the realities of existing life-styles, and the wishes of a majority. We have had this reality in mind when considering the many "scenarios" constructed here and overseas to demonstrate possible ways of life having low energy consumptions. The "Maiden Scenarios" in particular are a most valuable contribution. They themselves make it plain that they are not intended to say what should be done, but rather to test and compare the possible consequences of different policy choices. In the end, of course, as their authors recognise, it is the public who will decide what life-styles they want. We remain unconvinced that most New Zealanders are in 1978 ready to adopt a way of life which is greatly different from that which our society has enjoyed for the last 30 years.

NUCLEAR POWER—ITS PLACE IN THE WORLD ENERGY SCENE

19. Nuclear power is a relative newcomer to the world energy scene, confined for many years almost entirely to military objectives. This early and unfortunate association has bedevilled its later use for power production, and is partly at least responsible for the cloud of suspicion and distrust which envelops it today. Nevertheless, its use for power production has grown remarkably, and is thought by most people concerned with electricity production to be likely to climb during the rest of this century. In chapter 4 we discuss nuclear fission, and the way it is employed for electricity generation, touching on the extent of its present use, probable developments in technology, and what use may be made of it in the future.

20. Most New Zealanders are aware that a number of countries have for some years used nuclear energy to produce electricity. Nevertheless, they still view it as an emerging technology, novel and esoteric. They have no clear idea of to what extent, and for how long, it has been used. They know still less about its expected development. Electricity from nuclear power was first produced commercially at Calder Hall in England in 1956. Since then, in many countries, 1400 reactor years of commercial power have been accumulated, incidentally without a single accident leading to a radiation-related disability to the public. But there has come about in recent years a widespread protest against its use. This, with the

recent economic down-turn in western Europe and the United States, has resulted in few new orders for nuclear plant, some postponements of new installations, and in some cases, cancellations.

21. Though this state of affairs has not been confined to nuclear plant, some of the construction side of the industry has been affected by pessimism—it has been described as "sick". Certainly it appears that some earlier forecasts of growth were unjustifiably optimistic, making any forecast of growth suspect. Nevertheless, it was our experience that the officials and engineers responsible for delivering electricity to the nations we visited were almost unanimous that nuclear power was a necessary and irreplaceable source of the future energy for mankind in the short and in the longer term.

22. To get the widest possible view of the world's nuclear scene—the extent of its use at present and its plans for the future—we turned to the records of the International Atomic Energy Agency (IAEA) of 1 March 1977. (Other figures obtained from the Atomic Industrial Forum (AIF) detailed in chapter 4 are in places higher, because the information was collected on different dates.) The following are assessments from the IAEA records:

- 19 countries were producing electric power by nuclear means, from a total of 197 reactors with an aggregate capacity of 88 248 MWe.
- 33 countries (including 18 of the 19 mentioned above) had plans to extend their production, or to enter the field. There will almost certainly be delays in planned construction, but the figures were taken from committed programmes on which construction had begun or for which at least letters of intent had been signed. The aggregate planned was 564 reactors producing 428 597 MWe of which 356 337 MWe were expected to be available by the year 1984.
- Much of this will be developed outside the United States and British programmes. The communist countries are moving rapidly to an increased commitment. The Soviet Union had 26 operating reactors producing 6616 MWe. Its formed plans are to expand to 57 reactors producing 34 816 MWe. The German Democratic Republic (presently at only 879 MWe) plans to increase its output to 4959 MWe. The developing countries, too, are heavily involved. Plants are operating in five developing countries. Twelve other developing countries have nuclear plants under construction, or planned for operation by 1985, with an aggregate capacity of 28 000 MWe.

23. Planned programmes are not confined to the present types of nuclear reactors. Despite the opposition to the Fast Breeder Reactor (FBR) as promoting a plutonium economy, it is now increasingly recognised as a logical and an acceptable development. Five nations are now developing them—Japan, United States, Britain, France, and the Soviet Union. Indeed, in France and the Soviet Union, liquid-metal cooled FBRs are now entering their third stage of development with the building of the French 1200 MWe "Super Phenix", and a Russian 1600 MWe project. Even in the United States, despite President Carter's opposition to the substantial Clinch River programme, the FBR option still appears to be open. The predominant opinion among the nuclear power experts we met overseas was that, in the years to come, fuel considerations will most probably make FBRs inevitable. In Britain, the Royal Society considers that a credible nuclear policy must in the long run be based on them. There is also the possibility of using thorium in reactors of the breeder type.

24. At the International Conference on Nuclear Power and its Fuel Cycle held at Salzburg in May 1977, the Director-General of the IAEA, Dr Sigvard Eklund, summed up the future scene thus:

> For the world as a whole the indicated ranges of nuclear power capacity are of the order of 200 000 MW(e) for 1980, 900 000 MW(e) for 1990 and 1 300 000 MW(e) for the year 2000. The share of nuclear power which is today less than 10 percent of electricity and less than 3 percent of primary energy will grow to some 35 percent of electrical energy and 15 percent of primary energy by the turn of the century.

In his closing remarks Dr Eklund asserted agreement between the delegates present on these two points:

(a) In the short term nuclear power offers an immediate substitute for the oil and gas used for electricity production and represents for many countries deficient not only in hydrocarbons but also in coal resources, a substantial alleviation of their dependence on foreign imports.

(b) In the longer term it holds out to the world a technologically mature solution to its increasing energy needs and places a safety net under the future development of mankind; for the ultimate potential of solar energy remains difficult to assess and nuclear fusion is still at a laboratory stage.

25. These projected growths can all be affected by the flowing tide of objections by people concerned, usually deeply, about the moral, environmental, and health consequences of a nuclear programme. Such opposition could more seriously affect the projected figures than has often been allowed for; indeed, as we have already observed in chapter 1, the chairman of the UKAEA, Sir John Hill, has said that "the problems of nuclear power are not now engineering or technical, but problems of political will and public acceptability".

Public Acceptability

26. Any Government, weighing the advantages and disadvantages of a nuclear power programme, must of course take into account public acceptability or lack of it. The subject was covered at length during our inquiry, and full detail may be found in chapter 5. From the experience gained from our hearings, interviews, and visits, we discuss contemporary attitudes in New Zealand and overseas. Though it is difficult to identify the moral and social implications of a nuclear power programme, we deal with them in some detail in Part IV which is directed towards the consequences of introducing nuclear power.

27. We have remarked earlier that the history of nuclear power is one of official enthusiasm, early public acceptance or apathy, and then of rising opposition. Especially when the environmental movement directed attention to the wasteful use of global resources and to the high consumption of energy in developed countries, nuclear power provided a focal point for their arguments. Differing opinions held by eminent scientists have not helped resolve the conflict in the public mind. Voting in State polls in the United States, as well as opinion surveys there, show a two-to-one majority in favour of nuclear power. In Canada an opinion poll showed that nearly half the population knew little about nuclear power, but of those who did, 56 percent thought it "worth the risks" involved, with the rest divided between the undecided and the opponents.

28. In Britain, initially perhaps the leader in the new technology, nuclear power at first seemed to be welcomed enthusiastically, and several nuclear power stations were built in different places, in most cases after

the holding of local public hearings. Partly because other forms of energy later became available, no such planning hearings have been needed for some years, until the 1977 Whitehaven Inquiry into the proposed extension of the Windscale reprocessing plant made possible expressions of present public opinion on nuclear power. We formed the clear impression during our visit that in Britain there does not seem to be any appreciable opposition from those living in the neighbourhood of nuclear plants, and we noted the wide opportunities to communicate with plant staff through local liaison committees. But there are certainly some national environmental groups who object to nuclear generation, and who question Britain's needs for more electricity, and there are those who are worried by the moral issues arising from even the peaceful use of nuclear power.

29. It is well known that opposition to nuclear power has recently built up markedly in Sweden, West Germany, Switzerland, Austria, and France, with varied, but usually delaying effects on planned construction. At present the only European countries apparently able to proceed with their nuclear programmes unhindered by public opposition seem to be those of the communist bloc, most of which have substantial nuclear programmes.

30. The only scientific sampling of New Zealand opinion about nuclear power appears as a small part of a wider study of household energy consumption. In this postal survey, only 24 percent favoured nuclear power over oil-fired or coal-fired plants, though in a parallel survey of engineers, 41 percent favoured nuclear power. In a small pilot study based on Birkenhead and done in more detail, only 25 percent favoured nuclear power. The most extensive effort to mobilise New Zealand opinion against nuclear power has been Campaign Half Million whose petition attracted 333 088 signatures.

31. Whether a numerical count of submissions to our inquiry is a reliable guide to public opinion might be a matter of argument. Numerically, they have been heavily opposed to nuclear power. Most of the organisations which had sampled their members' opinions found very little support for introducing nuclear power into New Zealand. They considered it an expensive, dangerous, imported technology. However, it should not be overlooked that, though New Zealand with no established nuclear industries has no strong pro-nuclear lobby, it has a strong environmental lobby.

32. On one significant point New Zealand opinion appears to differ from that of many other countries. That is in the attitude of the trade unions. In the United States trade unions have generally supported the nuclear industry in various State initiatives as important for employment, and as far as we can gather the same view is generally accepted by the similar unions in Britain. But the New Zealand Federation of Labour stated that it was firmly opposed to introducing nuclear power until it could be shown to be "safe and not harmful to the environment". We imagine that any Government would consider trade union opposition a formidable factor to take into account in decision-making.

Information and Education

33. The origins of nuclear technology in weaponry did not for a long time encourage free exchange and dissemination of information about its peaceful uses. Recently, the opposite trend seems to be taking place, witness the almost notorious detail and bulk of the widely-known Rasmussen study on reactor safety. Articles, magazines, books, technical

and popular, appear daily. Much of the writing is identified with one side or the other of the nuclear controversy and so is suspect to those of the opposing view. It has been our hope throughout that our inquiry would stimulate the nuclear debate in New Zealand and help clarify the issues for the public. The way that participants in the hearings established communication with one another and exchanged opinions was greatly encouraging. We have, however, as we remark in chapter 1, been somewhat disappointed by the reporting of the hearings by the news media. Such reports as were made seemed insufficient to allow the New Zealand public to get more to grips with the mass of objective information at present available about nuclear power.

34. We heard various suggestions about possible public discussion programmes, and discussed their worth with people who have been promoting and running similar programmes in many countries overseas. We are left with reservations about the effectiveness of such methods of informing and involving the public. But we do see a positive need for more and better balanced education on energy matters, and especially for nuclear power to be discussed and taught in its proper place as one aspect only of the total energy scene, not as a separate isolated subject. Only if it is seen in such a setting and weighed along with its alternatives, can the educational process be of value. We believe that discussion programmes are more effective when they are based on small groups rather than on large formal debates. In Austria recently an ambitious attempt to promote wide public interest and education by formal debates proved disappointing. It was hard to find suitable participants and to get full and objective reporting. Such schemes can easily polarise opinion, and too often only the sensational parts are reported in the media.

THE CASE FOR NUCLEAR POWER IN NEW ZEALAND

35. As we have noted earlier, official attitudes towards the case for a nuclear power programme have changed considerably since we began this inquiry. Until recently the official forecast of electricity demand was 49 774 GWh a year in 1990, with perhaps 80 400 being needed by the end of the century. The shortfall in generating capacity in 1990 was likely to be 1200 MW. With no clear indication that this could be met in time from alternative indigenous resources, and with nuclear power being a commercially proven technology, an early "decision in principle" for a nuclear power programme was thought desirable. The proposal came in for much criticism, and, with the forecasts on which it was based, was considerably modified. In chapter 6 we discuss the 1977 CRPR forecasts and the changes in the NZED proposals—especially the reduction to a generation figure of 60–70 000 GWh a year for the year 2000, and the replacing of the request for an early "decision in principle" with a case for preparing for a nuclear power programme should that ever prove to be necessary.

36. In chapters 7 and 8 we reach the point where we must make the pivotal judgment of whether, despite the changes in general, and present official, viewpoints, nuclear power is, or is not, likely to be needed in this country in this century. That judgment requires as a preliminary step a survey of present generating capacity, patterns of consumption, the indigenous resources likely to be available, and their ability to meet the officially projected growth in demand. We outline now, as simply as practicable, our main considerations and conclusions on these matters.

Electricity Generation in New Zealand

37. At 1 July 1977, New Zealand's estimated generating capacity was 5324 MW (3488 MW hydro, 1836 MW thermal), and the estimated energy consumption for the year 1977–78 was 22 080 GWh (16 356 GWh hydro and 5724 GWh thermal). The actual net energy generated in the year 1976–77 was 20 915 GWh. Present patterns of consumption correspond to an annual load factor of 59 percent. (Load factor is the ratio of the average power demand to the peak power demand in any year.) At the moment, base load amounts to about 60 percent, intermediate load to about 37 percent, and peak load to only 3 percent of the energy output. The generating capacities in the different categories are about 45 percent base, 35 percent intermediate, and 20 percent peak load plant.

38. Two official 1977 forecasts for the years up to 1991–1992 have been made, the more rapidly growing of the two giving 47 664 GWh with an estimated generating capacity of 11 087 MW for that year. The 1977 PCEPD plan is based on this more rapid forecast. When fully completed it should be capable of supplying 49 000 GWh a year, the corresponding generating capacity being 11 422 MW. But irrespective of the date when the existing plan is completed, the prime concern of the Royal Commission is with developments beyond that date, and, as our terms of reference relate solely to the introduction of nuclear power, our inquiry must be orientated towards the introduction and type of further base-load plant, because nuclear power, though suitable for base load, is in its present development, not really suitable for intermediate and peak loads.

39. Looking beyond the 1977 plan, it is conceivable that there could be another 40 000–42 000 GWh a year available by the end of the century, 6000 GWh from North Island coal, 6000 GWh from South Island coal, 13 000 GWh from hydro, 7000 GWh from geothermal, 3–4000 GWh from small hydro, and 5–6000 from a number of other sources (see chapter 7). It is unlikely, however, that all of this could be developed by the year 2000 even if it were needed. For these later years the MWD put forward an accelerated feasible plan to develop the 20 000 GWh of hydro and geothermal power, considering that this was all that would be realistic. This programme could only be completed by the end of the century if there were no major environmental objection, and if the necessary manpower and finance were provided. It could result in some over-capacity in the earlier years of implementation.

40. For the years beyond the existing power plan (that is beyond 1992), the alternatives to nuclear seem to us to be either geothermal or coal. Because it is ideally suited for intermediate and peak load, hydro power should in the future preferably not be used for base load if there is a suitable alternative. The MWD programme is capital intensive, but the resulting unit cost of electricity from the geothermal plants is considered by the NZED to be 1.6 cents per kWh, and from the hydro plants 2.5 cents per kWh, which may be compared with the NZED estimate of 2.9 cents per kWh as the comparable nuclear cost.

41. A longstanding difficulty in the way of extended use of geothermal power is disposing of the waste water containing noxious substances brought up from underground. It appears that the problems of disposal may have now been solved. The water can be either treated and disposed of in natural waters, or (probably the more satisfactory choice) injected around the perimeter of the geothermal field. In either case the cost is only about 5 percent of the total cost of the electricity produced. Considered

purely as "mines" for hot water, the geothermal fields can be regarded as renewable for periods of at least 100 years, perhaps longer.

42. As we have said, the NZED estimate of demand for the year 2000 is now, allowing for uncertainties, 60–70 000 GWh. The MWD programme could just meet the upper limit of the forecast but may have to be supplemented by another Cook Strait cable and associated further development of the North Island coalfields. This could be done. But major development of the coalfields is limited by technological, environmental, and skilled manpower factors. Although coalfields could probably meet needs to 1992, coal-fired base-load stations using indigenous resources cannot be regarded as an alternative to nuclear power up to the turn of the century. The most promising indigenous alternative is, in our view, geothermal power.

43. We do not see further discoveries of natural gas providing a suitable alternative for base-load generation, although such stations could perhaps be built as combined cycle plants for intermediate loads, or as total energy systems. Nor do we see unorthodox sources—wind, waves, biomass, or solar radiation—making a significant contribution before the year 2000. New Zealand's low tidal ranges make the possibility of using tidal power negligible.

44. After the year 2000, there could be yet further contributions from hydro, geothermal, and coal. However, the use of coal for electrical generation would have to be carefully weighed against other possibly better uses, especially to replace oil for process heat in industry and for conversion to liquid fuel. For intermediate load, wind power is a possibility, and discovering further oilfields could contribute significantly.

45. It is doubtless possible, as we say later, that the levels of consumption by the year 2001 could be substantially less than 70 000 GWh a year. This would leave significant known reserves remaining. So in our view, with all suitable coal and geothermal resources in use (including others additional to those mentioned), it could be about 2005–2007 before an operating nuclear plant would be needed (see chapter 15). But beyond this time, considering that then existing base-load plant such as Auckland No. 1 and 2, Huntly, and perhaps even certain South Island hydro must be replaced as base-load units, the need for nuclear power becomes then a very real possibility.

46. It is not for us to construct a future overall energy policy for New Zealand. Such a policy is presently being considered by the Minister of Energy aided by a committee of officials. Nevertheless, as we have already indicated, because the case for nuclear power is founded entirely on an alleged need for further electricity generation in the future, we believe it essential that we investigate the most suitable means for reaching the production needed, the extent of local resources, and how they can best be husbanded. In this, we have had unavoidably to impinge on matters of general energy policy. We hope that our thoughts will be of some help to those who have to frame policy.

47. Certain steps can be taken to face the projected future. Summarised they are:

- For the moment planning should be based on the assumption that about 70 000 GWh (a figure later discussed and confirmed in this overview) could be needed for the year 2000. This figure could change as future trends become more apparent.

- The programmes of coal exploration and investigation of geothermal potential should continue to be accelerated.
- All necessary financial and manpower resources should be made available as needed to implement the MWD hydro and geothermal programme.
- There should be a complete demonstration, associated with the Broadlands geothermal project, of the adequate disposal of waste geothermal waters.
- The potential of unorthodox sources such as wind, wave, solar, and biomass should be continually investigated and surveyed. It is recognised, however, that developments in these areas primarily depend on overseas technological progress.
- Nuclear power should be retained as an option for the future with a possible commissioning date of 2005–2007 in mind. This timing may need to be revised as future trends become more apparent.

48. It is to be noted that these conclusions receive support from the FFGNP which, in a careful and extensive survey of New Zealand's resources, believes that, if they are fully developed, they could provide 70 500 GWh a year by the year 2000. The report stresses that to achieve these figures, electric power development must be given high national priority, and that the figure of 70 500 is probably the upper limit of what could be reached by orthodox methods of generation. Indeed, because of the huge effect of such a programme, the FFGNP considers that it might be difficult to reach, or even approach, the potential figure. As already implied, the MWD considers that similar figures can be reached by 2000 by adding more geothermal and hydro stations to the production set down in the 1977 power plan. It adds no fossil-fuelled stations beyond those specified in the plan, nor does it allow anything for unorthodox forms of generation. It, too, emphasises that these figures could be reached only if the necessary resources of manpower, time, and finance are made available. It considers that there is a reasonable expectation that the manpower resources could be found without introducing serious imbalances in the national construction industry, but it is doubtful if the programme could be further accelerated. The NZED, though accepting that full development of indigenous resources could meet its projected consumption figures of 60–70 000 GWh a year, thinks that development unlikely because of environmental and feasibility restrictions.

49. We agree that attaining a capacity of about 70 000 GWh a year will depend mainly on the resolution of the country to do it and on the priority given it. We believe that it can be reached by extending our geothermal and hydro potential, though (as we discuss in chapter 7) some increased use of domestic coal reserves will be necessary, and we do not overlook the forceful exposition of the special difficulties in the way of increased coal mining given by the Secretary of Mines, Mr I. D. Dick. Certainly it will call for resolution. The provision made by the Government in its 1977 budget statement setting up an intensified programme of geothermal investigation, and coal and petroleum exploration, indicates an understanding of the problem, and a resolve to ascertain the extent of our resources and to develop new ways of making energy available.

50. We believe that nuclear power is unwarranted in New Zealand until at least the end of this century. Doubtless the introduction of nuclear technology, with its demands for new skills and quality assurance, could stimulate and develop our manufacturing sector, an important consideration in a world where exporting is highly competitive. But

whatever the advantages of introducing nuclear generation, there are at this time decided advantages in delaying its introduction. The technology is going through intense activity and development. Improvements in design and construction of established forms are emerging. The FBR is in the stage of exploitation in several countries. Thorium may prove to be a more acceptable and more abundant fuel than uranium. Nuclear fusion presents exciting possibilities for the future. Moreover, the industry, presently facing articulate and widespread opposition and meeting rises in the capital costs of plants, is accepting standardisation along with the need for improvements in quality and safety. Finally, but most importantly, there are uncertainties in the supply of fuel and the disposal of waste. A satisfactory fuel supply must be reasonably certain before the unavoidably large capital investment of a nuclear programme could be justified. Shortages and steep price rises, as well as the political attitudes of supplying countries, could also present great difficulties in the future. The problems of final high-level waste disposal are being studied, but have not yet been demonstrated to be successfully solved though it is likely that they will be. Clearly the balance of argument is heavily on the side of postponing a decision.

51. But whether New Zealand can do without nuclear power does not depend on governmental action alone. To achieve that, the people of this country will have to accept the environmental consequences of enlarged programmes of hydro, geothermal, and coal development. The present levels of electricity production will not meet the needs of the years ahead. Further generating capacity must be installed. In the choice of the form of generation, nuclear power should be judged on its own objective intrinsic suitability and desirability; it should not be justified by fears of shortages brought about by subjective opposition. Nevertheless, the attitudes adopted by some organisations and witnesses during our inquiry oblige us to say quite firmly that unreasonable obstruction to the environmental impacts which the enlarged hydro, geothermal, and coal production will necessarily entail, could make the adoption of nuclear power inevitable, perhaps even in this century. This situation was not, in our view, always sufficiently faced by opponents of nuclear power who attended our inquiry, especially by environmental groups. On the other hand, we were impressed by the fact that comparable groups in Britain and the United States realised better the force of what we are saying—that unreasonable opposition to developing additional generation by conventional means could result in the case for nuclear power being made overwhelming, through the existence of unsatisfied demands which the opposition itself has helped to create. If New Zealand wants more electricity, and we are sure it will, some environmental price will have to be paid.

Future Electricity Consumption

52. Is the official figure of 60–70 000 GWh a year by the year 2000 a reasonable estimate of the demand of that time? We have thought it necessary to attempt our own estimate (chapter 8), primarily to understand the problems and assumptions involved. In doing this we have been guided by the methods used by the NZED, but we have tried to give our own tests of the validity of the departmental estimates. We have broken down the potential and likely market into its various economic sectors, and sought to estimate the growth and extent of the future sector demands. In so doing we have specifically considered end use, probable

growths of population, involvement of industry, and possible changes in life-styles, including an increased desire for space heating and cooling. We have also taken account of the probable effects of conservation and substitution, of the contribution from combined heat and power generation, from the substitution of one source of energy for another, and the adoption of some still largely undeveloped forms of energy use such as district heating. In the end we estimate that electricity consumption for the year 2000 should be in the range 50–70 000 GWh a year, and that the most likely demand which must be met by the NZED is about 60 000 GWh, though planning should take into account an upper limit of 70 000. All this is very much in line with the NZED forecast.

53. All methods of forecasting future markets or consumption are suspect for each must make assumptions which may or may not prove to be correct. Nevertheless, because at this point we are at the heart of any examination of the need for nuclear power, we think it desirable to recount here the more important of the factors and calculations which give rise to our estimates, (for detail see chapter 8).

54. The present pattern of electricity consumption by economic sectors is: domestic, 45 percent; commercial (including public services, etc.), 15 percent; total industrial, 40 percent; and transport almost nil. During 1969–76 the large industries (that is the forest-based and metal-smelting industries) were responsible for 42 percent of the increment in consumption. However, it is believed that this sector's share is likely to decrease rather than increase by the end of the century.

55. The present pattern of consumption by end use is: low-grade hot water, 30 percent; space heating, 9 percent; high-grade heat (other than specialist applications in industry), 7 percent; and "fixed", 54 percent. (By "fixed" we mean that there is no really suitable alternative to electricity.) This value for the fixed component is considerably higher than often stated. The practical acceptance of various conservation techniques would at present probably lead to only about a 15 percent saving. The MER claims that even by 1990–91 conservation techniques are likely to lead to only a 10 percent saving. The use of electricity to produce low-grade heat in industry appears to amount to only about 5 percent of the total electricity used by industry, and in the case of high-grade heat it is only about 16 percent, apparently used for specialist purposes.

56. A major problem in forecasting future demand is the inadequate identification of potential markets. The domestic sector has been extremely well researched, even down to consumption by individual household appliances, but the same cannot be said of other sectors. It was, however, apparent from cross-examination that both past and present work by the NZED and the NZERDC is quickly correcting this deficiency. The use of electricity in the large industries and the transport sector is, of course, well defined; but in the commercial and other parts of the industrial sector, mathematical models appear to be necessary. It is well recognised that automation could lead to significant growths in demand.

57. In the domestic sector, space heating is of most concern. Though most New Zealanders are at present satisfied with a low level of comfort heating, demands for more heating are expected to grow rapidly. However, subject to certain qualifications, we do not see this as of great importance, for, as the demand increases, certain conservation techniques will become economically attractive. Insulation and the use of heat pumps

are two of these, and in the long term, district heating is a possibility. In the end, of course, there will be only an apparent rather than a real saving in electricity, if all it results in is merely increased comfort.

58. Of these conservation practices, insulation is already economic, but heat pumps are not, though they would be, even now, if North American levels of thermal comfort were sought here. There could be many heat pumps in New Zealand by the end of the century, curbing the demand for electricity for space heating. In situations (especially in the commercial sector) where heat pumps are likely to be economic, we think they should be encouraged now. Although this may not lead to immediate savings, it is essential that an adequate sales and maintenance service should develop to support a large domestic market if and when this should occur. It would be unfortunate if heat pumps were rejected by the public because of inadequate servicing.

59. Air conditioning, in the form of summer cooling, appears to be unwarranted in New Zealand in the domestic, but possibly warranted in the commercial sector. At present the economics of solar hot-water heaters are uncertain, and further studies are being made. Obviously their economic comparisons with other fuels would improve if the price of electricity should be raised to near marginal costs, or the installation costs of solar heaters decrease substantially. Their future certainly appears promising.

60. Considering reserves of natural gas, we estimate that at most about 4500 GWh a year or less is likely to be saved by 2001 by substituting gas for electricity. Very recent announcements about increases in those reserves would correspond to only a 13 percent increase in the figures used in chapter 8. However, to be economic, gas must be used for two out of three functions of cooking, space heating, and water heating; and to save 4500 GWh a year, at least 300 000 houses (out of New Zealand's estimated 1.6–1.7 million by 2001) must have gas laid on.

61. In industry the first essential for saving electricity is good housekeeping. Tariff structures can help in this. The combined production of heat and power should be encouraged, although as this is capital intensive, governmental incentives may be necessary. We estimate that by the year 2001, the demand on NZED generation could be reduced by such practices by 3000 GWh a year. We also believe that there must be more attention paid in architectural design to passive techniques of energy conservation in all sectors.

Our Appreciation of Future Demand

62. Past patterns of growth and consumption lead to an estimate that New Zealand could need 68 000 GWh of NZED electricity supply for the year 2000. The figure is based on present rates of population growth, and a 3½ percent per annum rate of increase in real GDP, this being the upper limit suggested for New Zealand over the next decade by the OECD. This 68 000 GWh may be broken down by sector: 26 000 GWh domestic, 28 000 GWh total industrial, 11 000 GWh commercial, and about 3000 GWh transport. Present plans for the large industries could result in this figure being about 4000 GWh too high. If this were so, our base figure would reduce to 64 000 GWh for the year 2000. But an increase in the rate of change of real GDP to 4 percent, with a corresponding increase in population, could return it to about 68 000 GWh.

63. We recognise that certain possible large-scale movements could reduce the lower base figure of 64 000 GWh considerably, even down to 50 000 GWh. As we have said, the use of gas in 300 000 houses could save 4500 GWh. Industry producing some of its own electricity by total energy systems (TES) could save 3000 GWh. From "in-house" production, there could be a saving in the transport sector of 1500 GWh, and a further saving of 1500 GWh by using solar water heaters. Improvements in transmission could save about another 1000 GWh. Furthermore, real price rises over the next 20 years could curb demand in an absolute sense by about 5 percent. In total there could be a reduction of about 14 000 GWh. Even further savings could be stimulated by an increased use of TES in industry, and by adopting other techniques of economic conservation in all sectors.

64. We believe that conservation techniques are unlikely to succeed unless they demonstrate a well-defined economic advantage. Thus, the public must be made plainly aware of the magnitude of the advantage. The examples deserving encouragement are especially household insulation and heat pumps.

65. In arriving at our initial figure of 68 000 GWh we made the following assumptions: (a) that the pattern of use of electricity in the industrial sector for producing process heat will be virtually no different from that of today; and (b) that there will be no major developments in the electrification of the private transport sector, although the public sector was allowed for. If much private transport should be electrified, we would think it desirable to use present (and if need be introduce new) oil-fired power stations. It would result in a more efficient use of primary fuel, and the capital cost of such stations is low; they can be built relatively quickly, and respond quickly to demand. Nuclear power does not need to be introduced for this purpose at least initially. For these various reasons, we believe 50 000–70 000 GWh for the year 2000 to be a reasonable estimate of the range of possible demands.

66. Our higher base figure of 68 000 GWh is very much less than the so-called historical value of 124 000 for the year 2000, which projections of past growth would imply. It became apparent during the inquiry that "historical" rates of growth really only apply to the periods during which they occurred. Nevertheless, if all houses end up being all-electric, and all are heated to suggested levels of thermal comfort by electrical resistance alone, and if the transport sector is completely electrified, then the figure of 124 000 GWh might well prove to be accurate. At the present time, however, one can detect signs of saturation in all sectors apart from transport (where negligible electricity is at present used). Further analytical studies could help much to clarify this aspect. Again, our figure of 68 000 GWh for the year 2000 falls within the NZED range of 60–70 000 GWh. This is not surprising as we adopted a similar approach, though we tested the assumptions and limitations in a somewhat different way.

67. Finally, we mention the steps which we would like to see adopted now in relation to future electricity consumption:

(i) The use of heat pumps should be encouraged wherever a distinct economic advantage can be shown.

(ii) As a minimum all houses should have ceiling insulation of one form or another.

(iii) The use of electricity for producing process heat in industry should be constantly monitored.

(iv) Space heating (with particular emphasis on the criteria for thermal comfort) should be exhaustively studied.

(v) Analytical techniques for forecasting and predictions should be further developed. Although these may give incomplete views or inadequate analyses, they could be very sensitive indicators of departures from past patterns of consumption.

(vi) Every encouragement short of coercion (which we believe to be unnecessary) should be given to adopting economically viable techniques in an attempt to limit demand on NZED generation. If demand can be reduced to about 50 000 GWh for the year 2000, New Zealand should enter the next century with a surplus of resources. It would then have many options open to it.

Conclusions

68. It is our view then that, subject to certain conditions, nuclear power is not justified for New Zealand until about the turn of the century, or even perhaps later. But this does not mean that a decision to adopt or reject it can with certainty be postponed until the year 2000. In the course of our overseas study we discussed the lead times (the period between the decision and the coming on stream of a nuclear station) with a number of utilities and construction firms presently engaged in nuclear work. Owing in no small part to the opposition of environmentalist and other groups opposed to nuclear power, the lead times have recently been considerably extended in all except communist countries. Little opposition is reported in the communist bloc to their substantial present and projected nuclear programmes. Many power plants now being built in the non-communist world are years behind their schedule dates. The advice which we received from many places (including the IAEA and the International Energy Agency (IEA)) is that in a country like New Zealand, which has not already begun a nuclear programme and where opposition to it is likely to arise, a lead time of 15 years should be allowed for. The NZED also suggests 15 years as an appropriate period. If this be accepted, then it is all the more clear that consumption and production figures must be constantly watched, as indeed they are. Moreover, it also follows that the question of nuclear power or not should again (as we have already indicated) be considered in depth before too long, say no later than 1985. Furthermore, we believe that the Government should, as the PCEPD urges, take the necessary steps to ensure that New Zealand maintains and updates its knowledge of nuclear generation as well as evaluating and proving alternative means, so that it is to that extent qualified to avail itself of the nuclear option should it prove desirable. The MWD, the MER, and the NZED share this view.

69. Of course, it could be argued (though it was not) that even though nuclear power may not be necessary to meet our demands up to the end of the century, nevertheless nuclear generation has such advantages (for example, in cost and convenience) that it should, to meet the demands, be preferred *now* to further reliance on those conventional present or available methods of electricity generation. For reasons which we detail later in discussing the consequences of a nuclear programme compared with the consequences of alternatives, we are far from the view that, in this decade of the 20th century, nuclear power has advantages for New

Zealand which markedly outweigh its disadvantages. Indeed, as we have said, we believe that the balance of considerations heavily favours delaying its introduction for as long as is reasonably possible.

70. We conclude then that in these circumstances nuclear power should only be adopted if there is no really satisfactory alternative, or if it is shown to be so much better for New Zealand than other methods of generation that to reject it would be unwise. Neither of these situations exists now. But things could change in the not too distant future, when, as is confidently expected by scientists overseas, many of the contemporary difficulties and disadvantages of nuclear power generation will have been overcome. Nuclear power could, indeed, well prove in years to come to be a cheaper, more efficient, and wiser choice than using much of our remaining hydro and geothermal potential.

Maintenance of the Nuclear Option

71. We have said that no one now asks for a recommendation that nuclear power should be made available before the year 2000. When this inquiry began there was some advocacy, especially from the MER and the NZED, for a "decision in principle" to be made quickly. The phrase seemed to us an unfortunate piece of administrative jargon of uncertain meaning. It soon became clear that it meant different things to different people. To some it clearly implied a substantial but undefined degree of final decision and commitment; to others it was less final. However, the MER and the NZED eventually conceded that no decision in principle in the sense of any commitment need be taken at this stage, though both stressed that New Zealand must keep itself continually informed about nuclear development. Specifically, the NZED asked that we endorse preparatory steps which would keep it informed about nuclear energy and its application to New Zealand. These were:

- (i) Monitoring world activity in unresolved areas (for example, waste disposal facilities, the development of multinational fuel cycle centres, uranium availability, cost escalation).
- (ii) Studying other important developments in nuclear energy (for example, new technologies, standardised designs).
- (iii) Establishing the viability of reactor sites in New Zealand.
- (iv) Investigating in a New Zealand context the disposal of radioactive wastes, including spent fuel.
- (v) Sending staff overseas for training in nuclear technology to maintain a small core of staff with a suitable depth of knowledge and experience.
- (vi) Actively promoting understanding and discussion of the issues associated with nuclear power and energy in general.

We view these activities as being in line with the recommendation of the PCEPD that New Zealand should maintain and keep up to date its knowledge of nuclear generation—a recommendation which we support. We think it appropriate that the NZED should pursue these particular activities.

72. Two other preparatory steps were recommended as desirable for any future nuclear programme should that prove to be needed: that a research/training reactor be bought; and that there be a "timely" establishment of a licensing authority to which, if it were decided to begin

a nuclear programme, application could be made for licences to build and run a particular station. The first of these was raised in two different contexts. The New Zealand Institution of Engineers favoured an early purchase for training purposes independent of a decision to proceed with a nuclear power programme. The MWD, NZED, and the DSIR on the other hand saw the purchase of this form of reactor as part of a nuclear power programme already decided upon, arguing that it would give incentive and opportunity for the preliminary administrative steps to be undertaken without the pressure of dead-line dates. In that context the plant would not be bought until after a firm decision to adopt nuclear power had been made.

73. On our overseas investigations we inquired at research institutions whether a training reactor was worth its high cost. Almost invariably the response was unfavourable. We were told, even in places where research reactors were operated, that they had little value for training, certainly before a firm commitment to nuclear power, unless the institution could do, and did do, original nuclear research. Otherwise nuclear scientists of ability would quickly lose interest, as such things as making isotopes and sterilising pharmaceuticals are not enough to maintain it. Greater training value seems to come from sending scientists overseas to the great centres of nuclear research and engineering. A cadre of about 5 or 6 trained scientists and engineers are needed to start a nuclear programme, and a larger number must be trained to ensure that this many are always available. Training is costly, but the cost is small compared with that of trying to start a programme without sufficient local expertise.

74. Although a research reactor could possibly have some value even now for training purposes and for educating the public in the nuclear debate, we remain unsatisfied that it would be presently worthwhile here. Moreover, there is little doubt that the opponents of nuclear power would see its purchase as indicating a firm intention to follow the nuclear path. But if and when a firm commitment to a nuclear programme is made, a training reactor could possibly be justified. However, we have no sufficient evidence to convince us that that will be so, and we prefer to leave the question entirely open to be dealt with in the light of future circumstances.

75. We take a like approach to departmental requests for the "timely" establishment of a licensing authority as essential to prepare for any introduction of nuclear power. If by "timely" the departments mean establishing such an authority in the near future, we would not favour it as it is unnecessary at present. Opponents of nuclear power would certainly see the setting up of such an authority as a step in a firm commitment to nuclear power. But if (as we think clearly emerges from the evidence of the NZED's Chief Engineer—Development, Mr K. D. McCool) all the departments ask is that a regulatory authority be set up soon *after* a firm decision on a nuclear power programme is made, without prejudicing the decision or the timing of it, then we would agree that it would be a necessary early step so that the authority could give guidance and rulings from the start of planning.

76. Chapter 13 discusses in detail suitable regulatory and administrative procedures for a nuclear programme, and draws attention to the basic principles of setting up a licensing authority, even though such an authority is unnecessary at this stage. Chapter 13, too, mentions the help in the matter that can be obtained from the IAEA, which has

already assisted other countries in setting up regulatory and licensing processes. The IAEA Secretariat in Vienna has said that it would be prepared to send a task force to New Zealand for this purpose, and furthermore, that it would help hire experts to act in a licensing authority, either as members or as advisers, until New Zealand can train its own. The advantages of these services could be kept in mind.

LIKELY CONSEQUENCES OF A NUCLEAR POWER PROGRAMME

77. Though we conclude that an *early* final decision on nuclear power cannot be justified, our Warrant obliges us to consider and report on the likely consequences of adopting it for electricity generation. In Part IV the consequences, as they now appear, are discussed. But we must stress that these consequences are being constantly affected by further scientific discovery and invention, by engineering developments and experience, and by changing political and social attitudes. So much so that even if a decision were made now, there must be over the lead time (at least 15 years) which would elapse before the first nuclear station could be operating, many significant changes in technology which could alter those very consequences—for example, a final solution to the high-level waste-disposal problem. If the decision is postponed, as we suggest, there are far greater probabilities of change. So though Part IV deals with these consequences at quite some length, a more summary treatment is given in this overview.

Environmental Consequences

78. It is not surprising, given modern concern about protecting natural environments, that there was much argument during the inquiry about the environmental effects of a nuclear power programme. Chapter 9 deals with the effects on the physical environment. Chapters 10 and 11 deal with the impacts a nuclear programme may have on human beings.

79. In debates about nuclear power it is too often overlooked that environmental changes result from the generation of electricity whatever the means adopted, be it from fossil fuel, hydro, or any unconventional method. The changes may be seen in land use, water resources, air quality, noise and visual impact, and in social conditions. So always a comparison of methods should be made. In chapter 9 we include a study prepared by the MWD comparing the likely impacts of nuclear and hydro stations. Though long, it is novel and most valuable. Which method is preferable depends largely on matters of opinion influenced by the standpoint from which each is regarded, or the particular aspect considered to be important. The difference between the two in environmental terms is not as marked as might have been expected.

80. Siting is a major aspect of any decision on nuclear power, and has a special bearing on environmental effects. The site must meet a number of stringent geological and engineering conditions. We observed while overseas that near urban siting is not unusual. Public safety is thought to be protected by high standards of design and construction rather than by the remoteness of the site. A New Zealand installation would probably be on a coastal or estuarine site with low seismic susceptibility. Most nuclear

reactors overseas are built in areas where the seismic risk is considerably lower than that of most parts of New Zealand where no part of the country could be considered free from the possibility of a large earthquake. This country, with its record of earthquakes and volcanic eruptions, must pay greater attention to detailed geological considerations in site selection if only because the level of seismicity varies considerably over the whole country. Though certain preliminary work has been done towards selecting sites most suitable from a seismic point of view, up to now no really suitable site has been located. The Geological Society of New Zealand is by no means certain that one will ever be found. However, nuclear reactors have been built in Japan and California, both highly earthquake-prone regions. There, geological factors have dominated site selection, and strict codes covering selection, and reactor construction, are enforced. New Zealand would need to do the same.

81. It goes without saying that, in the event of a nuclear power programme in New Zealand, arrangements must be made for the management of radioactive waste. This is discussed in detail in chapter 9. Chapter 4 discusses the origin and nature of this waste. Intermediate- and low-level wastes could be managed locally in accordance with procedures described to us overseas. It is unlikely that a New Zealand programme would justify the establishment of a fuel reprocessing plant to extract plutonium for reuse in the fuel cycle. We believe quite firmly that before any decision is made to establish a nuclear power plant in New Zealand, suitable arrangements for the disposal of high-level radioactive waste must be convincingly demonstrated. We share this view with the Flowers report.

82. The problem of dealing with a nuclear power station at the end of its effective life (about 30 years) must be regarded as another aspect of waste disposal. Decommissioning presents three prospects: lock up with surveillance ("mothballing"); conversion and restricted site access ("entombment"); and unrestricted site access ("dismantling"). It should be stressed that no large nuclear station has yet been decommissioned anywhere. Nevertheless, one can say that the cost of the process will be a further charge on any programme (see chapter 14). The plan, and financial provision, for decommissioning should be laid down at the time of the initial planning of the siting, design, and construction so that the ultimate environmental impact of the decommissioned facility is thought through and felt to be acceptable.

83. Today many eminent scientists are drawing attention to the possibility of a large global increase in the thermal generation of electricity bringing about major changes in both local and world climates. Changes may occur in two ways: by the emission to the atmosphere of waste heat from nuclear parks; and, especially, by the emission of carbon dioxide and particulate matter from fossil-fuelled stations. Levels of carbon dioxide are expected to double early next century, and theoretical calculations predict a rise of several degrees in global temperatures. The effects on climate and sea level could be disastrous. But this area of possible grave danger is at present inadequately understood, though steps are being taken, especially in the United States, to increase research efforts. It may well be that in future years findings from these investigations will materially influence the choice of methods of electricity generation.

Moral and Social Implications

84. Many people were concerned with the moral and social implications of a nuclear programme and its consequences. Such concern will, we think, increase. Chapter 10 discusses these moral and social issues, though they are not easy to identify, and are almost impossible to quantify. The moral implications raised by the submissions related mainly to possible links of nuclear electricity with weapons development; to the issues of prodigal and unequal use of the world's resources; and to the legacy of radioactive waste left to future generations.

85. Although the origins of the peaceful nuclear technology are to be found in the same scientific research which led to nuclear weapons, the extent of present connections between the peaceful and military uses of the power from the atom are less readily established. Some witnesses contended that New Zealand, if it were to reject all nuclear technology, including nuclear generated electricity, would set a moral example to the rest of the world. We doubt that many people in other countries would so view it. The general issues involved in the increasingly large use of energy (electricity in particular), the depletion of global resources, and the whole matter of waste disposal, are all discussed elsewhere in this report. However, as these raise pointed moral issues, it is important to realise, as we have said, that all methods of generating energy make demands on the environment. However unpopular a heritage of nuclear waste (probably the most troublesome aspect) would be, its impact, both present and future, must be compared with that of the alternatives. Undue depletion of fossil fuels, a process which is already well under way, can surely be regarded as morally irresponsible conduct towards future generations. Another proposal of some environmental groups, that New Zealand should concentrate on exports with a low energy content, and so save its own resources at the expense of some other country's power for further processing, does not seem to us to be a moral solution of the problem. Indeed, some even suggested that it was an attempt to evade responsibility for consumption and pollution.

86. One of the few advocates of nuclear power raised a moral argument specifically and directly linked to reactor safety. He argued that its risks are so much more meticulously investigated and documented than are those from other forms of power generation that they should be morally the most acceptable. This argument raises an interesting point of view, but ignores other moral aspects of introducing nuclear power.

87. The most frequently cited social effect of nuclear power was its constant need of stringent security measures to protect all parts of the fuel cycle. Fissile material must be safe-guarded so that it cannot be diverted to the manufacture of nuclear weapons, or used for threats either by terrorists or by nations, especially those who have not signed the Non-Proliferation Treaty. Nuclear plants must also be protected both from actual sabotage, and from a credible threat of sabotage being used as blackmail. Such protection is not always objectionably visible. Our own observations of security checks at overseas nuclear plants showed them to be unobtrusive in Britain and Canada, and though more obvious and stringent in the United States, still comparable with other industrial security arrangements there.

88. The matter of security assumes another dimension where the so-called plutonium economy is concerned. It was this aspect of the possible development of breeder reactors and fuel recycling which led to those

comments of the Flowers report which were so often quoted: that Britain should not rely for energy supply on a process that produces such a dangerous substance as plutonium unless there is no reasonable alternative. This attitude could change if fuel cycles suitably resistant to proliferation were developed. The Atomic Energy (Special Constables) Act providing for the arming of guards is now in force in Britain. When we visited the country only four establishments (those involved with plutonium) appeared to employ armed guards.

89. The methods which would be needed to counter the threats of nuclear fuel diversion or blackmail would not be welcomed by New Zealanders who value an informal, relaxed way of life, and were considered by some witnesses to be the chief threat to civil liberties which a nuclear programme might produce. We are doubtful whether such measures would really threaten civil liberties, or would more significantly affect the country's social climate than do present measures to counter serious crime. We do not see this as one of the more substantial arguments against introducing nuclear power.

Consequences for Health

90. Some lay people and organisations were afraid of the possible effects on man from even the routine operation of a nuclear power programme. We found also marked differences of opinion among scientists and medical witnesses, especially on the genetic effects of ionising radiation. The differences indicate uncertainties in some areas of radiobiology. We are not competent to resolve them but must discuss them to show where the differences lie, and to bring them into some perspective. This is done in chapter 11.

91. The quantitative effects nuclear power may have on health must be fully compared with the corresponding effects of alternative energy sources, and the background radiation to which we are all exposed, if they are to be put in perspective. Radiation exposure of workers in the nuclear power industry appears to us to be kept firmly within the dose limits recognised as safe by the International Commission on Radiological Protection (ICRP). Moreover, the exposure of local and worldwide populations to average radiation from even extensive nuclear power production is low compared with the average exposure from natural sources. The annual collective radiation dose to workers in nuclear power plants is greater than that of the general population.

92. The known or alleged effects of ionising radiation on both somatic (non-reproductive) and genetic (reproductive) cells were much debated. Present estimates of radiation-induced biological effects are obtained from experience of high doses and dose rates, and also from experimental data on non-human systems. The results are tentative, and a linear dose-response relation without a threshold is assumed. The main non-hereditary delayed effect of radiation is cancer which usually appears years or even decades after irradiation. However, it is impossible to identify a particular cancer as being due to radiation. Present estimates of radiation-induced genetic effects are based on experimental data from low dose rate exposure of mice and flies. The possible mutagenic properties of radiation (including the radioactive isotope carbon-14) originating in nuclear power stations must be assessed in relation to those derived from non-radiation causes. Unfortunately, there is here a conspicuous lack of

data from medical sources. All we can say is that on present evidence there is no need for concern about the effects of emissions from the routine operations of nuclear power stations.

93. During our visits to overseas operating nuclear power plants, we were impressed with the monitoring procedures used to record the presence or otherwise of routine or accidental emissions. Nevertheless, we stress that public health authorities should at an early stage be involved in establishing and reviewing emergency arrangements which would apply to any accidental release of radioactivity.

Accidents and Compensation

94. A main concern both of those who oppose nuclear power in New Zealand, and of those scientists and technologists who have knowledge and experience of operating stations, is that of an asserted inherent danger in the technology that could conceivably lead to a structural or operating accident. This is discussed in chapter 12.

95. Notwithstanding the excellent safety record of conventional power reactors, which surpasses that of most other large industries, there is a continuing association in the public mind with past incidents which, on examination, mainly prove to have involved nuclear weapons and military establishments, not commercial electric power stations. There is no evidence that nuclear power reactors have hitherto caused injuries to the general public, though some workers have been killed and injured. Generally speaking the safety record of nuclear power generating plants is excellent, but this is not accepted as ensuring safety. The IAEA has reported that in over 1400 reactor years of commercial power operation no accident leading to a radiation-related disability has occurred—a kind of record that is unparalleled in any other modern large-scale industry. Chapter 12 deals with the kinds of accident that might occur in a reactor installation. The foreseeable frequency of such accidents has been included in our considerations of safety analysis procedures illustrated by the Rasmussen report on reactor safety. Overseas experience has shown that the risks to employees in a reactor programme through accident are well below those in the general manufacturing industry.

96. In New Zealand, the possibility of a core melt (potentially the most dangerous accident) would have to be assessed in a context of the contributing effects of earthquakes. A serious reactor accident in this country might cause large loss of life, depending on its location, and might contaminate much land through radioactive discharges, particularly if caesium-137 was released. In some circumstances these consequences could be most grave—how grave would depend on a number of factors. One can imagine other catastrophes in New Zealand which would also have consequences unparalleled in its history.

97. Probability studies, such as the Rasmussen report, must necessarily be accepted with qualification. The confidence in reactor safety shown by both the Flowers and the Ford Foundation - MITRE reports is based on very high standards of technical expertise in design, operation, and maintenance in the industry as a whole. In the view of some who met the Royal Commission, New Zealand at present lacks skilled people, not only in the nuclear field, but also in quality assurance techniques in "basic" engineering. However, we believe that as long as adequately trained engineers and scientists are available in New Zealand, the safety of nuclear reactors should not be a major stumbling block to a nuclear power programme.

98. If New Zealand adopts a nuclear power programme, there will be need to devise a system of compensation for the public in the event of personal injury or property damage resulting from accidents within, or emissions from, nuclear installations. There are many available examples in what has been adopted in other countries, and international organisations have prepared model schemes. We discuss their suitability in the light of New Zealand law. We also confirm the need for further legislation to clearly define liability, and to ensure that funds are available to meet claims for compensation (see chapter 12).

Licensing and Control

99. All countries using or planning to use nuclear power generation have recognised its potential public and environmental dangers as both a world problem requiring international surveillance and control, and as a domestic matter requiring local licensing and regulatory procedures. There are several international organisations which impose obligations on their member States. The best known is the IAEA, of which New Zealand is a member. New Zealand has also signed the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), thereby agreeing not to divert nuclear energy from peaceful uses to weapons or explosive devices. The NPT obliges us to conclude agreements with the IAEA to apply safeguards on all peaceful nuclear activities in this country, or in territories under our control. New Zealand is also a party to the 1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere in Outer Space or Under Water, to the 1972 Convention on Prevention of Marine Pollution by the Dumping of Wastes or Other Material (known as the "London Convention"), and to the 1959 Antarctic Treaty designed to prevent, among other things, the disposal of radioactive waste in the Antarctic.

100. Membership of the IAEA and also of the IEA entitles New Zealand to access to a large reservoir of experience and expertise accumulated over many years, especially in such fields as domestic licensing and regulatory procedures.

101. The adoption of nuclear power would demand a system of licensing and regulatory control to ensure high standards of safety in plant construction and operation and yet suit New Zealand. The United States, Canada, Britain, and West Germany, all of which have nuclear programmes of some years standing, have chosen different regulatory patterns. The United States prefers to impose detailed criteria which are spelled out at great length in regulations; others like Britain give broad guidelines and prefer that the licensing authority demands high standards of safety, with those seeking licences for stations having to convince the authority that the standards have been met. Chapter 13 discusses the merits and weaknesses of the different models for New Zealand, and notes that the source from which the nuclear plant is bought might have an important influence on the regulatory model chosen. We are in no doubt that the licensing authority and the regulatory inspectorate must be completely independent in form and personnel from the departments or organisations promoting, or intending to run, nuclear plants. We say how we think that can be best achieved in a New Zealand setting, and we discuss detailed proposals submitted by a sub-committee of the New Zealand Atomic Energy Committee for a licensing and regulatory structure and procedures.

The Cost of Nuclear Power

102. The economic implications or consequences of a nuclear power programme are of obvious importance. Chapter 14 considers, from a New Zealand point of view, the cost of producing electricity from nuclear compared with the more conventional fossil-fuel sources. Chapters 7 and 15 briefly analyse the costs of hydro and geothermal generation. For a proper comparison, both capital and running costs must be involved. The comparison is best made between the unit costs of electricity produced (that is, the cost per kWh or "unit").

103. Submissions brought up a diversity of estimates of the capital cost of a nuclear power station in New Zealand. In many cases the assumptions made in arriving at these estimates differed to the extent of making comparisons difficult, if not impossible. The problem is not peculiar to New Zealand. Almost everywhere we went overseas we found that nuclear capital costs were in a most fluid and indefinite state, making it quite impossible for us to express any confident opinion about local capital costs, especially for a station with a commissioning date as far away as 1990–91, the originally suggested date. But in spite of that, the different analyses, especially those of the NZED, have enabled us to make useful comparisons of unit costs of nuclear with other forms of generation.

104. Striking divergences in recent years between estimated and actual costs of nuclear plants in many countries led the IAEA to convene a meeting of experts in 1976 to try to devise more accurate methods of estimating costs, especially in developing countries. The meeting produced the Woite report which was used by the NZED as the basis for its own calculations. It took the figure given by Woite for a pressurised water reactor built to United States safety and environmental standards, and adapted the cost to make allowances for New Zealand conditions. It included an enlarged seismic allowance, training of staff, and provision for a regulatory authority. General monetary inflation or other causes of escalation were not allowed for, but interest on capital during construction of the plant was. This cost, defined as the "capital cost", is expressed in constant 1976 dollars, and is not the ultimate actual cost in paid dollars. The approach followed by the NZED is widely adopted: it is known as the "constant dollar" approach, as distinct from the "current dollar" approach in which monetary inflation as well as escalation must be assumed.

105. The NZED's estimate is $1,345 million for a station of two 600 MW generating units. This was strenuously criticised as being much too low by some of those taking part in our inquiry, notably Professor R. H. Court on behalf of the Environmental Defence Society Inc., and also Ecology Action (Otago) Inc. The NZED estimate and these criticisms are discussed in chapter 14. The NZED submissions also estimated the initial costs of coal- and oil-fired stations of similar capacity at $384 million and $492 million respectively. However, the cost of nuclear fuel is very much less than the fuel needed for fossil-fuelled stations.

106. The Treasury regards such estimates as only indicating the magnitude of the capital cost because of the distance in time that now seems likely before a nuclear station is commissioned. Indeed, the Treasury thought that, because a decision in favour of nuclear power is not likely to be needed for the next 20 years, a detailed cost estimate was of little value, especially in an environment as dynamic as the energy sector

where nuclear technology, costs, and methods can change so often. Nevertheless, we accept that the methodology used by the NZED in arriving at the figure of $1,345 million is on the whole satisfactory for allowing comparisons of relative unit costs, and for considering the general economics of the options available, though the figures may be understated, or even overstated, in some particulars.

107. The capital costs of generating electricity with different fuels, translated (along with other costs) into unit costs, give economic comparisons helpful for future policy. The following figures supplied by the NZED (in 1976 dollars) give the unit costs in cents per kWh for various methods of generation.

Nuclear	N.Z. Coal	Oil	Hydro	Geothermal
2.9	1.9	3.1	2.5	1.6

We agree with the NZED that for New Zealand the proper conclusion on the present evidence (and in general economic terms) is that geothermal electricity is cheapest to produce per unit, followed by indigenous coal, and hydro. The most expensive, apart from oil, appears to be nuclear. In some other countries coal-fired stations do not have the same cost advantages (see chapter 14).

108. But it is not only unit production costs which must be considered in selecting the most suitable form of generation on economic grounds. As the Treasury was at pains to point out, the amount of foreign exchange expenditure in the total cost (capital plus fuel) can prove a most important consideration for New Zealand's economic future. An analysis by the NZED engineers, Wong and Hewlett, presented to the third New Zealand Energy Conference in May 1977, showed that over the expected lifetime of stations of like capacity, oil generation demands most foreign exchange, followed by imported coal, nuclear, and then indigenous coal. Neither hydro nor geothermal generation was included in their analysis.

Overall Future Implications

109. Notwithstanding our belief that no early commitment to a nuclear power programme is justified in New Zealand, or even a "decision in principle" desirable, it does seem to us that to assess the overall impact which nuclear power could have here, it is necessary to look at a long-term development, not just the introduction of a single reactor in the relatively near future. To do this we must estimate movements in a number of sectors beyond the turn of the century. This involves inference or speculation, for we had little or no evidence relating to such possible movement. The method has obvious dangers, but we consider it worthwhile to round off our assignment. Chapter 15 sets out our attempt.

110. It is inevitable that in this process we either directly or indirectly move into areas of overall energy policy which, as we have already said, may be considered outside our intended field. However, we stress that much of the discussion is little more than speculative, and that the purpose of the chapter is primarily to reach some kind of measure of the overall economic consequences of introducing a sustained nuclear power programme in the next century.

111. It is convenient for this purpose to take the year 2020 as the end of the period of our consideration. After visualising possible growth of electricity consumption within the OECD countries as a whole, and its

relevance in New Zealand, likely future population and GDP movements, and other indicia, we think it reasonable to take a figure of around 130 000 GWh as New Zealand's electricity consumption in 2020. There are, of course, many factors that could invalidate this estimate, especially changes in population growth rates and immigration rates, but *any* estimate is similarly vulnerable. Accepting, however, that 130 000 GWh is a reasonably sound estimate, the issue we must next consider is how it is to be satisfied.

112. We have already said in chapter 7 that, assuming no major environmental objections, by 2001 New Zealand could supply 70 000 GWh per annum using its own indigenous resources. We take the then anticipated demand at 60 000 GWh per annum. This, in our estimation, would leave about 30 000 GWh per annum which could possibly be generated from known indigenous resources after the year 2001. If the necessary development is done, this should meet New Zealand's needs till about the year 2010–2011, and we believe that it should be aimed at before introducing a nuclear or other station dependent on imported fuel and a complex advanced technology. But between the years 2010 and 2020, the chances of New Zealand needing nuclear power to meet its base load are real indeed.

113. Assuming that the nuclear programme we have mentioned is really needed, what are the capital, manpower, reactor type, fuel, and training requirements? We consider these too in chapter 15, and reach the conclusion that a significant nuclear power programme during the early part of the next century should be economically possible. As we have said, commercial operation of the first unit may not be needed until 2011, but to gain necessary early experience, 2005–2007 may be a more desirable target. The successful development of certain alternative electrical sources, such as wind-powered turbines, could greatly affect the size of the programme but would be unlikely to delay the introduction of the first unit. On the other hand, changes in the assumed economic climate, which we took in chapter 8 as growth in GDP of about 3.5 percent a year, could either significantly retard or advance the date at which such a unit may be first needed. The 3.5 percent is considerably less than that projected for most OECD countries up to 1985.

114. The relatively long breathing space now expected before it is necessary to make a decision on nuclear power will depend on the almost complete implementation of the MWD accelerated geothermal and hydro programme. The discovery of other large resources of natural gas and oil is unlikely to have any significant effect on our conclusions, since these would almost certainly be allocated to industrial process heat, and to transport.

115. For the commissioning of the first unit in 2011, a firm decision to proceed would be needed by 1996; for a unit in 2005–2007, this would become 1991. In general, it appears that New Zealand has about 20 years or more before needing to place the first order. From the discussion in chapter 15 and earlier chapters, it will be seen that there is at present, however, no guarantee that reactors of a suitable type will exist if and when they are needed. Thus over the next 20 years, possible alternatives must be thoroughly investigated. Similarly, there is no guarantee that suitable economic alternatives can be found within the time that may be available. Thus, New Zealand must maintain an interest in the nuclear field and continue to survey it closely. Furthermore, there appears to be a

need for further preliminary site investigations, especially in connection with seismic risk and possible high-level waste disposal areas. These should not be postponed till a firm decision to proceed is taken, since this itself may depend on answers which can only come from such investigations.

116. Though it appears that New Zealand has, say, 15 to 20 years before it needs to make any firm decision, in view of all the uncertainties and the speculative nature of much of our discussion, there should be no complacency. There must be yearly reviews of the situation. Any long-term plan will almost certainly be a victim of change, and what we believe to be true and possible now may not be so even in the immediate future. For example, there could be an upsurge or down-turn in electricity demand, elements of the MWD proposal could prove to be impracticable, and international matters relating to oil, proliferation, waste management, the availability of nuclear fuel, etc., could all lead to a complete reassessment. Thus, to conclude, we agree with the DSIR submission that there should be a major review if not in 1982 (their date), then at least by 1985, to update New Zealand's knowledge and experience of the whole situation in all its aspects.

SUMMATION

117. Though our report, and even this overview, takes in a mass of detail, and discusses many aspects and consequences of energy and a nuclear power programme, the reader will be aware that our basic conclusions are few. They can be quite briefly stated:

(1) There is no satisfactory case for New Zealand to immediately commit itself to a nuclear power programme. On present evidence it appears to have sufficient indigenous resources to enable it to meet its reasonably projected needs for electricity into the next century.

(2) New Zealand should aim to rely on its own resources for electricity as long as it is economically and environmentally sensible to do so, rather than introduce such a sophisticated and changing technology as nuclear power.

(3) The development and use of indigenous resources to postpone a decision on nuclear power will call for resolution, for substantial allocations of money and manpower, and for the acceptance of some environmental impacts.

(4) However, the chances of New Zealand needing nuclear power for electricity generation early in the next century are real indeed, and a significant nuclear programme should then be economically possible, if a similar relationship to that which in the past has existed between economic and electricity growths is maintained.

(5) The future ability to meet electricity needs is subject to many uncertainties, mainly those of population and economic growths, those of the possibilities of indigenous resources proving smaller or more difficult to develop than expected, and those of the new forms of generation, alternative to nuclear, failing to prove economic.

(6) Nuclear power generation for New Zealand also has its uncertainties and difficulties, especially those of obtaining reactors of a suitable type, reasonably certain fuel supplies, and disposing of the waste products of a fission technology.

(7) New Zealand should not embark on a nuclear power programme until suitable arrangements for the disposal of all high-level radioactive wastes from any proposed nuclear stations have been convincingly demonstrated.

(8) Apart from the disposal of radioactive wastes and the ascertainment of sites suitably located and of acceptable levels of seismicity, there is no one aspect of the consequences of a nuclear power programme which, taken by itself, would lead us to conclude at this time that nuclear power as a form of electricity generation, if needed, should be rejected.

(9) Although some groups within New Zealand believe strongly in the advantages of a low energy "conserver" society (both for its own sake and as a means to avoid introducing nuclear power), we are unconvinced that significant energy savings would thereby result without more changes in life-style than are likely to be acceptable to most New Zealanders.

(10) For the reasons outlined above, New Zealand should continue to keep in touch with developments overseas and extend its experience and understanding of nuclear technology. Within New Zealand, in particular, preliminary site investigations should be made, related especially to seismic risk and the ascertaining of areas for high-level waste disposal. There should be an active public education policy to place nuclear energy in the context of the whole energy situation rather than consider it as an isolated technology.

(11) Moreover, because change will almost certainly call for alterations to any long-term plan of electricity production, we believe that another major review should be made by at least 1985.

PART II

Chapter 3. THE ENERGY PROBLEM

INTRODUCTION

1. In this chapter, we look briefly at the total energy situation first world-wide, then for New Zealand in particular.

2. Energy is not just one among many of mankind's resources. It is essential if other resources are to be used. The amount, availability, and form of energy strongly influence the nature of a society. The different forms of energy, and even mass, can all be expressed in the same units; the concept of energy can thus become a unifying principle. This does not mean, however, that it is necessarily feasible to substitute one particular form of energy for another. Energy is valuable to mankind not for itself but for what it can do, and all forms of energy are not equally available. Many submissions (one at considerable length (1)) emphasised the desirability of suiting particular forms of energy to their most appropriate end uses.

3. Electricity is a versatile form of energy, able to do many different sorts of work, and hence may be referred to as high quality energy. Other forms of energy, such as the heat in hot water, are not as versatile, but may be well suited to specific purposes. We were strongly urged that "low grade heat", such as space heating and hot water heating, should not be obtained mainly from electricity (2). We shall discuss these issues in more detail later in this report.

Units and Definitions

4. In scientific usage, energy is that which has the capacity to perform work. Many different terms are used to quantify energy: e.g., joule, kilowatt hour, unit. We list some and their conversion factors in the glossary. Power is the term used to describe the rate at which energy is produced. The relationship between energy and power is more fully discussed in the report of the FFGNP (4).

5. To describe energy production and consumption, the MER defines the following categories (5): *Primary energy* is energy as it is first obtained from natural resources. In general terms coal is accounted for as it is mined, oil products as they are imported in various degrees of refinement, and natural gas as it is taken from the wells. Primary electricity in the MER definition is electricity generated from hydro and geothermal sources, ignoring the generation efficiencies.

6. *Consumer energy* is energy in the form in which it is distributed to the consumer. In this context "electricity" includes the electricity which is generated from thermal stations burning coal, oil, or natural gas; and "gas" includes the small quantity of gas manufactured from coal, naphtha, and natural gasoline. This accounting includes transmission losses, but does not include consumption or losses at the point of production or at final conversion to consumer forms.

7. The Energy Research Group (ERG) of the NZERDC further defines *effective energy* as the amount of energy delivered to the first point of use, taking into account the efficiency of the final machine or appliance: for example, heat delivered into a room by a space heater (6).

8. *Heat* is a form of energy and is measured in the same units as energy. Where it is desirable to distinguish between electrical energy and heat, the symbolism used in this report is *MWe* representing a megawatt of power as electricity, and *MWt* for a megawatt of power as heat (4).

WORLD ENERGY CONSUMPTION AND RESOURCES

9. Apart from that emanating from the earth's core and a small amount from the tides, the energy which powers the earth's natural and man-made processes comes from the sun. The sun's energy which reaches the outer levels of the earth's atmosphere is termed the "solar flux" or "solar constant" (about 1.4 kW per square metre).

10. By far the greatest part of the solar flux consists of visible light and short wave (ultraviolet) radiation. About 30 percent is reflected back into space mainly by clouds and the earth's surface, the amount varying with the nature of the surface, being greatest from snow and ice. The reflected solar flux plays no part in heating the earth or its atmosphere.

11. About 17 percent of the solar flux is absorbed by atmospheric gases, water vapour, and cloud droplets, and thus heats the atmosphere. Ozone in the upper atmosphere absorbs most of the harmful ultraviolet radiation. A greater part of the solar flux, about 47 percent, is absorbed by the earth's surface, raises its temperature, and returns to the atmosphere, so much so that most atmospheric heat is received indirectly from the earth's surface. If the atmosphere did not retain this heat, the average temperature of the earth would fall by some 40°C making most life impossible.

12. Of the 47 percent absorbed by the earth's surface, some is radiated back in the form of invisible infrared (long wave) radiation much of which is absorbed by water vapour, carbon dioxide, clouds, and dust in the atmosphere. The concentration of these substances may therefore have a significant effect on the inward and outward balance of energy flow and hence on the temperature of the earth. The energy used in evaporating water is returned to the atmosphere in the form of latent heat in the water vapour, to be released when the water vapour condenses to cloud droplets, or forms rain or snow.

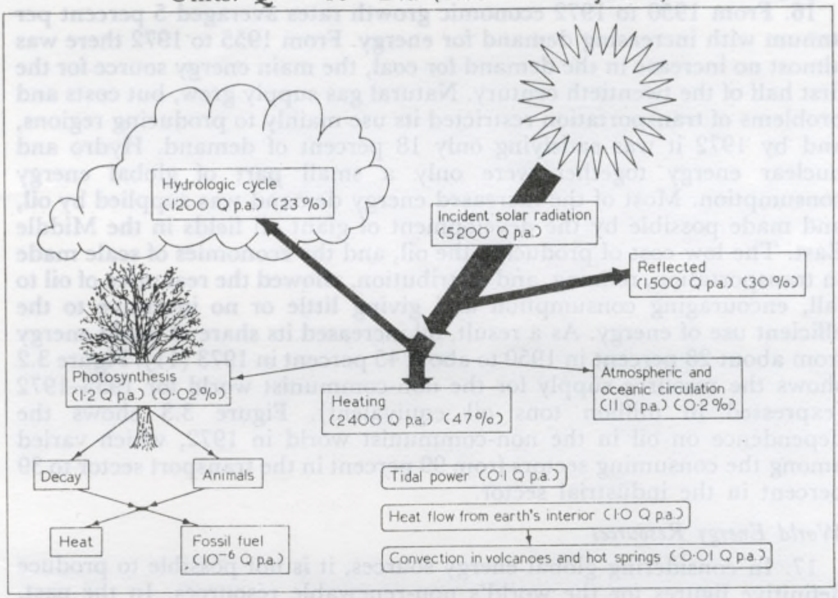
13. On average 23 percent of the solar flux reaching the earth goes into the hydrological cycle of evaporation and precipitation; 0.2 percent goes into the interconnected system of winds, waves, and currents; and about 0.02 percent is used by living organisms and obtained from the energy used by the green plants in photo-synthesis. By means of photo-synthesis green plants chemically store some of the sun's energy which then becomes available, though in constantly decreasing amounts, to all other organisms through complicated food chains. Photo-synthesis also provides the stored energy which can be released by burning or fermenting plant material. When the organic material is returned to mineral constituents again, by whatever means of decomposition, the solar energy originally captured by photo-synthesis is all dissipated as waste heat. During the history of the earth some organic matter has been preserved within the sedimentary rocks of the earth's crust. This has become our fossil fuel. Figure 3.1 shows diagrammatically the energy flow from natural sources in the earth-atmosphere system.

Figure 3.1

ENERGY FLOW IN THE WORLD FROM NATURAL SOURCES

(*Source:* J. K. Wright, *Physics in Technology*, 1975, p.145)

Units: Q = 10^{18} Btu (1.05×10^{21} joules)



14. Society has developed and changed as mankind has learned to harness the energy sources of the earth. But recently there has grown a realisation of the finite nature of many of the world's resources, especially of its present energy sources. *The Ecologist* in 1972 said: "The combination of human numbers and per capita consumption has a considerable impact on the environment, in terms of both the resources we take from it and the pollutants we impose on it. . . It should go without saying that the world cannot accommodate this continued increase in ecological demand. [*Ecological demand* is defined as a summation of all man's demands on the environment, such as the extraction of resources and the return of wastes.] *Indefinite* growth of whatever type cannot be sustained by finite resources. This is the nub of the environmental predicament. It is still less possible to maintain indefinite *exponential* growth—and unfortunately the growth of ecological demand is proceeding exponentially (i.e., it is increasing geometrically, by compound interest)." (7).

World Energy Consumption

15. In 1975 the world consumption of primary energy was about 75 000 TWh (that is 2.7×10^{20}J or 0.26Q). Of this OECD nations used some 43 000 TWh or 58 percent; eastern Europe, the USSR, and China 22 000 TWh or 29 percent; and the rest of the world 9700 TWh or 13 percent (8). However, data on energy consumption in developing countries is generally incomplete and a significant share of their total energy comes from non-commercial sources such as firewood, cow dung, and vegetable waste (9). These fuels cause their own problems of depletion. In 1975 oil supplied 45 percent of the world's primary energy (including that used to

generate electricity), coal 30 percent, and natural gas 18 percent. Most of the rest was hydro-electric and geothermal, with nuclear energy contributing 1.3 percent. These statistics exclude non-commercial sources of energy, which, although important in many developing countries, are negligible in developed countries (10).

16. From 1950 to 1972 economic growth rates averaged 5 percent per annum with increasing demand for energy. From 1955 to 1972 there was almost no increase in the demand for coal, the main energy source for the first half of the twentieth century. Natural gas supply grew, but costs and problems of transportation restricted its use mainly to producing regions, and by 1972 it was satisfying only 18 percent of demand. Hydro and nuclear energy together were only a small part of global energy consumption. Most of the increased energy demand was supplied by oil, and made possible by the development of giant oil fields in the Middle East. The low cost of producing the oil, and the economies of scale made in transportation, refining, and distribution, allowed the real price of oil to fall, encouraging consumption and giving little or no incentive to the efficient use of energy. As a result, oil increased its share of world energy from about 28 percent in 1950 to about 45 percent in 1973 (11). Figure 3.2 shows the resource supply for the non-communist world for 1955–1972 (expressed in million tons oil equivalent). Figure 3.3 shows the dependence on oil in the non-communist world in 1972, which varied among the consuming sectors from 99 percent in the transport sector to 39 percent in the industrial sector.

World Energy Resources

17. In considering global energy sources, it is not possible to produce definitive figures for the world's non-renewable resources. In the past, exploration and technological change have continually increased the estimates of what will be available. A recent Australian report gave the following data on world consumption and supplies of the principal forms of energy.

Table 3.1

ESTIMATED WORLD CONSUMPTION, RECOVERABLE RESERVES AND RESOURCES OF COAL, OIL, AND NATURAL GAS: 1975

(*Source:* First Report Ranger Uranium Environmental Inquiry, Canberra, 1976.)

	Consumption in 1975 (energy units: 10^{18} joules)	Reserves (energy units: 10^{18} joules)	Reserves (physical units)	Ultimately recoverable resources (physical units)
Coal (black and brown) ...	73	15 080	665×10^9 tonnes	5 400–7 300 $\times 10^9$ tonnes
Oil	112	4 360	110×10^9 m^3	210–300 $\times 10^9$ m^3
Natural gas ...	45	2 500	65×10^{12} m^3	80–170 $\times 10^{12}$ m^3
Oil shale ...	...	...	80×10^9 m^3	180–255 $\times 10^9$ m^3
Bitumen rocks ...	...	...	56×10^9 m^3	160–400 $\times 10^9$ m^3
Uranium (thermal reactors) ...	3	[a]1 130	2 700 $\times 10^3$ tonnes	3 800–5 000 $\times 10^3$ tonnes
Thorium ...	...	...	320×10^3 tonnes	2 000–2 800 $\times 10^3$ tonnes

Sources: 1975 consumption: Information provided to the Commission by R. Krymm, Head of the Section for Economic Studies, Division of Nuclear Power and Reactors, IAEA.
Reserves and Resources: U.S. ERDA: *Creating energy choices for the future, 1976.*

[a]Using a conversion factor which does not allow for recycling fuel, 1 tonne of uranium is equivalent to 1.30 short tons of U_3O_8.

Figure 3.2

HISTORICAL VIEW OF RESOURCE SUPPLY MEETING DEMANDS FOR THE NON-COMMUNIST WORLD (1955–1972)

(*Source:* Based on BP (N.Z.) submission 51)

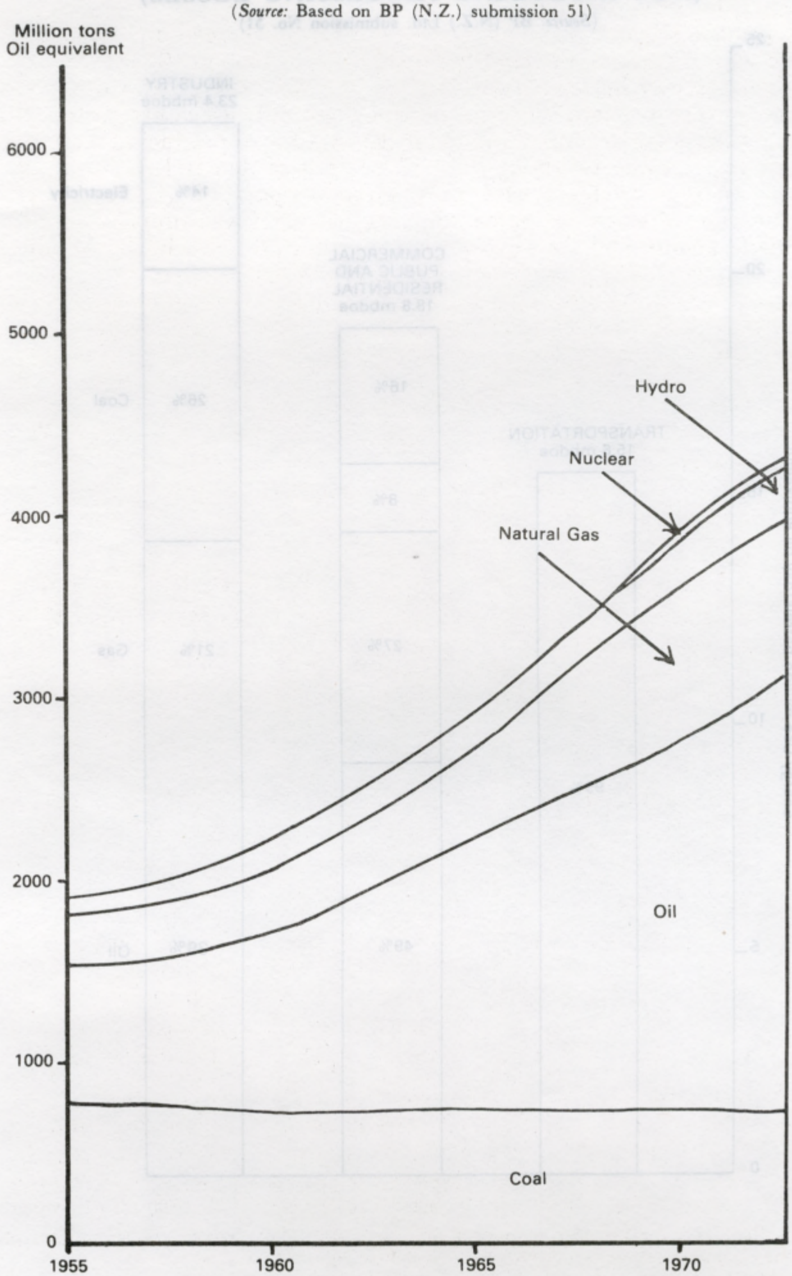
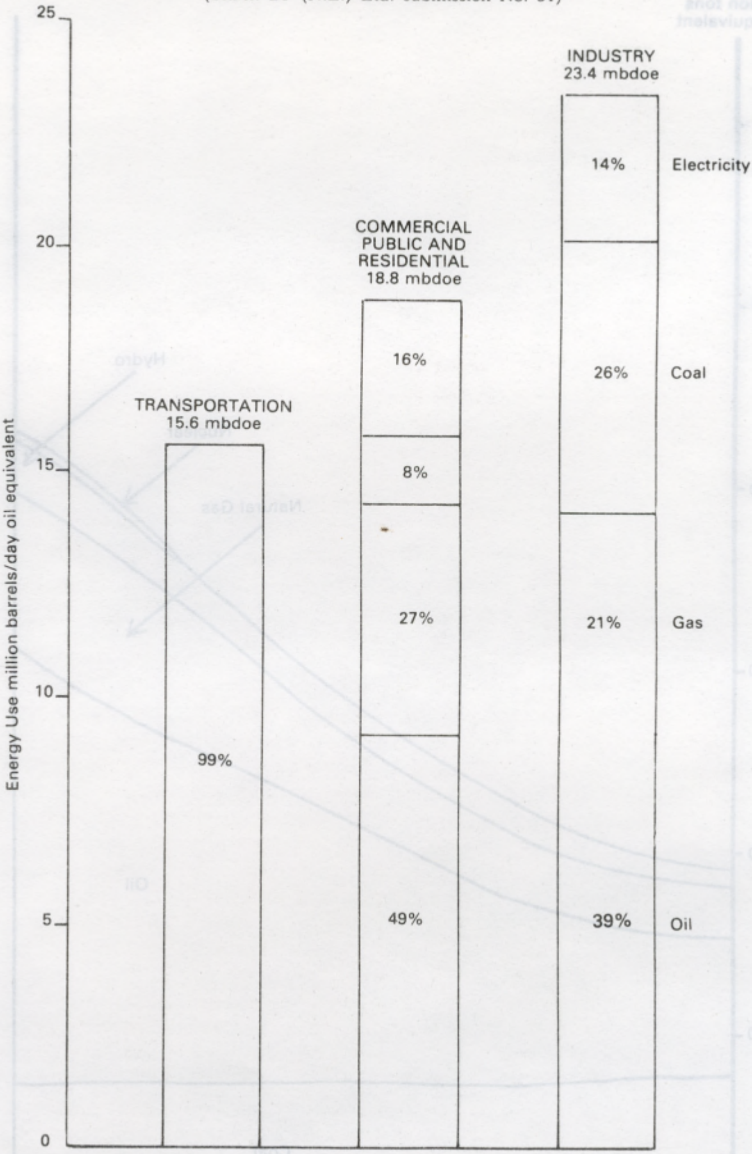


Figure 3.3

HISTORICAL RESOURCE UTILISATION BY DEMAND SECTOR FOR THE NON-COMMUNIST WORLD, 1972 (NOT INCLUDING PROCESSING LOSSES)

(*Source:* BP (N.Z.) Ltd. submission No. 51)



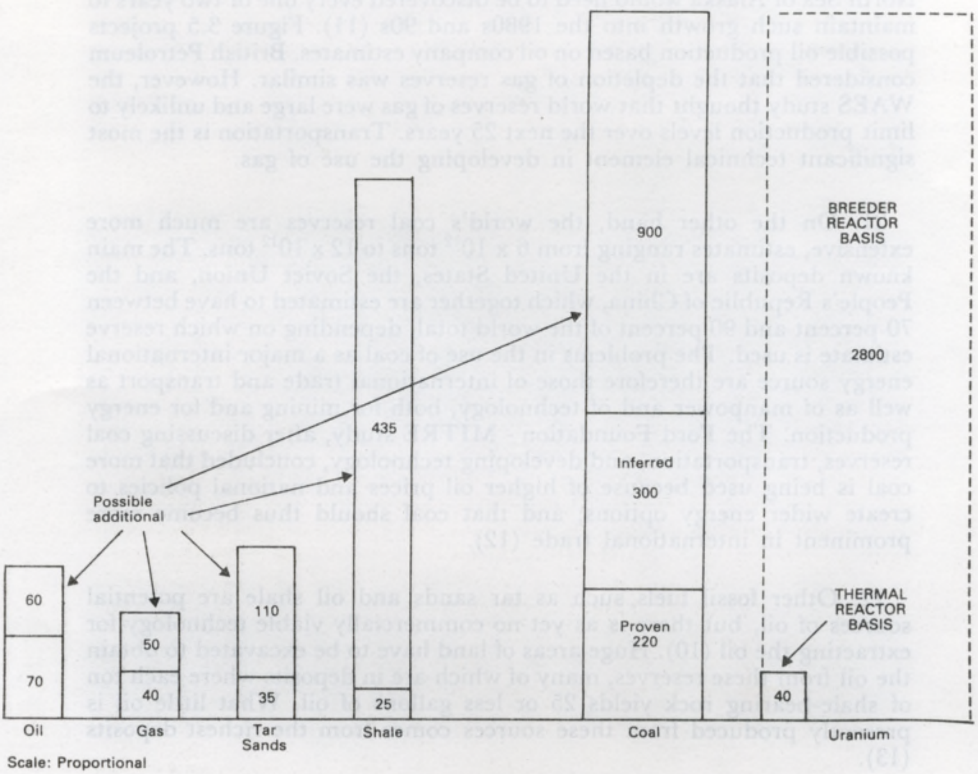
18. In the table the term "reserves", applied to coal, oil, natural gas, and uranium, refers to quantities known to be present following geological exploration, which can be economically recovered with present technology. For oil shale, bitumen rocks, and thorium, which are not yet used to provide energy, the "reserves" figures are derived from assessments of the eventual economic capabilities of the technologies now being developed. Estimates of "ultimately recoverable resources" which are many times higher than the reserves estimates, include quantities of fuels not yet established, but expected to be present in existing proven areas, and speculations about other potential discoveries. Thus, not only is the existence of some of these resources uncertain, but considerable advances in technology may be required before they can be developed and used in environmentally acceptable ways. Figure 3.4 represents global energy resources diagrammatically.

Figure 3.4

NON–COMMUNIST WORLD ENERGY RESOURCES

Billion (10^9) tons oil equivalent

(*Source:* BP(N.Z.) Ltd., submission 51)



Fossil Fuels

19. Oil and gas are both non-renewable sources of energy whose reserves are limited. Although there are continuing uncertainties about the size of global oil resources, two recent American studies of energy prospects have concluded that oil will pose the first major supply problem. The first conclusion of the Workshop on Alternative Energy Strategies (WAES), an international project sponsored by the Massachusetts Institute of Technology, was that the supply of oil will fail to meet increasing demand before the year 2000, most probably between 1985 and 1995, even if energy prices rise 50 percent above present levels in real terms. Additional constraints on oil production will hasten this shortage, thereby reducing the time available for action on alternatives (9). The Ford Foundation - MITRE study concluded that, on present knowledge, oil and gas are unlikely to be available in sufficient quantities to meet growing demands for energy. Natural oil and gas will have a short life historically, spanning merely the mid-nineteenth to the early twenty-first century (12).

20. It was pointed out to us that sometime in the future the production of oil must peak and then begin to decline, and that the point at which the decline will occur depends on the interaction between supply and demand. As the remaining undiscovered reserves diminish, the difficulty in finding them will increase, along with the cost of developing them. At the historical growth rates of oil demand, a new oil province such as the North Sea or Alaska would need to be discovered every one or two years to maintain such growth into the 1980s and 90s (11). Figure 3.5 projects possible oil production based on oil company estimates. British Petroleum considered that the depletion of gas reserves was similar. However, the WAES study thought that world reserves of gas were large and unlikely to limit production levels over the next 25 years. Transportation is the most significant technical element in developing the use of gas.

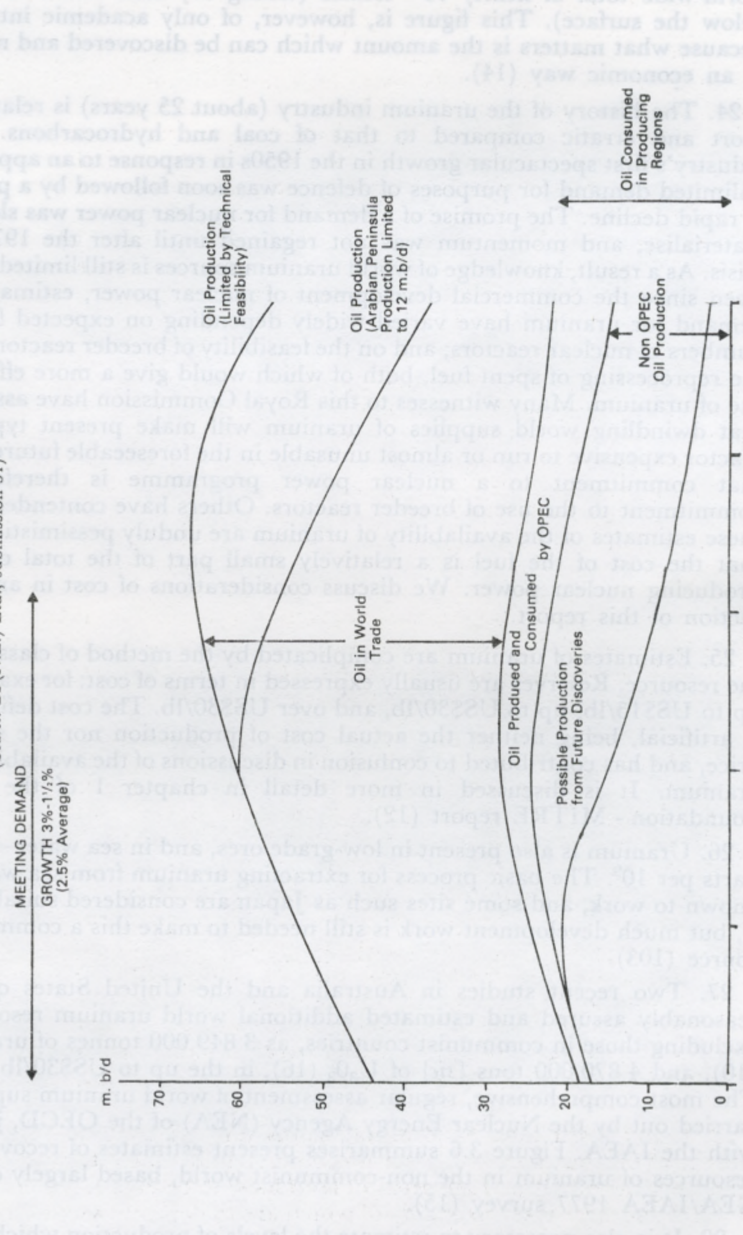
21. On the other hand, the world's coal reserves are much more extensive, estimates ranging from 6×10^{12} tons to 12×10^{12} tons. The main known deposits are in the United States, the Soviet Union, and the People's Republic of China, which together are estimated to have between 70 percent and 90 percent of the world total, depending on which reserve estimate is used. The problems in the use of coal as a major international energy source are therefore those of international trade and transport as well as of manpower and of technology, both for mining and for energy production. The Ford Foundation - MITRE study, after discussing coal reserves, transportation, and developing technology, concluded that more coal is being used because of higher oil prices and national policies to create wider energy options; and that coal should thus become more prominent in international trade (12).

22. Other fossil fuels such as tar sands and oil shale are potential sources of oil, but there is as yet no commercially viable technology for extracting the oil (10). Huge areas of land have to be excavated to obtain the oil from these reserves, many of which are in deposits where each ton of shale-bearing rock yields 25 or less gallons of oil. What little oil is presently produced from these sources comes from the richest deposits (13).

Figure 3.5

POSSIBLE NON-COMMUNIST WORLD OIL SUPPLY

(*Source:* BP(N.Z.) Ltd. submission 51)



Uranium

23. Uranium is relatively abundant, occurring in the earth's crust in an estimated average concentration of two parts per million, implying a world-wide total of nearly 10^{12} tonnes (taking dry land down to 1 km below the surface). This figure is, however, of only academic interest, because what matters is the amount which can be discovered and mined in an economic way (14).

24. The history of the uranium industry (about 25 years) is relatively short and erratic compared to that of coal and hydrocarbons. The industry's first spectacular growth in the 1950s in response to an apparent unlimited demand for purposes of defence was soon followed by a period of rapid decline. The promise of a demand for nuclear power was slow to materialise, and momentum was not regained until after the 1973 oil crisis. As a result, knowledge of world uranium sources is still limited (15). Even since the commercial development of nuclear power, estimates of demand for uranium have varied widely depending on expected future numbers of nuclear reactors; and on the feasibility of breeder reactors and the reprocessing of spent fuel, both of which would give a more efficient use of uranium. Many witnesses to this Royal Commission have asserted that dwindling world supplies of uranium will make present types of reactor expensive to run or almost unusable in the foreseeable future, and that commitment to a nuclear power programme is therefore a commitment to the use of breeder reactors. Others have contended that these estimates of the availability of uranium are unduly pessimistic, and that the cost of the fuel is a relatively small part of the total cost of producing nuclear power. We discuss considerations of cost in another section of this report.

25. Estimates of uranium are complicated by the method of classifying the resource. Reserves are usually expressed in terms of cost: for example, up to US$15/lb, up to US$30/lb, and over US$30/lb. The cost definition is artificial, being neither the actual cost of production nor the selling price, and has contributed to confusion in discussions of the availability of uranium. It is discussed in more detail in chapter 1 of the Ford Foundation - MITRE report (12).

26. Uranium is also present in low-grade ores, and in sea water—three parts per 10^9. The basic process for extracting uranium from sea water is known to work, and some sites such as Japan are considered suitable for it, but much development work is still needed to make this a commercial source (103).

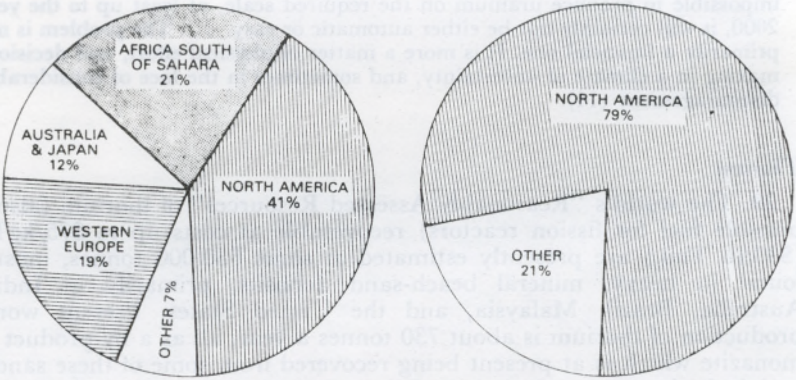
27. Two recent studies in Australia and the United States quoted reasonably assured and estimated additional world uranium resources, excluding those in communist countries, as 3 849 000 tonnes of uranium (10), and 4 870 000 tons [*sic*] of $U_3 0_8$ (16), in the up to US$30/lb class. The most comprehensive, regular assessment of world uranium supply is carried out by the Nuclear Energy Agency (NEA) of the OECD, jointly with the IAEA. Figure 3.6 summarises present estimates of recoverable resources of uranium in the non-communist world, based largely on the NEA/IAEA 1977 survey (15).

28. It is also necessary to estimate the levels of production which these uranium resources could support. 1977 production capacity is estimated at some 33 500 tonnes of uranium a year, largely distributed between North America and Africa south of the Sahara. World capacity could rise

Figure 3.6

ESTIMATED WORLD RESOURCES OF URANIUM RECOVERABLE AT COSTS UP TO $130/KG U (AS OF JANUARY 1977)

(Source: World Energy Conference (15))



(tonnes uranium)	World Region	(tonnes uranium)
825 000	1. North America	1 709 000
388 800	2. Western Europe	90 100
244 700	3. Australia, New Zealand and Japan	42 000
57 000	7. Latin America	94 400
32 100	8. Middle East and North Africa	69 600
427 800	9. Africa, South of Sahara	134 500
2 400	10. East Asia	. .
29 200	11. South Asia	23 300
2 007 000	Total World	2 162 900

to some 53 600 tonnes of uranium a year by about 1980. Known resources are believed capable of supporting a maximum level of production by 1990 of about 100 000 tonnes a year, but new sources would need to be identified if this figure is to be exceeded (12). The Ford Foundation - MITRE study concluded:

> Our review convinces us that current official estimates of uranium reserves and resources substantially underestimate the amounts of uranium that will be available at competitive costs. We believe that there will be enough uranium at costs of $40 (US 1976 dollars) per pound to fuel light-water reactors through this century and, at costs of $40 to $70 per pound, well into the next century (12).

Other expert opinion, however, is more cautious:

> Although (in line with the Ford conclusion) it does not appear physically impossible to produce uranium on the required scale, at least up to the year 2000, it will certainly not be either automatic or easy. . . . The problem is not primarily a financial one. It is more a matter of physical effort, and decision-making in a climate of uncertainty, and sometimes in the face of considerable discouragement (14).

Thorium

29. The world's "Reasonably Assessed Resources" of thorium (also a possible fuel for fission reactors) recoverable at costs up to $75/kgTh ($30/lb ThO_2) are presently estimated at some 630 000 tonnes, mostly found in heavy, mineral beach-sand deposits, primarily in India, Australia, Brazil, Malaysia, and the United States. Present world production of thorium is about 730 tonnes a year, all as a by-product of monazite which is at present being recovered from some of these sands, mainly for its rare-earth content. It is estimated that world production of thorium could be considerably expanded should it be required for use in nuclear reactors, and it seems unlikely that thorium demand would outstrip available supply from known sources by the year 2020 (15).

Renewable Energy Resources

30. The increasing recognition that fossil fuel supplies must have their limits and will grow more costly, as well as the concern about the environmental consequences of their intensive use, have led to interest in other sources of energy, often referred to as "renewable" or "alternative". These would involve either harnessing the earth's heat (for example, geothermal steam, hot dry rocks) or making more use of the sun's radiation directly or through the energy systems of the biosphere. At present such commercial energy production is restricted to hydro-electricity, geothermal bores for hot water and electricity generation, and solar water-heating. Other proposals take many forms, ranging from direct use of the sun's radiation to the use of the solar energy stored in the ocean, waves, wind, and vegetation. There is considerable optimism among environmentalists that these energy sources would be viable alternatives to nuclear power if they were to receive greatly increased research and development funds. The technical problems of tapping these sources of energy commercially remain formidable, though many reports see them as the necessary and desirable energy sources of the future.

31. In North America and Europe we frequently discussed the development of renewable energy sources. In the United States, in addition to solar energy having substantial use for low-grade heat, there

are prototype experiments on using it for electricity. British experiments with wave power have reached one-tenth of the planned industrial scale. It is at the "development" stage of full-scale engineering (as distinct from the research stage) that these technologies will need large sums of money, and will make their environmental effects more obvious.

32. We were impressed by the considerable effort now being made overseas in energy conservation, especially in building standards and community planning. But the effects on energy consumption cannot yet be quantified.

NEW ZEALAND ENERGY CONSUMPTION AND RESOURCES

33. Before the Industrial Revolution, wood was the major world source of energy. When European settlers first came to New Zealand much of the land was forested. Timber, though used as fuel and a building material, was more often regarded as an obstacle to farming. Coal, mined in New Zealand from the mid-nineteenth century, was the country's main source of energy for a hundred years (5), as a domestic fuel, in shipping and railways, as a steam-raiser for industry, and as a feedstock for the coal-gas industry. Over the past 50 years, coal's proportionate contribution has declined compared with other forms of primary energy, despite periods of heavy demand. Electricity replaced it as the main domestic fuel, oil as the industrial fuel. Electricity from hydro and geothermal resources has saved much fossil fuel, but has given rise to some environmental changes. Trends in the consumption of primary energy since 1924 are set out in table 3.2.

34. In 1975 some 10 percent of all primary energy was converted into other forms, mainly electricity, while smaller amounts were lost in processing or supplied to international transport. Table 3.3 illustrates the trends in consumer energy since 1924.

Table 3.2

PRIMARY ENERGY CONSUMPTION
(in thousands of terajoules[1])

(*Source:* Ministry of Energy Resources, Submission 13)

Calendar Year	Coal	Oil	Natural Gas	Primary Electricity	Total[2]	Imported Oil as % of Total
1924	75	10	. .	0.5	86	11
1934	56	19	. .	3	78	24
1944	72	30	. .	7	109	28
1954	66	59	. .	14	139	42
1964	66	103	. .	34	203	51
1973	60	208	13	55	335	60
1974	61	201	14	55	331	58
1975	56	195	15	64	331	57

NOTES:
[1] The terajoule (TJ or joule 10^{12}) makes comparisons among different forms of energy possible.
[2] Because of rounding totals may differ slightly from sum of individual figures.

Table 3.3

CONSUMER ENERGY
(in thousands of terajoules)

(*Source:* Ministry of Energy Resources, Submission 13)

Calendar Year	Coal	Oil	Gas	Electricity	Total
1924 ...	59	5	2	1	66
1934 ...	49	19	2	3	73
1944 ...	62	30	2	8	101
1954 ...	55	59	2	16	132
1964 ...	48	90	2	30	170
1974 ...	41	150	7	58	256
1975 ...	40	153	11	61	264

35. In 1975 the 264 000 TJ of consumer energy was used in the following proportion: industry 37 percent, transport 37 percent (nearly all oil), households 15 percent, and commerce 11 percent. The energy used in 1975 by the different sectors is shown in petajoules in the following table 3.4.

36. New Zealand's known major fossil fuel resources consist of coal and natural gas, though exploration for others continues. Hydro and geothermal resources have been developed, and could be further developed, if the economic, environmental, and social consequences were found to be acceptable. New Zealand's energy resources will be discussed further in chapter 7.

Table 3.4

CONSUMER ENERGY USE BY SECTOR, 1975
(in petajoules)

(*Source:* Ministry of Energy Resources, Submission 129)

	Solid	Oil	Gas	Electricity	Total
Industry	25.7	36.4	7.8	22.8	92.7
Transport (Including International)	...	122.2	...	0.1	122.3
Domestic	7.7	2.8	1.5	29.2	41.2
Commercial and Other ...	6.2	11.1	1.4	9.2	27.9
Total Consumer Energy ...	39.6	172.5	10.7	61.3	284.1

ENERGY STRATEGIES

37. Many studies have stressed the limited physical resources of the earth. Computer investigation of various strategies of resource use now allows the consequences of possible courses of action to be examined. Best known are probably those of the Club of Rome, whose project *The Limits of Growth* examined "the five basic factors that determine, and therefore, ultimately limit, growth on this planet—population, agricultural production, natural resources, industrial production, and pollution." Though their assumptions can often be questioned, such studies direct attention to some very real problems of the immediate future, and show the need for thoughtful and co-ordinated planning on an international scale.

38. One approach has been to form the World Energy Conference (formerly the World Power Conference). The Conference was founded in 1924 in Britain and now has over 70 member countries, including some of the less developed. It forms a link between different branches of power and fuel technology, between experts from different countries throughout the world, as well as between engineers, administrators, scientists, and economists.

39. The World Energy Conference aims to promote the development and the peaceful use of energy resources to the greatest benefit of all, both nationally and internationally, by considering the potential resources and all the means of production, transportation, transformation, and utilisation of energy in all their aspects; by considering energy consumption in its overall relationship to the growth of economic activity in the area; by collecting and publishing data on these matters; and by holding conferences of those concerned.

40. The affairs of the World Energy Conference are managed by its International Executive Council, made up of representatives from each member country's national committee. Meetings of the Council are held annually, hosted by national committees in different countries each year. New Zealand was host in 1972.

41. A large-scale technical conference has been held recently every 3 years. For example: 1971 in Bucharest on a theme "Improving the Utilisation of Energy with Special Reference to Complex Uses"; 1974 in Detroit on a theme "The Economic and Environmental Challenges of Future Energy Requirements"; and 1977 in Istanbul on a theme "Availability and National Uses of Energy Resources". These conferences are attended by 3000 to 4000 representatives of energy interests from most countries. Apart from the technical papers, they provide a forum for meeting, and for discussing broad matters of mutual interest. Administration and policy aspects are much stressed.

42. The New Zealand National Committee aims to maintain liaison with other national committees; arrange for the presentation of papers at meetings of the World Energy Conference; promote the attendance of New Zealanders at conference meetings; supply information to members concerning conference activities; and to broadly promote the objects of the World Energy Conference (17). Three New Zealand energy conferences have been held, the most recent being in Wellington in May 1977, with the theme, "The Dynamics of Energy Utilisation".

43. Following the oil crisis of 1973, the IEA was formed in the OECD under the Agreement on an International Energy Programme. At the end of 1976 New Zealand notified its consent to be bound by that agreement which includes an undertaking to hold oil stocks at specified levels and to

implement measures to hold down the demand for oil in the event of further oil embargoes. The IEA reviews each year the oil consumption of its members and their use of other sources of energy which may be able to replace oil. Every year about one-third of the members are singled out for an intensive on-the-spot survey, the results of which are discussed by the members of the IEA at a meeting at which the country concerned is represented. New Zealand was investigated in 1977. In March 1977, the IEA reported on energy conservation in the member countries, and this review concluded that New Zealand's conservation of energy was slightly above the average for the IEA group as a whole, but that its energy efficiency in transportation ranked poorly (18, 19).

New Zealand Energy Research

44. There is considerable research into energy, mainly funded by the Government, but also by the universities, by industrial contributions to research associations, and by private firms. The total estimated Government expenditure on energy research and development for 1977–78 (excluding exploratory drilling) was $3.7 million ($2.9 million in 1976–77). This represented about 4.7 percent of the total Government research expenditure of $78.7 million (excluding funds for medical research).

45. The NZERDC was allocated $0.5 million a year for research for the first three years from the time it was formed in April 1974. For the 1977–78 year the figure was $0.47 million but the committee was no longer required to fund State department contracts. It is also interesting to note that the amount spent on investigations into nuclear fission from Government funds—primarily the DSIR provision for technical information for the FFGNP report, and that of this Royal Commission—is much less than 5 percent of the total Government energy research and development expenditure.

46. The NZERDC seeks research projects from interested organisations and individuals. It has developed these priorities for projects: determining current and future energy demand; conservation and the more efficient use of energy; assessment of indigenous energy resources; assessment of human, financial, and organisational resources for increasing energy production and use; economic, technological, and environmental aspects of energy use and production over the next 15 years. All projects must include consideration of environmental and sociological issues, and in addition there are special environmental projects (20). A series of reports has been published of completed NZERDC projects, and these provide valuable information on various aspects of energy production and consumption.

47. The energy scenarios for New Zealand derive from the work of the small ERG, and are published as Report No. 19 of the NZERDC, with a summary being published as Report No. 20. The research arose out of an Energy Scenario Workshop held in March 1975, and discussed critically in September 1976. Although some criticism of the research approach and assumptions was expressed, it was generally felt that the work was worth while and that most of the conclusions would not be altered by further refinement. The scenarios are often referred to as the "Maiden Scenarios" from the name of the chairman of the NZERDC, Dr C. J. Maiden. To emphasise again the nature of this approach to the discussion of energy options we quote from his preface to the report:

The scenarios are not offered as predictions. Instead, their use is to help test and compare the consequences of different policy choices. In reality, there are infinite energy futures open to the nation, and it is not likely that the real energy future will closely resemble any of the scenarios. The purpose is to spotlight three possibilities among the many, in order to clarify thinking about the implications of different rates of energy growth (6).

48. The ERG research examines the implications of main shifts in the values society places on material wealth, environment, and resources, tracing over 50 years the implications of the major policies arising from the dominant theme of values underlying each scenario. The themes of the three scenarios chosen were:

(a) A *continuation scenario which would develop an extension of past trends, policies, and attitudes with continued economic growth, and emphasis on industrial growth;*

(b) A *low pollution scenario for New Zealand which would concentrate on the minimisation of pollution as a primary aim in government, business, and personal decisions, providing for the sacrifice of a small amount of economic growth for its achievement; and*

(c) A *limited-growth scenario which would represent a strategy for New Zealand in a world beset by resource depletion, environmental degradation, insufficient energy supply, and the social and economic consequences of rising population. It envisaged a lower population growth, slow economic growth, and a switching to indigenous renewable energy resources.*

49. It is assumed in the research that such social conditions would prevail that all decisions would conform to the scenario theme in a way not probable under present social and political conditions. This, as the research group points out, implies an unlikely degree of consensus in the community. It also stresses that the scenario research will not remain valid for long because of changes in society, the economy, and technology. It suggests a review every 5 years (6).

50. We heard further comment that these scenarios may be of only restricted value as they depended on assumptions about liquid fuel (21).

51. It is beyond the scope of this report to discuss the content of the scenarios. The ERG has summarised the main features in table 3.5 (22). It will be seen that the only scenario which postulates the use of nuclear power is the "Continuation". The ERG has constructed another scenario in which New Zealand maintains high economic growth while delaying the introduction of nuclear power until 2020. The scenario includes a substantial programme of energy conservation and restraint in the growth of electricity demand, particularly in the use of alternatives to electrical resistance heating; for example, heat pumps, gas-fired heating, and district heating (6).

52. The scenario research data can be used to assess specific energy issues. The ERG considers that for New Zealand, the most important energy supply issue is the security of liquid fuel supply over the next 50 years. This issue is seen as much more important than that of nuclear power. The research indicates that there is no simple answer to the liquid fuel problem, and the ERG concludes that none of the scenarios demonstrates a satisfactory solution—"Continuation" and "Low New Zealand Pollution" rely almost entirely on liquid fuel imports for transport energy, and "Limited Growth" includes the production of alcohol from trees, eventually obtaining from it all liquid fuel (6). The scenario research has also shown that if economic growth continues at anything like past rates, then New Zealand's fossil fuel reserves will be virtually depleted by 2030.

Table 3.5

KEY FEATURES IN THE THREE NZERDC SCENARIOS

(Source: Third New Zealand Energy Conference (22))

			Continuation		Low New Zealand Pollution		Limited Growth	
		1975	2000	2025	2000	2025	2000	2025
Population	Millions	3.1	4.2	5.0	4.2	5.0	3.6	3.7
GNP per capita (1973) prices	dollars	2,591	4,840	8,060	4,490	6,620	3,782	4,111
Primary energy per capita	GJ	134	285	498	179	184	130	151
Total consumer energy	PJ	302	816	1 621	594	813	368	332
Domestic energy per capita	GJ	11	19	27	17	20	13	13
Commercial energy per employee	GJ	43	75	128	63	93	58	60
Industrial consumer energy	PJ	103	361	849	238	311	122	112
Steel production	kt	110	1 000	1 500	850	1 000	110	110
Pulp production	kt	946	4 300	12 000	2 400	2 400	1 300	1 300
Aluminium production	kt	96	220	220	110	110	10	10
Fuel use in cement, glass etc.	PJ	15	40	79	31	45	15	10
Fuel use in food processing	PJ	23	44	66	26	22	21	18
Car kilometres	10^9 km	13	30	36	23	27	13	8
Aviation fuel	PJ	12	56	109	33	51	21	20
Total transport energy	PJ	126	232	460	217	310	136	104
Total primary energy	PJ	415	1 195	2 512	747	924	471	556
Electricity generation	PJ	71	211	550	134	180	81	86
Nuclear	PJ	0	9	363	0	0	0	0
Other thermal (including geothermal and in-plant)	PJ	15	100	48	29	36	6	5
Non thermal	PJ	56	102	139	105	144	75	81
Solid fuel	PJ	65	312	446	112	179	68	95
Percentage coal remaining	%	100	77	36	90	71	92	86
Gas (including wood gas)	PJ	12	235	103	172	161	62	35
Percentage natural gas remaining	%	100	60	20	71	29	86	80
Liquid fuel	PJ	213	375	631	275	370	173	102
Geothermal heat extracted	PJ	56	105	180	52	7	61	61
Energy imports	PJ	205	314	1 597	221	320	154	0
Percentage imported primary energy	%	49	26	64	30	35	33	0

53. The report includes, as its final section, comments on the draft report by interested people qualified in a wide range of disciplines. These comments, both appreciative and critical, include suggestions for further research such as scenarios based on other sets of values, more economic analysis, case studies, demographic and behavioural research.

54. In submission 128 the NZED has devised two basic scenarios "Static" and "Normal Growth", and a third "Electrified Transport" ("Normal Growth" with electrification of part of transport energy needs). These will be referred to in chapter 4.

Energy Consumption and Social Organisation

55. Many submissions were concerned, not only with the specific characteristics and impacts of nuclear technology nor with the energy question as such, but with the very structure of society and the influence of energy consumption on it. In the early stages of our inquiry, the Commission for the Environment stated that "Our energy base and pattern of use can determine the kind of society we are and become. Alternatively, we can choose the kind of society we want and find the energy base and pattern of use appropriate to that kind of society." (23). Many who appeared before us adopted the second of these approaches.

56. We were told that assumptions of energy demand and the consequent provision of generating capacity, the availability of relatively cheap energy, and especially the provision of electricity through a centralised system, have a wide influence on the structure of society (24). It was further contended that nuclear power, which, for economic reasons is usually supplied in large blocks of power, would reinforce these tendencies towards a high energy, industrialised, and centralised society, and that this would not be in the best interests of the welfare of the community (25, 26, 27).

57. There was much criticism of the way that energy, and especially electricity, demand (or use or requirements) is estimated, and it was alleged that in practice electricity use rises to make use of installed capacity (24, 28). It was also said that growing industrialisation based on greater energy use is not necessarily synonymous with economic growth, better employment opportunities, or a desirable life-style (23, 29, 30). The subject of forecasting power needs will be dealt with later. We comment here that, while we agree that it is not possible to plan for uncontrolled exponential growth of energy demand (or indeed of anything else), the planners involved denied that this was, in fact, being done.

58. An increased dependence on a centralised electricity system was criticised, as was the vulnerability that this is alleged to produce (24, 31). As somewhat extreme expressions of this point of view, we quote the submission of, first, the Friends of the Home: "Small scale simple technologies allow a wider choice to the individual. Centralised control closes off options. There is independence, satisfaction, and creativity for the individual in deciding where and how to site a solar water heater, in planning his house to take advantage of the sun, in stoking a wood fire on a cold night, in feeling the added comfort after insulating the house. There is only boredom and alienation in turning on a switch to release a flood of expensive electricity." (26). And second, that of Dr E. Geiringer: "The inhabitant of the all-electric house becomes conditioned to accept it as a fact of life that the flick of a central switch can make life unbearable for him, and that, in the last analysis there is somebody sitting in the centre who has the right to tell him when and how to use the energy he needs to

maintain his basic standard of living. I submit that the inhabitant of a house that has retained an open fire place, that has a solar panel on the roof (regardless of who supplied it), and a kerosene lamp in the cupboard—just in case—is a different political animal. He is conditioned to a different view of his relation to central authority." (25). While we respect the sincerity with which these views are held, neither our own experience nor our observations lead us to endorse them. More importantly, we are very conscious that they may be at variance with the goals of most of the community.

59. We were told that "social attitudes have changed dramatically over even a few years, to responsibilities to fellow men and to the environment" (23), and that "in all of the western industrialised countries, the perception of what are genuine goals for society has been changing very rapidly over recent years." (3). However, witnesses were unable to evaluate how widespread such changes in attitude are throughout society, and it is a matter of regret to us that, as we have already said, those organisations which might have been expected to advocate energy growth and the expansion of the economy did not choose to appear before us to give us evidence of their viewpoints. That there is another attitude towards energy and the quality of life, was expressed forcibly by the Secretary of Mines in that part of his department's third submission which contained his more personal views. He asserted: "The quality of life is to a surprising extent dependent on the amount of energy available. Consider the following areas—housing, educational facilities, cultural activities, health, women's life-style. All these factors are of high social and human interest. But what is frequently overlooked or not even realised is that the achievement of these aspirations will certainly make quite heavy demands on primary energy." (32). Mr. Dick then discussed expressions of overseas public opinion about nuclear power and suggested that there could be marked differences in opinion about the need to curtail energy production and consumption between those groups whom he called the "Resolute Minority" and the "Silent Majority".

60. As we had no convincing evidence of to what extent the community would accept a reduced level of energy consumption, we would agree with the MER that: "Much has been said about the desirability of reverting to simple life-styles in order to reduce the consumption of energy and other resources, as well as for a wide variety of other reasons. It is very doubtful, however, whether radical changes from the present patterns would be acceptable to the majority of the population." (33).

61. Even if there were a consensus that society should aim for simpler life-styles, we were given little indication of ways to attain these aims, and of how present society could be induced to change its values and aims without prejudicing that personal freedom which was also so strongly advocated. There were advocates of wide-spread public information, education, and discussion with reference to the Swedish programme on energy options in 1974, and the New Zealand Educational Development Conference of 1975 (27, 34, 35). We strongly support the dissemination of accurate information on energy matters, including nuclear power, and we hope that there will be informed discussion on the matter in New Zealand and that the publication of our report will make a contribution to such debate. However, we are less convinced of the efficacy of an organised discussion programme in involving a truly representative number of people, or in making them feel of real value in the policy decisions which must be made (see chapter 5).

62. While there can be considerable doubt about the willingness of people to change their way of life in order to conserve energy unless large (and probably unpleasant) constraints were placed on its use, there is much that could be done without radical changes in the styles of life in society and in the individual. Many witnesses advocated movement towards a "sustainable society" or a "conserver" rather than a "consumer" society by more efficient use of non-renewable resources, greater conservation of energy (especially electricity), and much more emphasis on the development of renewable resources such as sun, wind, and waves. This concept was expounded to us by Dr F. Knelman (36) who was brought to New Zealand from Canada by the Environment and Conservation Organisations. It has been eloquently expressed by Amory Lovins in *Energy Strategy: The Road Not Taken* (2), quoted to us by many witnesses. In this concept the so-called "hard technology" is contrasted with the "soft technology" of renewable energy resources, asserted to be diverse and flexible, and matched in scale and energy quality to the end-use needs. It was argued that one consequence of a decision in principle in favour of nuclear power for New Zealand would be the diversion of resources from the development of these "benign" sources of energy.

63. It now seems to be generally accepted (see chapter 1) that New Zealand has time and opportunity to defer a decision on whether to import an electricity technology (especially nuclear power). Instead, it could combine a lower energy growth rate, improved energy efficiencies, and accelerated development of indigenous resources (23, 37). This would be attractive if it could be done without adversely affecting the economy or penalising any sections of the community. However, reducing demand and substituting other energy sources have their own long lead times which we consider are too often overlooked or underestimated by their proponents. The economic and environmental effects of the development of further indigenous energy sources require serious consideration and are dealt with in other sections of this report.

CONCLUSION

64. Mankind at present uses only a small part of the total energy reaching the earth from the sun. The fossil fuels relied on so heavily for energy resources are finite. How large the reserves are, and when they are likely to be exhausted, is a matter of speculation and dispute. The looming energy problem, however, is not so much a matter of complete depletion of fuels, as of demand outstripping supply, appearing first in the form of rising real prices for energy.

65. Scenarios which project energy demand and supply well into the twenty-first century show that with our present consumption patterns and energy technology there will be a widening "energy gap" opening up. On present knowledge the means of filling this gap would seem to consist of limiting per capita energy consumption, of making more efficient use of non-renewable energy resources, of developing renewable energy resources, and of using nuclear power, including fast breeder reactors. Probably a combination of all of these will be needed. This is the context in which we discuss electricity and nuclear power.

Chapter 4. NUCLEAR POWER

INTRODUCTION

1. From the discussion given in Part III it appears unlikely that New Zealand will need to commission a nuclear station before the turn of the century. It is even conceivable that the introduction of such plant may be unwarranted for many years beyond that time. However, we are not prepared to say that it will never be needed, nor that it will always be undesirable. Many of the problems that make it appear an unattractive alternative at present could be satisfactorily resolved in the future, and basic economic and environmental factors could well lead to nuclear power becoming the first choice.

2. Within the OECD countries, the IEA sees no alternative to the use of nuclear power. If present plans were dropped, a further 6 million barrels of oil a day would be needed by 1985. This corresponds to 214 GWe and is to be compared with an estimated 26 million barrels a day of world imports of oil by that time. It appears that Japan in particular has little choice, as most of its electricity is at present generated from oil and there is considerable opposition there to using coal. Again, countries like France and Spain have few indigenous resources that can be used to produce electricity.

3. There are of course, as implied in the previous chapter, many who believe that we should reduce our energy demands now rather than develop a future dependence on nuclear power. They believe that questions of safety, waste disposal, proliferation, etc., all make it an unacceptable solution to our long-term energy needs. They point out that, depending on the final form nuclear power may take, it may be only short-lived as a major technology, and the high-energy society which demanded it may be unsustainable. It would thus be prudent to plan our societies now in such a way that our future energy demands could be met from renewable as distinct from finite resources. This assumes that such societies can exist, allowance being made for the presently ever-increasing world population.

4. New Zealand is fortunate in that it does not have to make an immediate decision. It can observe the many present studies and inquiries before it must decide. Such a situation, though, does not make our task any the easier. In being asked to report on the consequences of a nuclear power programme for the generation of electricity, we are essentially being asked to report on technologies which may well be different, or even abandoned, by the time they may be needed; and to comment on international matters that still remain to be raised, let alone resolved.

5. However, the fundamental concepts of radiobiological protection, waste disposal, and, from the long time-scales associated with development, even reactor types and their relevant fuel cycles are unlikely to change drastically for at least 20 to 30 years. It follows that a reasonable

assessment of possible consequences can be made for periods of time relevant to a New Zealand context. Such an assessment is obviously necessary to define those problems peculiar to New Zealand and thus ensure that these are adequately studied before any final decision on the possible introduction of nuclear power is made.

6. In this chapter we discuss nuclear power in general terms, detailed discussion of specific topics of direct interest to New Zealand being left till Part IV. In doing this we are aware of the wealth of material given us by those making submissions, which we acknowledge with appreciation. However, in what is essentially a review, we must inevitably be selective in our topics, and the emphasis given to various aspects no doubt reflects the impressions and experience we gained while overseas.

THE GENERATION OF ELECTRICITY BY NUCLEAR POWER

7. Many adequate accounts of the generation of electricity by nuclear power have been given (for example, references 103, 12, 4, and 111). We have no wish to add to this literature, but it is necessary for us to summarise the more pertinent aspects to define the many problems brought to our attention during our hearings.

The Steam Cycle

8. In a conventional thermal base-load plant, electricity is produced by boiling water to make steam. This drives a turbine which in turn drives an electrical generator which produces electrical energy. The steam is produced in a *boiler* or (in the language of nuclear power) a *steam generator*, from which it normally passes through several turbine stages to a *condenser* where it is returned to water and subsequently pumped back into the boiler. The complete sequence of events is referred to as a *steam cycle*. An external flow of water about the condenser carries away the heat associated with condensation. This cooling water may be obtained from a river, a cooling pond, the oceans, or be continuously circulated through cooling towers, the heat eventually being discharged to and dispersed in the atmosphere.

9. The heat for the boiler, or steam generator, may be obtained from fossil fuels in a furnace, or from the core of a nuclear reactor. The fossil fuels used are coal, oil, and natural gas. The heat originates from the chemical interaction between carbon and/or hydrogen with oxygen in the air. The reaction products, carbon dioxide (CO_2) and water vapour (H_2O), are continuously discharged to the atmosphere through a chimney stack. In the case of a nuclear reactor, the basic fuels are isotopes of uranium and/or plutonium, the heat originating from the *fissioning*, that is the breaking up of these atoms into others of lower mass such as iodine, strontium, caesium, etc. These reaction products are retained with the unburnt fuel.

10. In a fossil-fuelled plant we can think of the water and steam in the boiler as cooling the furnace. In certain types of nuclear plants the core is cooled in a similar manner, but in others the cooling is indirect. That is, the core is cooled by a separate fluid, liquid or gas, referred to as the *coolant*. The coolant provides the heat for the steam generator.

11. Normally within a station there is more than one turbine-generator unit, each such unit being driven by a separate heat source. But in the case of nuclear reactors, there may be more than one steam generator, each normally requiring its own cooling *loop*; although, again, it is usual for these generators to supply only the one turbine unit. The characteristics of a station are usually expressed in terms of its net generating capacity (MW) and generating capability (MWh). Of more fundamental importance is its *thermal efficiency* and output or, to be more exact, *availability factor* which is the fraction of time for which the station is available for use.

12. *Thermal efficiency*, expressed as a percentage, is defined as the fraction of energy released by the fuel which leaves the generating station as electricity. In a fossil-fuelled plant there are heat lossses of 6–11 percent through the chimney stack, losses of 1–2 percent in converting the turbine mechanical power to electrical power, and losses of about 4 percent associated with station use of part of the electrical output to run auxiliaries such as pumps, fuel handling devices, forced draught fans, etc. Similar losses (except for chimney losses) occur in a nuclear plant. In both cases the largest loss is inherent in the steam cycle, and this appears as waste heat in the condenser cooling water. The ratio of this energy loss to the energy provided to the boiler or steam generator is a function of the temperature of the steam before it enters the turbine. It is an inevitable loss determined by basic thermodynamic principles rather than by inadequate design. It can be minimised by optimising the steam cycle by *superheating* the steam coming from the boiler, by *reheating* the steam after it has passed through the high-pressure stage of the turbine, and by *feedheating*, that is, by heating the water in transit from the condenser to the boiler with steam bled from various turbine inlet and outlet stages. In superheating, the steam from the boiler, or steam generator, is returned to the heat source before entering the first turbine stage. To be effective the temperature of the heat source must be significantly greater than that of the steam.

13. With such techniques, at best only about 45 percent of the heat originally transferred from the heat source to the boiler or steam generator can be converted to mechanical energy by the turbine. The remaining 55 percent appears as waste heat in the condenser cooling water. The upper limit is set by the inherent properties of steam, and the mechanical properties of the materials used. It corresponds to steam temperatures of about 550°C and associated steam pressures close to safety limits. It follows that in a fossil-fuelled plant, on allowing for the other losses, station efficiencies of about 38–40 percent only are possible. In the case of nuclear plants, since there are no chimney losses, it is possible with gas- and liquid-metal cooling of the core to reach values higher than this. But if the coolant is water, there is little opportunity for superheating. In all cases, the steam temperatures used can be limited by both the reactor core materials and fuel type, rather than pressure in the steam circuit. Because of this, most present commercial nuclear stations have efficiencies of significantly less than 38–40 percent.

14. The second fundamental characteristic of a generating station is its *output factor*, that is the fraction of time it is in operation (see chapter 7 for an exact definition). In a conventional system, one would plan for this to be 70 percent or greater in standard base-load operation. Unfortunately, because of unforeseen problems, this may not be attainable. For normal maintenance and repair, one expects a unit to be on average unavailable

for about 1 month a year; that is, it has a planned *outage factor* of about 8.5 percent. However, it could also have forced outages from malfunction, etc. These could be associated with the operation and control of the heat source, but are just as likely to be associated with the steam cycle, in particular with the turbine unit.

15. Turbine-generator units of 660 MW are being installed in the new fossil-fuelled as well as the nuclear plants in Britain. In many nuclear plants still larger units of about 1100 MW are being used, and units of 1300 MW are being contemplated. The new large units have inevitably had problems, giving, at least during the initial stages, low output factors. In general, in the first years of a station's operation, problems are to be expected. However, availability factors should increase with use to a maximum and thereafter slowly decrease as the plant ages. Finally, as newer and more efficient plant is introduced, a base-load plant will be transferred to intermediate-load or load-following duty (see chapter 7).

16. At maximum efficiency, a modern 1 GWe fossil-fuelled plant needs for a 70 percent output factor, the following fuel for a year's operation (in million tonnes): coal, 2.3; oil, 1.4; or natural gas, 1.1. In the case of a nuclear station, the actual value depends on the reactor type and the specific nature of the fuel. Unlike a fossil-fuelled plant in which fuel and air are continuously fed into the furnace and burnt, existing nuclear plants have the fuel in rods which are mounted in geometrically fixed positions within the core. After a certain fractional burn up these are replaced, the frequency of replacement depending on reactor type.

17. In general, for a 1 GWe station and the types of reactors at present in commercial operation, approximately 200 tonnes of natural uranium are needed a year; that is, each station represents a commitment of about 5000 tonnes for a 25-year life. Advanced reactors can reduce this by about a factor of 50, although in some such concepts thorium is also needed.

18. Irrespective of reactor type, a 1 GWe nuclear station produces about 1 tonne of reaction (that is, fission) products a year. From the preceding paragraph it follows that for the present commercial type of reactor, about 200 tonnes of "ash" or "slag" equivalent (that is, material that is not burnt) must be disposed of each year. For comparison, in a fossil-fuelled plant about 3–6 million tonnes of carbon dioxide are produced each year, and in the case of coal about 350 000 tonnes of ash, primarily fly ash, which is removed from the flue by electrostatic precipitators with an efficiency greater than 98 percent. There is virtually no ash with plants fuelled by oil or natural gas.

19. Such a comparison between the outputs of a fossil-fuelled and a nuclear station is, however, misleading. In the first place, 1 tonne of natural uranium requires the mining of about 1000 tonnes of ore. Thus, counting the *tailings* (that is, what is left after the uranium has been extracted), the present type of nuclear station produces the equivalent of about 200 000 tonnes of ash and slag per 1 GWe per annum, not so very different from a plant fuelled by coal. In addition, nuclear plants produce other wastes which require careful attention. Second, the physical nature of the reaction products is quite different. However, if other reaction products (such as oxides of sulphur and nitrogen which can also be produced in fossil-fuelled plants) are taken account of, both types of waste are deleterious and potentially dangerous to man (see chapter 9).

Reactor Physics

20. A nuclear reactor consists of a *core* which contains the fuel immersed in a *moderator* and surrounded by a *reflector.* The core is cooled by the coolant, and the heat produced is controlled by inserting rods. The whole is contained within a *reactor vessel* which is in turn surrounded by a *biological shield* and enclosed within a *containment building.* If the coolant is maintained at a high pressure, the reactor vessel is referred to as a *pressure vessel.* The containment building encloses the reactor vessel and steam generating plant, but does not normally enclose the turbine-generator, etc.

21. The fuel contains the fissile nuclei. Fission occurs when a neutron is absorbed, the nucleus of a fissile atom splitting into nuclei of lighter atoms. The lighter atoms, which are the reaction or fission products, are accompanied by the emission of two to three neutrons. If these neutrons can cause another fission, then a chain reaction can be produced, the energy released appearing as the kinetic energy (that is, the energy associated with motion) of the reaction products and emitted neutrons. Not all the emitted neutrons cause a further fission. Some may be absorbed by a variety of atoms without fission, and others may escape from the fuel before they have time to react. The core of a reactor is so designed that at least one neutron from each fission may be made to induce a further fission. This is done through the geometric structure and the exact nature of the fuel, and by the use of a moderator and/or a reflector. The latter reduces the escape of neutrons from the core and the former reduces the speed of the emitted neutrons to values for which the probability of capture followed by fission is greatly enhanced.

22. The reactor is controlled in various ways; in a gross manner, by replacing burnt by fresh fuel, by the use of *control rods* made of neutron-absorbing material such as boron or hafnium, and sometimes the moderator is varied in one way or another to control the reaction rate. In all cases the basic aim is to control the flux of neutrons. Depending on the type of reactor, the life-time of most neutrons produced in a fission event is measured in either micro-seconds or milli-seconds. Such neutrons are referred to as *prompt.* There are others, referred to as *delayed,* which are emitted by certain of the fission products in times of the order of seconds or longer after the fission event. The delayed neutrons enable the core to be adequately controlled. Control rods are used to ensure that the reactor can never become *critical,* that is, never reach a state where the number of neutrons produced equals the number lost per unit time, on prompt neutrons alone.

23. Obviously nuclear reactors of the type at present being discussed depend on the existence of fissile atoms. Provided the neutron energy is sufficiently high, all heavy atoms (that is, those heavier than iron) may be fissioned. But only a few types may be fissioned by neutrons with energies characteristic of those emitted by the fission process itself, that is, only a few types can be used to sustain a chain reaction. It is these which are called *fissile,* and are isotopes of uranium and plutonium.

24. All isotopes of a given element have the same number of electrons (and hence, protons), but differ in the number of neutrons in the nucleus. That is, *isotopes* of the same element have the same atomic, as distinct from nuclear, structure and are chemically indistinguishable, but can be distinguished at a nuclear level. Of particular interest are the uranium isotopes uranium-235 and uranium-238, which are chemically the same but show

quite different nuclear properties. A uranium atom has 92 electrons and within its nucleus 92 protons. In uranium-235 the total number of nucleons (that is, protons plus neutrons) is 235 and hence there are 143 neutrons. By comparison uranium-238 with 238 nucleons has 146 neutrons. The difference is sufficient for uranium-235 to be a fissile material, whereas uranium-238 is not.

25. Uranium-235 is the only fissile isotope of any consequence which occurs naturally. Natural uranium contains 0.7 percent fissile uranium-235, the remainder being the non-fissile uranium-238. Other fissile isotopes may be created by the neutrons released in a fission process. Uranium-238 and thorium-232 in particular are said to be *fertile* materials because when they absorb a neutron, a series of reactions occur leading to the isotopes plutonium-239 and uranium-233, both of which are fissile. The process which changes a fertile atom into a fissile atom using neutrons released in a fission process is called *conversion*. As reactor fuel in general consists of both fertile and fissile material, it is convenient to define a *conversion ratio* as given by the ratio of the number of fissile nuclei formed by conversion to the number of fissile nuclei consumed. If the design of a reactor and its fuel is such that this ratio is less than unity, then the number of fissile nuclei decreases with time; but if it is greater than unity, the reactor can breed more fissile material than it consumes. The ratio is then referred to as the *breeding ratio* rather than the conversion ratio. Reactors are designated as *converters* or *burners*, *advanced converters* or *near breeders* or *breeders* depending on whether the conversion ratio is significantly less than, slightly less than, or greater than unity.

26. Another concept of fundamental importance is that of *enrichment*; that is, the percentage of fissile material in the fuel. The rest of the fuel normally consists of fertile material. If the fertile and fissile atoms are chemically different, and the enrichment throughout the core is not homogeneous, the term often used is *spiking*, rather than *enrichment*.

27. For low enrichments, the neutrons emitted from a fission process are too fast to cause sufficient subsequent fissions to maintain a chain reaction. They must therefore be slowed down by about a factor of 10 000 to speeds comparable with the thermal speeds of the surrounding molecules. This is done by a moderator, commonly of light water (H_2O), or heavy water (D_2O), or graphite. In *heavy water*, deuterium, a heavy isotope of hydrogen, replaces hydrogen. The neutrons are slowed by collision with the atoms of the moderator. At very low enrichments, like that of natural uranium, light water cannot be used as it absorbs too many neutrons, changing hydrogen to deuterium, for a critical state to be reached. In contrast, high enrichment may allow sufficient fissions per unit volume to occur even where there is no slowing of neutrons, and the moderator may be dispensed with. In such a case we have what is called a *fast reactor* as distinct from a *thermal reactor*. This general classification refers to the speed of the neutrons responsible for fission.

28. In general, a thermal reactor using uranium and/or plutonium as the fissile, and uranium as the fertile, material is a converter. A thermal reactor using uranium as the fissile material and thorium as the fertile material can be an advanced converter or a somewhat inefficient breeder. But if the degree of enrichment is sufficient for either type of fuel to be used in a fast reactor, then breeding occurs, and it becomes a *fast breeder reactor* or *FBR*.

29. In general, the reactor fuel will consist of a mixture of fertile and fissile material which may exist in a number of different physical and

chemical forms. It can simply be the metal uranium, or uranium and/or plutonium dioxide, or uranium and thorium dioxide, or a carbide or nitride. In certain experimental reactors, it has even taken the form of a molten salt solution consisting of fluorides. The exact form depends on the required physical properties. As an example of how such properties may influence choice, we note that the melting points of metallic uranium and thorium are 1130°C and 1700°C respectively, and that the melting points of the ceramic forms, uranium dioxide and thorium dioxide, are 2750°C and 3290°C (160). Again, metallic uranium undergoes a crystalline phase change at 665°C, further limiting its usefulness.

30. In existing reactor types, the dioxide form is the most common. In such cases the fuel is fabricated as small cylindrical pellets which are sealed inside tubes of stainless steel or zircaloy, an alloy of zirconium. Each such tube is called a *fuel rod* or *pin* and these are clustered into what are called *fuel assemblies.* In a reactor the number of rods and assemblies depends on the power output required, and is quite different for different reactor types. The assemblies are immersed in the moderator and coolant. The fuel tube material is referred to as the fuel *cladding* or *canning*, and this can often limit the operating temperature of the core.

31. During the operation of the reactor, fission products build up within a fuel element. These products are contained within the element, although some of the gaseous products can leak into the space between the fuel element and the cladding. Some of the fission and other transmuted products absorb neutrons, and after a certain time, before all the original fuel is consumed, fuel rods must be replaced to maintain the reactor in a useful power producing state. This can be done in certain reactor types with the reactor still on load, but in others the reactor must be shut down.

32. The removed fuel is said to be *spent.* It does, however, contain some of the original fissile material and a contribution of new fissile material from the conversion of fertile material, some of which could of course have also been consumed. In fact, up to 50 percent of the energy output can come from converted material. The recovery of this fissile material (that is, in particular, the separation of the spent fuel into fissile, fertile, and fission products) is called *reprocessing.* The fabrication of the recovered fissile component into new fuel elements and its re-use in a reactor is called *recycling.* To take full advantage of the conversion or breeding properties of a reactor, there must be reprocessing followed by recycling.

33. In a uranium-plutonium FBR, the breeding ratio can be made significantly greater than unity, and it is therefore possible to breed enough fuel to supply a second reactor, as well as enough to sustain the original. In a thorium-uranium thermal breeder, the breeding or conversion ratio is unlikely to be significantly greater than unity. Thus it is possible after an initial charge of uranium-235 to produce only enough uranium-233 to sustain the original reactor. Additional reactors would need further initial charges of uranium-235, or plutonium-239, as there would be no surplus uranium-233. Therefore, at best, a thorium thermal breeder will be self-sustaining only, the associated events being termed the *self-sufficient thorium cycle.* (In fact even this may not be possible, as the uranium-233 may need to be supplemented with other fissile material, uranium-235 or plutonium-239.)

34. For either type of breeding system the net effect is similar, the effective uranium reserves being increased by about 50 times. Similarly,

the use of advanced converters (near breeders) would also have major effects on uranium reserves, although in all cases reprocessing followed by recycling would be necessary.

35. For reactors in which the breeding ratio is significantly greater than unity, one can define a *doubling time* corresponding to the time taken for a reactor to double the fissile material. Since, however, continual refuelling followed by reprocessing is necessary, this time must also take into account the material in the reprocessing plant and that in transit between the plant and the reactor. This could be two to three times that in the reactor itself, the exact value depending on the speed with which the spent fuel is reprocessed and new fuel fabricated. The total amounts of both fissile and fertile material in existence at any instant of time is referred to as the *inventory.* For a thermal breeder, the inventory would also include both thorium and uranium-233. Since thorium may have to be stored for some years after reprocessing (see paragraph 81), the thorium inventory could be large, though the rate of consumption would be negligible.

36. The introduction of breeding reactors into an electrical generating system would have little immediate effect on the demand for uranium. The initial inventories for the reactors must be filled with both fertile and fissile material. Uranium-plutonium fuels would be supplied from the spent fuel of thermal reactors (an indirect demand), and thermal breeders would need freshly mined thorium and uranium, or recycled uranium, or plutonium.

37. The doubling time of the system itself must also be taken into account. For the uranium-plutonium breeder, if this doubling time is shorter than that of the fuel, the demand for uranium will be almost the same as if only thermal reactors are used. If the doubling time of the system is longer than that of the fuel, the demand for uranium will quickly drop once sufficient breeders have been established, and will eventually become negligible.

POWER REACTOR TYPES

38. From the previous discussion it is apparent that a specific type of reactor and power station is characterised by many parameters which include the type of fuel, the degree of enrichment, the number of fuel assemblies and rods for each assembly, fuel replacement rates, the fuel cladding, the type of moderator and coolant, whether the coolant is used directly or indirectly to drive the steam cycle, conversion or breeding ratios, steam temperatures, thermal efficiency, output and availability factors, whether refuelling is on load or off load, etc. The specific power (expressed in MW per kg of fissile material consumed) is of interest, as is a related parameter the *core power density* in, say, kW per litre, which is inversely proportional to the physical size of the reactor.

39. At present there are three basic types of reactors in commercial operation: the gas-cooled graphite-moderated reactors manufactured and used in Britain, the light-water reactors which were originally developed in the United States but now also being produced by certain European countries, and the heavy-water reactors, for example, the Canadian CANDU. A fourth type, a hybrid in terms of the other three, is a Soviet reactor in which the coolant is light water and the moderator, graphite. All are thermal reactors, and to date there has been little or no recycling, except to provide fuels for prototype fast reactors. There is an increasing

tendency to standardise on the turbine-generator units, with sizes of 600 MW and 1000–1200 MW being favoured. Units of 1300 MW are also contemplated, as the larger the unit the cheaper the output per unit of electricity. Fossil-fuelled boilers are not available for the very large units, a basic reason for a sustained interest in nuclear power (161).

40. Fast breeder reactors employing uranium-plutonium fuels are at the prototype stage and in some cases have been feeding electrical energy into generating systems. Thermal breeders are essentially in the experimental and developmental stages, although one such plant is still in the process of being fully commissioned as a commercial plant at Fort St. Vrain in the United States.

41. In the following subsections we briefly summarise the more important characteristics of the present and potential commercial reactor systems. We had the opportunity to see most in operation, and a number being built. The quantitative values given for a particular reactor type can only be regarded as average or typical. The exact values are often peculiar to an individual plant, even though other plants may be basically the same. Details can be found in the IAEA report on power reactors (162).

Magnox Reactors

42. The CEGB operates 8 Magnox stations in Britain. The name derives from the magnesium-aluminium alloy used for the fuel cladding. In these reactors the fuel consists of rods of naturally enriched uranium metal. The moderator is graphite and the coolant carbon dioxide. Refuelling is carried out on load. The conversion ratio is high, 0.86 (174), but the core power density is low at about 0.6 kW per litre. There is no superheat; the steam temperature is about 350°C, and station efficiencies of about 25 percent are low. However, lifetime output factors of close to 80 percent have been reached. The CEGB 1976–77 annual report notes that:

> The Board's first two Magnox stations, Berkeley and Bradwell, which were commissioned in 1962, have each generated more electricity already than any fossil-fuelled station of comparable size and age would be likely to generate over its 30 year lifetime.

At present the Magnox stations provide about 12 percent of the CEGB's total electrical output. In spite of this record, no further Magnox stations are to be built, as there are said to be superior alternatives. The difficulties of this type of reactor are associated with limitations of temperature imposed by the fuel cladding and by corrosion in general which occurs even though carbon dioxide is the coolant. Again, the low core power density leads to high capital cost, making the reactors unsuitable as heat sources for large generating units. Nevertheless, the existing units are still likely to be in use in the 1990s.

AGR

43. The acronym stands for "advanced gas-cooled reactor". In Britain there are two working AGR stations and three under construction. They are basically an upgraded version of the Magnox type. The fuel cladding is stainless steel and the fuel pellets slightly (1.6 to 2.3 percent) enriched uranium dioxide. The coolant is still carbon dioxide and the moderator, graphite. Enrichment is necessary since stainless steel absorbs neutrons. The steam temperature is 541°C; there is superheat, and the steam cycle is little different from that of a fossil-fuelled plant. Station efficiencies of 41–42 percent can be reached, and core power densities are low (about 2.7 kW per litre) but considerably higher than those in the Magnox type. The

conversion ratio is 0.44 (174). The two stations in operation are at present completing commissioning procedures, and, hence, output factors are for the moment irrelevant. The turbine-generators are 625 MW units. The pressure vessel and biological shields are combined into one pre-stressed concrete cylinder, 5 metres thick. Refuelling is carried out on load.

LWR

44. This stands for "light-water reactor" and refers to the moderator-coolant as both moderating and cooling is done by the same volume of water. There are two basic types of LWR, the PWR ("pressurised-water reactor") and the BWR ("boiling-water reactor"). In both, the fuel is pellets of uranium dioxide clad in zircaloy. Enrichment is about 3 percent uranium-235, and is lower on the initial loading.

45. In the PWR, the coolant is under pressure to prevent boiling, the pressure vessel consisting of welded steel 0.203 metres thick. The coolant outlet temperature is 318°C, and the steam temperature about 280°C. There is little or no opportunity for superheat, and station efficiencies of about 32 percent only are reached. Turbine-generator units of about 1100 MW are now being installed in most new stations. The efficiency is limited by the coolant temperature which in turn is limited by the strength of the reactor pressure vessel. In the BWR, the coolant-moderator is allowed to boil, and the steam produced used to drive the turbine directly. The steam temperature is about 280°C, and station efficiencies similar to those of the PWR are reached. In the PWR, the core power density is high at about 100 kW per litre, and in the BWR it is about 50 kW per litre. Conversion ratios are about 0.55. Of an initial loading of about 90 tonnes of uranium per GWe, about 35 tonnes per GWe are discharged once each year with the reactor off load. In LWRs the reactor vessels are surrounded by concrete biological shields, and, together with the steam generators, enclosed in usually cylindrical, dome-capped, post-stressed concrete containment buildings.

46. In the United States output factors have not been entirely satisfactory up to the present although it appears that many stations are still going through a learning stage. The Atomic Industrial Forum (AIF), an American organisation with members within and outside the United States, reports the following output and availability factors for both nuclear and fossil-fuelled plants in the United States for 1976 (163):

	Output Factor percent	Availability percent
Nuclear	61.6	71.6
Coal	58.7	75.9
Oil	50.7	75.5

For the first half of 1977, the AIF gives the following figures for nuclear: output factor, 65.8 percent; availability, 74.7 percent. In the United States nearly all nuclear plants are LWRs.

HWR

47. The acronym stands for "heavy-water reactor", and refers to the moderator. The most successful of such concepts is the *CANDU* (Canadian-deuterium-uranium). The moderator and coolant are separate in a CANDU. The moderator is unpressurised, but the coolant is driven under pressure through individual tubes surrounding the fuel elements, the whole being contained within what is referred to as the "calandria".

The fuel is naturally enriched uranium dioxide with zircaloy cladding, refuelling being continually carried out with the plant on load. There are two types, the CANDU-PHW and the CANDU-BLW with only one of the latter built. In the PHW ("pressurised heavy water"), the coolant is also heavy water, but in the BLW ("boiling light-water") the coolant is light water which is allowed to boil and drive the turbines directly, as in a BWR.

48. In the standard PHW, the steam temperature is about 250°C and the station efficiency about 29 percent. The lower efficiency compared with the LWR is due to the lower steam temperature, and energy losses in the moderator which is not in the steam raising circuit. However, the conversion ratio in an HWR is about 0.7, significantly higher than that of an LWR, and hence, in the absence of recycling, there is a claimed improvement of 30 to 40 percent in overall fuel use. Core power density is about 9 kW per litre. Output factors for CANDU plants have been high. The Pickering A station of 2000 MWe has had a lifetime output factor of 77 percent, and an annual factor of 93 percent in 1976 (165). Other stations, such as Bruce with an ultimate capacity of 3000 MWe, have still to prove themselves.

49. New plants standardise on 600 MW turbine-generators. There were at the time of writing 13 GWe of CANDU power stations under construction or in operation, with contracts in Argentina and Korea as well as in Canada. Discussions and negotiations were also taking place in Italy, Romania, Japan, and Mexico.

50. A British counterpart to the CANDU-BLW is the SGHWR ("steam generating HWR") in which the fuel is enriched to 2.6 percent uranium-235. Although approved as a replacement for the Magnox reactors by the British Government in 1974, the future for this type of reactor is still uncertain.

51. HWR technology demands an adequate supply of heavy water. New plants are now being built close to nuclear power stations to use the low-cost process steam. Since a 1 GWe plant requires 800 to 900 tonnes of deuterium oxide at a world price of about $100 per kg, this is obviously of major importance (44).

FBR (Fast Breeder Reactor)

52. The USSR is committed to FBR technology though it operates other reactor types, namely PWR and LWGR ("light-water cooled, graphite moderated"). Two prototype FBRs of 350 MWe and 600 MWe are at present operating. In France, after an initial programme of study on a prototype plant "Phenix", a full scale 1200 MWe commercial version, "Super Phenix", is at present planned. In Britain a 250 MWe prototype ("PFR") at Dounreay in Scotland is feeding electricity into the grid.

53. There are a number of possibilities for this type of plant, including loop or pool, with gas or liquid, cooling. The one at present favoured is the LMFBR ("liquid metal FBR") which is of the pool type, so-called because it uses a pool of liquid metallic sodium as the coolant. The fuel consists of fissile plutonium dioxide and fertile uranium dioxide. The sodium cooling the core becomes radioactive and hence this is used to heat a secondary sodium circuit which provides the heat for the steam generator.

54. In the PFR the enrichment is 20–27 percent depending on the positioning of a particular fuel element in the core. The core is surrounded by a blanket of uranium depleted in uranium-235, which, besides provid-

ing additional fertile material, also acts as a neutron reflector. The steam temperature is about 520°C and station efficiencies of about 42 percent are reached. The core power density is 500 kW per litre. In the absence of the complete fuel cycle facilities, fuel doubling times are somewhat irrelevant. However, members of the Commission were informed that 45 years might be a representative figure.

55. In the plants at present planned for truly commercial operation (Super Phenix in France, and CFR ("commercial fast reactor") in Britain), the average enrichment is less than that in the PFR. Core power densities are reduced to around 270 and 150 kW per litre respectively, and steam temperatures are 480°C, though superheat will still be used.

56. It has been suggested that an LMFBR could operate with uranium-233 with a thorium blanket. Its breeding ratio would be less than that of an LMFBR fuelled with uranium and plutonium, but it should, nevertheless, be able to provide sufficient uranium-233 to maintain itself, and as well, support two or three burners.

Thermal Breeders and Advanced Converters

57. Of these types of systems the one closest to commercial use is the HTGR ("high temperature gas-cooled reactor"). The temperature at the coolant outlet is about 785°C, and, for a conventional steam cycle, steam temperatures of 540°C and net thermal efficiencies in excess of 40 percent are anticipated. The fuel is a mixture of enriched uranium, about 93 percent uranium-235, uranium-233, and thorium-232, the thorium-232 replacing the uranium-238 in a uranium-type thermal reactor. The mix of fuels varies over the lifetime of the reactor. The initial loading consists of highly enriched uranium and thorium-232; in subsequent loadings, recycled uranium-233 replaces uranium-235. The coolant is helium, and the moderator graphite. The fuel cladding consists of layers of graphite and silicon carbide, the basic fuel elements being microspheres of uranium or thorium oxide or carbide. The reactor must be shut down for refuelling. It is believed that a conversion ratio of 0.95 can be reached. Thus, in subsequent cycles it would need little topping up with fissile material over and above uranium-233. The core power density could be about 6 kW per litre. An associated concept is the "pebble bed reactor" represented by AVR and TTHT-300 in West Germany, with coolant temperatures reaching 950°C.

58. The only strictly commercial HTGR is at Fort St. Vrain in the United States. This has still to reach full power. However, contrary to common belief, the American vendors, General Atomic, are extremely hopeful about future developments in this field. With such high coolant temperatures there is the possibility of a direct gas turbine cycle and process heat applications.

59. Other possibilities include the LWBR ("light-water breeder reactor"), a concept based on the PWR, and the MSR ("molten-salt reactor"). In both cases it is hoped that at least the self-sufficient thorium cycle may be achieved. In particular at Shippingport in the United States, a PWR has been changed to an LWBR, and should be operating now on a commercial basis (158). A further possibility is the use of thorium in a CANDU-type reactor. If the breeding ratio is less than unity, then topping up will be needed. Nevertheless, there could be significant improvements in the utilisation of uranium. It will be 1995 before the complete thorium cycle in the CANDU is demonstrated to the point

where commercial implementation could begin. This system would then have the flexibility to operate on either the uranium or thorium cycle, depending on economics and the availability of fuel (160).

FUEL CYCLES

60. The processes the fuel for nuclear reactors undergo are referred to as the *fuel cycle*, a term which includes mining the ore, milling, conversion to a gas for enrichment, enrichment, fabrication, irradiation in a reactor, storage as spent fuel, reprocessing, and recycling. At all stages there are radioactive wastes, and associated dangers range from the trivial to the extreme. Wastes must be managed in a manner which protects both human health and the environment. Although economics are of great importance, they are not prime considerations, as a recent publication on waste management by an NEA group of experts states: "The overriding considerations in the evolution of satisfactory radioactive waste management schemes are human health and safety with due regard being paid to any other potential impact on human activities and the environment" (99).

61. The basic principles of radiological protection underlying waste management fuel-cycle activities, and reactor operations in general, are based on a set of criteria recommended by the ICRP. This is an independent organisation originally established in 1928 to set dose limits for diagnostic X-rays and radium therapy. Its recommendations on radiobiological protection are continually updated (a new set was published in 1977), and are widely used internationally. We are primarily concerned here to define the nature and origin of radiation. We discuss its effects in chapter 11.

Radiation

62. Radioactivity is the emission of particles or quanta from the nuclei of various isotopes. Such particles can ionise, and since ionised molecules can enter into chemical reactions different from those of the un-ionised state, they have the potential to cause serious damage to living tissues. Most subatomic particles can cause such damage. Those of interest in nuclear power technology are neutrons, and gamma, beta, and alpha particles.

63. The neutrons inherent in the fission process are confined to the reactor vessel and are not a direct danger, except in particular types of accidents. Gamma rays consist of quanta of hard X-rays, and beta rays consist of positively (or, more likely, negatively) charged electrons. Alpha particles are the nuclei of helium atoms, consisting of two protons plus two neutrons tightly bound together. The biological damage that these particles can cause depends on their energy, with alphas in general being able to cause significantly more damage than betas or gammas. However, alphas may be stopped by a sheet of paper, and are only a biological hazard if alpha emitters are taken into the body by ingestion, inhalation, or through a wound. In such cases they cause dense trails of ionisation on a cellular scale, killing many cells and leaving others in a state potentially cancerous. Although a single gamma quanta may cause less but similar damage than an alpha, gammas are extremely penetrating, hence an external source of them can be equally, if not more, dangerous than an internal source of alphas.

64. In emitting a particle, a nucleus is said to disintegrate or decay, becoming with the emission of an alpha or beta an isotope of a different chemical substance, which could itself be radioactive. The individual nuclei of a radioactive substance decay at random with each radionuclide being characterised by a particular half-life. The half-life is the time taken for half the initial number of nuclei of a given isotopic type to disintegrate. The strength of the source at any given instant in time is expressed in curies (Ci), one curie being 3.7×10^{10} disintegrations per second, that is, the number of alphas emitted per second by one gram of radium.

65. The strength of the source should not be confused with the number of radionuclides present, though they are related. To emphasise this, both uranium-238 and plutonium-239 are alpha emitters. The half-life of uranium-238 is 4 500 000 000 years and that of plutonium-239, 24 000 years. For equal numbers of uranium-238 and plutonium-239 nuclei present at a given instant in time, it follows that, due to its shorter half-life, plutonium-239 will emit many more alphas (about 200 000 times more per second) than uranium-238. Because of this, plutonium-239 is considerably more radio-toxic than uranium-238, and in this context, contrary to popular understanding, the real problem with plutonium-239 is its relatively short, rather than long, half-life.

66. Inadequate knowledge of the possible existence or absence of a threshold level below which any damage might be repaired by normal biological processes makes the problem of setting limits on radiation doses extremely complicated. Furthermore, at the relatively low dose levels that the general public could be subject to even by accidents, it is virtually impossible to design experiments which would lead to effects which could be observed over and above those already existing from natural causes. It is therefore necessary to base criteria on cases in which relatively large doses have been given, leading to recognisable results, and extrapolate the effects to lower dose levels in a linear manner. The problem is further compounded by the fact that biological aspects as well as the half-life of the radionuclide and the type of particle emitted must also be taken into account. The method of absorption into the body is important, as is the tendency to concentrate within certain organs. The time spent within the body varies from one radionuclide to another, and leads to the concept of a biological, as distinct from a physical, half-life.

67. In spite of the general complexity of the problem, an extremely comprehensive set of recommendations on radiobiological protection has been developed. These include maximum permissible values for annual dose to the more critical organs of the body, for the body burden for each radionuclide, annual body intake, and concentrations in air and water. Such recommendations have enabled a completely rational approach to be followed for all health and safety aspects of nuclear power, with dose rates considerably lower than those recommended by the ICRP being achieved whenever practicable.

68. Of course the application of the recommendations, especially in the case of waste management, is neither simple nor direct. The many different half-lives involved, and the growth of *radioactive daughter products* as one radionuclide decays into another, present those responsible with a dynamic rather than a static problem. Pathways to man have to be investigated, and critical nuclides and critical groups of people have to be identified. Waste management and associated practices are discussed in Part IV. We deal now with the origin of radioactive substances produced in nuclear power.

Fuel Processes

69. Uranium mining is similar to coal mining with open pit and underground methods being used. But over 2 million tonnes of coal must be mined annually for a 1 GWe station, compared with only 200 000 tonnes or less of uranium ore. After it is mined, the ore is mechanically and chemically processed to produce yellowcake, a concentrate of the uranium oxide U_3O_8. As already noted, the ore contains only about 0.1 percent of uranium oxide, the rest being rejected as tailings. These tailings contain the radioactive daughter products of uranium, and, although not a great danger, they must be treated with care.

70. To prepare it for enrichment or subsequent treatment, the yellowcake is converted to uranium trioxide by the addition of nitric acid. From the trioxide can come the dioxide which may be used in CANDUs, or, alternatively, uranium tetrafluoride may be produced which can be converted into either metallic uranium of natural enrichment, or uranium hexafluoride (UF_6) if enrichment is needed. Uranium hexafluoride is a solid at room temperature, but a gas at temperatures above about 57°C.

71. Since isotopes of the same element exhibit identical chemical properties, enrichment depends on physical as distinct from chemical processes. There are several techniques, the most important to date depending on the speeds of the gaseous hexafluorides $U(235)F_6$ and $U(238)F_6$ differing on passing through a porous barrier. This diffusion technique consumes large amounts of electrical energy. A centrifuge method, which uses less energy but is somewhat capital intensive, has been developed by international companies: Urenco Ltd., in Britain and the Netherlands, and Centec GmbH in West Germany. A jet-nozzle process is close to being commercialised. The possibility of using lasers, which could have considerable advantages, is also under investigation. At present the process of enrichment accounts for about one-third of the cost of the fuel cycle for most reactors.

72. Once enriched, the uranium hexafluoride is converted to uranium dioxide powder or any other compound that may be needed. If uranium dioxide is needed for fuel, the powder is pressed and sintered into small cylindrical pellets and then loaded into tubular cans of stainless steel or zircaloy. These cans are filled with helium to ensure adequate thermal conduction between the pellets and the can and hermetically sealed by caps welded on at each end. After a thorough inspection for possible leaks, these fuel pins or rods are assembled in circular, square, or hexagonal clusters. These assemblies are the fuel units dispatched to the reactor site. Procedures may change according to reactor type. In all cases much care is taken to ensure the integrity of the final containment of the basic fuel elements, thus guarding against subsequent leakage of fission products. Up to this stage of the cycle, with suitable management, there are only minimal radioactive dangers.

73. A 1 GWe reactor after several months' operation develops within the fuel a radioactivity of about 10^{10} Ci, a huge value. This starts to decay once the fission process stops, but is still dangerous after several hundred years. Many different radionuclides are produced, the exact quantities of each depending on reactor type. Besides the fission products, there are also *actinides,* elements heavier than actinium. Uranium and plutonium are examples. Others such as americium, neptunium, curium, etc., along with various isotopes of plutonium besides plutonium-239, are produced

by the transmutation of uranium and plutonium in the core. The quantities, although not large compared with the total fuel content, are radiobiologically significant.

74. During normal operation of a plant, about 0.1 percent of the more volatile reaction products can escape into the coolant and moderator through effective "pinhole" defects in the fuel cladding. In addition, short-lived isotopes of nitrogen, together with tritium, radioactive corrosion products, and small amounts of carbon-14, are produced in the surroundings and coolant. All of these have to be continually removed and dispersed. The result is large volumes of low-level and intermediate-level beta-gamma type wastes in gaseous, liquid, and solid forms. With present techniques, their disposal does not present a major problem (see chapter 9).

75. When removed from a reactor, the spent fuel is stored in a cooling pond, which resembles a very deep swimming pool. In principle, zircaloy or steel claddings allow it to be so stored for many years, as is at present being done at Pickering A in Ontario. The accumulated spent fuel from a 1 GWe station over its lifetime of about 30 years needs no more storage space than an Olympic-size swimming pool about 9 metres deep. Such depth is necessary to reduce radiation levels at the surface to enable the free movement of attendants about the pool.

76. In general there are optional ways of dealing with the spent fuel after a cooling period of about 6 months at the reactor site. Most spent fuels could remain within the pool for many years. Alternatively, the fuel could be transferred to a national repository for long-term storage with subsequent retrieval in mind. It could be disposed of once and for all without any intention to recover (termed the "throw-away" option), or it could be transferred to a reprocessing plant. Steel flasks about 35 centimetres thick and typically weighing 50–70 tonnes are used to transport spent fuel. Each flask can carry about 3 tonnes and is built, in compliance with international regulations, to withstand any credible accident no matter what the method of transport.

77. Following President Carter's statement in April 1977 in which he expressed concern about the possible proliferation of nuclear weapons as a consequence of reprocessing and recycling uranium-plutonium fuels, there has been considerable interest in the "throw-away" option. However, no detailed scheme has yet been established to dispose of spent fuel. From the discussion with the NEA group of experts, it appears from a waste management point of view, that the problems are likely to be no simpler than those associated with the reprocessing option. In particular, isolation of the spent fuel from the biosphere will be necessary, with ultimate disposal in geological formations (99).

78. In the reprocessing option already practised in some countries, the spent fuel is transferred to a reprocessing plant, where, after removal from the storage flask, it is again stored for a time under water to allow the shorter-lived fission products to decay. This is followed by the removal of the fuel from its cladding and the separation by chemical techniques into fission products, uranium (depleted in uranium-235), and plutonium. After purification, the uranium and plutonium are converted into oxide powders for fabrication into either thermal or fast reactor fuels.

79. Once the initial inventory of plutonium is provided, a uranium-plutonium fast reactor would develop its own, almost independent, fuel cycle. Because of the required rapid turnover in fuel, and the high radioactivity and enrichment of such fuels, it would possibly need its own

on-site reprocessing plant, although fabrication might be carried out elsewhere with the recovered fissile material being transported in a liquid nitrate form (not, however, permitted in the United States (12)) to the fabrication plant, and before its return as solid fuel being irradiated to discourage hi-jack attempts.

80. In general, each reactor type will have a different fuel cycle making varying demands on enrichment, fabrication, and reprocessing services. For thermal breeders and/or advanced converters using thorium, mining and milling will produce concentrates of the oxide thoria, ThO_2. Like uranium, the thorium would be separated from its daughter products, and, like uranium, there are two isotopes, thorium-232 and thorium-228, which are of importance, though neither are fissile. The half-life of thorium-232 is of the order of 10^{10} years, and it decays into thorium-228. But the half-life of thorium-228 and its daughters is extremely short, and within weeks, freshly milled thorium is again in equilibrium with its daughter products, which, in particular, include certain high-energy gamma emitters. Thus shielding of fresh fuel could be necessary. Of more importance, though, is the fact that spent thorium fuel, besides containing the fissile uranium-233, also contains a second uranium isotope, uranium-232 (160).

81. Uranium-232, although not affecting reactor performance and only constituting about 0.2 percent of the total uranium content in the spent thorium fuel, decays with a half-life of 72 years to thorium-228. Even if the concentration of uranium-232 in the initial thorium is only one part in a million, the effect of this short cut from uranium-232 into the natural thorium chain is to lead to gamma ray intensities about 200 times greater than those which occur in the natural chain. On chemically separating the spent fuel into thorium and uranium, and fission products, both the thorium and uranium become within days, because of thorium-228, lethal gamma emitters. The result is that subsequent fuel fabrication must proceed under remote control from shielded working areas. In practice, the spent fuel could be stored for a decade or more until most of the enhanced thorium-228 had decayed. In contrast, mixed oxide-plutonium fuels can be prepared in unshielded glove-boxes, the dangers coming from inhaling or ingesting dust rather than from direct radiation. New techniques using the sol-gel process, for which thoria is especially suited, could simplify the production of both types of fuel (160).

82. There are many possible fuel cycles, but in all cases the fission products will be little different, although concentrations of actinides could change. At present the fission products are discharged from the reprocessing cycle as a liquid, and present practice is to concentrate this waste and store it as a liquid in large stainless steel tanks in containments lined with stainless steel and shielded with concrete. The liquid in the tank is continuously cooled and may be transferred from one tank to another. There is continuous surveillance and monitoring.

83. Because they are more potentially easy to disperse, liquid wastes are more difficult to manage than solid. Thus in the long term *vitrification* of these wastes (that is, mixing with glass at a molecular level and solidifying) is proposed. The techniques are well understood, and the first commercial vitrification plant will be working this year at Marcoule in France. Solid wastes will be much easier to store and finally dispose of. It is already possible to provide storage for several decades, and even up to a century or more if need be. This is discussed further in chapter 9.

84. The fission waste from the reprocessing plant is called high-level waste. (If the "throw-away" option was adopted, the spent fuel would be the high-level waste.) This waste contains more than 99.9 percent of the non-volatile fission products. After reprocessing, and with the appropriate standards, it contains only 0.1–0.5 percent of the uranium and plutonium present in the spent fuel, but contains all the other actinides (99). In general the fission products are beta-gamma type emitters, and the actinides are alpha emitters.

85. Other wastes of the low and intermediate levels, and alpha wastes (which are solids with high concentrations of alpha emitters) also occur in reprocessing plants. The cladding hulls must be treated with as much respect as high-level waste. Gaseous and volatile products such as krypton-85, though not problematic at present, will need, with future increases, storage to permit decay before they can be released to the atmosphere. There are various developments under way.

86. A final aspect is that further types of problems in waste management arise when a reactor or a servicing plant is decommissioned. The technology exists, however, as members of this Royal Commission observed in visits to Oyster Creek in the United States, and Dounreay in Scotland. At Oyster Creek we discussed the results of decommissioning a power reactor, and at Dounreay we inspected the completely decontaminated core areas formerly used for reprocessing fast reactor fuel.

THE STATUS OF NUCLEAR POWER

87. As of about 1977 the total world electrical generating capacity of nuclear plants was 95 GWe, equally divided between the United States and the rest of the world. The general situation, based on information given us by the AIF, was (163, 164):

Reactors		*GWe*
205 operable	... ...	95
209 in construction	... ...	189
109 on order	... ...	110
181 planned	... ...	188
704	Total	582

For comparison, the IAEA gives as of 1 March 1977: 197 reactors with a total capacity of 88 GWe in operation and 367 reactors with a total capacity of 340 GWe under construction, ordered and planned (162). Apart from a difference in the time of reporting, the discrepancy between the AIF and IAEA figures appears to lie in different interpretations of what is and what is not "planned".

88. At present 19 countries run power-producing reactors. According to the AIF, 23 others have firm commitments (164). In terms of energy output, within OECD countries in 1976, the United States produced about 200 000 GWh, followed by Japan and Britain with each over 30 000, West Germany with about 25 000, and France, Canada, and Sweden with each from 15 000 to 20 000 (165). Nuclear power now provides about 4 percent of the world's electrical needs, and about 1 percent of its primary energy (15, 166). For the OECD countries, the corresponding figures are significantly higher at 8 percent and 2.4 percent respectively. At present LWRs, with a ratio of PWR to BWR of about 3 to

2, provide about 85 percent of the electrical energy produced by commercial plants, HWRs about 5 percent, and gas-cooled graphite-moderated, the rest (174).

89. In Japan, nuclear production of electricity more than doubled in 1976 (165). France had (according to the IAEA 1977 Report on Power Reactors) 21 PWRs under construction and 9 planned as of 1 March 1977. We were told of French Government plans to provide 60 percent of electricity needs by nuclear means by the year 1985, with a programme of 1 GWe every 2 months from 1979, up to a total of 40 GWe by 1985. Spain also has a comparably ambitious programme. At present it has built only three reactors, but it has nine under construction, and eight planned (162). By the year 2000, France hopes that its electrical supply system will be 90 percent nuclear, and Spain hopes for between 65–70 percent (164).

90. The Soviet Union had 27 reactors operating with a generating capacity of about 8 GWe (164). Only 3 percent of its electricity was supplied from nuclear sources in 1976–77, but a further 11–13 GWe is expected to be commissioned by 1980. It intends to mass produce 1 GWe units in a factory, at a rate of at least three to four a year from a production line (44, 164).

91. The total world electrical generating capacity of 95 GWe as of mid-1977, represented a 23 percent increase in one year. In general, although not often appreciated, the growth of nuclear power has been rapid. It should be noted that, on past trends, certain models of market penetration suggest that 50 percent of all electricity in OECD countries could come from nuclear sources by 1986 (174). This is, however, unlikely to happen. Over the past couple of years there has been a lull in ordering, especially in certain European countries and the United States. In many cases this has arisen in part from "environmental" pressures leading not only to a re-examination of existing licensing and regulatory procedures, but also to a complete re-examination of possible future developments. In other cases the absence of orders appears to be little more than a direct result of decreased electricity demand and of uncertainties about future economic growth. In the United States the situation for 1977 is summarised in the following licensing and order activity for January to August of that year (163):

Operating licences issued	3
Construction permits issued	10
Limited work authorisations	4
Orders placed	4
Letters of intent; options	0
Deferrals announced	23
Deferrals reinstated	4
Cancellations announced	4

In Britain, because of over capacity, no new reactor has been ordered since about 1970. However, approval has recently been given for the construction of two new AGRs, site work to start in 1980 and the plants to be operating about 1987. In Sweden, environmental concern has delayed work on a number of reactors already under construction.

92. In a press interview in Britain (September 1977) Sir John Hill, Chairman of the UKAEA, said that the case for nuclear power had always been based on three arguments. These were the increasing scarcity and cost of other fuels, the cheapness of nuclear electricity, and the acceptability of nuclear power from an environmental and human standpoint. Each of these had been challenged over the last 2 years (167).

93. The basic environmental and human concerns centre on waste management, proliferation, and safety of nuclear installations. We will now briefly identify the various general aspects of public concern. Detailed discussion of the more important problems is given in Part IV.

Cost

94. The AIF gave the following generating costs for electricity in the United States for 1976 (163):

Nuclear	...	1.5c per kWh
Coal	...	1.8c per kWh
Oil	...	3.5c per kWh

with nuclear providing about 9.4 percent of the total electricity generated. In Britain for the same year electricity was generated by the Magnox stations at a cost of 0.62p per kWh. This is to be compared with the corresponding value of coal-fired and oil-fired plants of 1.08p per kWh (168). The British figures do not include capital repayments, but members of the Royal Commission were assured that similar differences existed even when such repayments were included. In England and Wales nuclear sources provide 12 percent of the electricity generated. In Canada similar advantages for nuclear generation are claimed. In 1976, 19 percent of Ontario Hydro's electricity was supplied by nuclear power (165).

95. Estimates in the Ford Foundation - MITRE report give nuclear an advantage comparable to that which exists at present in the United States, even for plants coming into operation in 1985 in certain regions. It has been claimed, however, that nuclear estimates do not reflect the true costs with especially research and development, and capital costs associated with certain fuel processes, being neglected. Members of the Royal Commission were assured that this is not so either in the United States or Britain. In Britain, for example, even services rendered by the Department of the Environment, the Health and Safety Executive (that is the Nuclear Installations Inspectorate), and other such organisations are charged to the generating utilities. It is difficult for us to judge the exact situation, and the best we feel we can do is give an indication of the relative scale of various operations, taking Britain as the example.

96. Although until recently no nuclear plant has been ordered since 1970 in Britain, the industry is still extremely active. There are two utilities both operating nuclear stations, the CEGB and the South of Scotland Electricity Board (SSEB). The CEGB, the larger, supplies electricity for England and Wales. It runs 137 stations, has a net generating capacity of 56 GW, and in 1976–77 supplied approximately 210 000 GWh. It runs eight Magnox stations with a total capacity of 4.6 GWe, one AGR of 1.3 GWe, and has three other AGRs of a total of 3.8 GWe under construction. The ordering of a thirteenth station, Sizewell B, an SGHWR of 2.6 GWe, has been deferred (161). The CEGB employs close to 61 000 people, about 2000 of whom work in research. Its sales to Area Boards (the equivalent of the supply authorities in New Zealand), and to direct consumers amounted in 1976–77 to £3100 million corresponding to an average charge of 1.5p per kWh. Its capital expenditure on fossil-fuelled plant for that year was £272 million, that on nuclear plant £92 million, and that on research £11 million (168).

97. The nuclear industry is based on two commercial companies, British Nuclear Fuels Limited (BNFL), and the Nuclear Power Company (NPC), as well as the Government research and development organisa-

tion, the UKAEA. BNFL is State-owned, and the NPC, the single supplier of commercial nuclear plants in Britain, is the wholly-owned subsidiary of the National Nuclear Corporation (NNC). The shareholders in the NNC are the General Electric Company Limited (GEC) which is privately owned, 30 percent; the UKAEA, 35 percent; and British Nuclear Associates (BNA) comprising a number of privately-owned engineering and construction firms, 35 percent.

98. The NPC employs about 2400 and is primarily concerned with the development, design, and construction of nuclear power plants. It is supported by its member organisations, GEC for example employing in all its activities over 200 000. Its present scale of activities may be partially measured in terms of the CEGB's £92 million capital expenditure on nuclear plant. It has, however, also been engaged in the examination of possible future thermal reactors for Britain, and is responsible for the design and development of the first British commercial fast reactor (CFR).

99. BNFL is wholly owned by the UKAEA. It operates a fabrication plant at Springfields, Lancashire; an enrichment plant at Capenhurst, Cheshire; and a reprocessing plant at Windscale, Cumbria. The company also owns and operates the Calder Hall plant at Windscale and a sister station, Chapelcross, in Dumfriesshire. It offers a complete service from mine to enrichment process, and its Windscale plant can reprocess at present 2500 tonnes of spent fuel a year. It has a number of foreign customers for all its services including fabrication and reprocessing. It has about 11 000 employees and its turnover is about £120 million a year. This can be compared with the CEGB's cost for nuclear fuel of about £80 million in 1976–77, and the CEGB is merely one of BNFL's customers.

100. Finally, the UKAEA employs about 13 000 and in 1976–77 its expenditure was £175 million of which 53 million was spent on fast breeder development, 18 million on safety, and more than 6.5 million on fusion. Including the SSEB, as well as the CEGB, it follows that Britian is investing the equivalent of about 4 percent of its electrical generating costs, including transmission to the Area Boards, on nuclear research and development. If these costs are not passed on to the utilities, they represent at present quite a significant subsidy on electricity produced by nuclear means. On the other hand, they are less than 0.1 percent of the British GNP, and this may well be regarded as an acceptable investment for the future.

Waste Management

101. Under this heading, reprocessing and final disposal are of considerable public concern. In the case of disposal the United States is committed to a demonstration of its feasibility by 1985, possible sites existing in Nevada and New Mexico (44). Burial will be in salt. Since, however, the United States has forgone, at least for the moment, the reprocessing option, any such demonstration must use spent fuel.

102. In Britain no attempt will be made until waste has been vitrified, although sites are at present being investigated. Hard rock disposal sites are being sought as part of an overall European programme in which clays and salt mines are also being considered. It will be towards the end of the 1980s before vitrification is operating commercially. The consensus is that it will be from 15 to 20 years before burial is adequately demonstrated.

103. To date the BNFL Windscale plant has reprocessed about 20 000 tonnes of fuel (170). Nearly all this has been of the Magnox type, with

corrosion problems restricting its cooling-pond storage time. There has been only a small amount of oxide fuels from thermal reactors reprocessed so far. Last year there was an inquiry held at Whitehaven into the extension of the Windscale facilities to include a large reprocessing plant for thermal oxide fuels. The Windscale inquiry was concerned with the establishment of a plant able to reprocess 1200 tonnes of oxide fuel a year. It would ultimately handle 500 tonnes a year for British thermal reactors, with spare capacity being sold to foreign customers (170). A vitrification plant would also be added to the site. A reprocessing plant for handling the entire PFR annual fuel loading (4.1 tonnes) is nearing completion at Dounreay.

104. A second thermal oxide plant is already in operation at Cap de la Hague in France. Japan is also developing a reprocessing plant to facilitate waste management but with American approval since enriched uranium from the United States is used. In the United States, President Carter withdrew support for the Allied General Nuclear Services plant at Barnwell, South Carolina. Of a capacity of about 1500 tonnes a year, this was to be used to recycle plutonium in thermal LWRs (12). The plant is essentially complete. For the United States, with its large indigenous resources of uranium, the economics of recycling are questionable at present costs (99). Coupled with this there have been environmental pressures to restrict the production of pure plutonium (by separation), and hence the United States has forgone (at least for the moment) the reprocessing option in waste management. It appears unlikely, however, that the "throw-away" option will be adopted as an immediate alternative, retrievable stores for spent fuel being preferred.

Proliferation

105. It is generally accepted that nuclear proliferation is a political problem to be solved by international agreements and understandings. However, it is thought by many that certain "technical fixes" may be possible which would greatly simplify the problem. Such "fixes" can range from finding a complete alternative to nuclear power, to finding nuclear alternatives to the uranium-plutonium fuel cycle itself. The simplest of the latter is the "throw-away" option in which plutonium is never separated from the spent fuel.

106. When it was recognised that the United States had adequate reserves of uranium, a number of advisory groups recommended that recycling, and development of the FBR, should be postponed until various alternatives were adequately investigated. As a result, in April of last year, President Carter as well as withdrawing support for the Barnwell reprocessing plant proposed that work on the Clinch River uranium-plutonium LMFBR should be stopped. Congress did not agree, and at the time of writing this report the state of the FBR and recycling in the United States is unclear. Nevertheless, President Carter ordered the Energy Research and Development Administration (ERDA) (now the Department of Energy) to find a better fuel cycle. This led to the "Nonproliferation Alternative Systems Assessment Program" which hopes to arrive at a conclusion by October 1978. President Carter also proposed that an International Fuel Cycle evaluation programme should be established, and this is under way. A promising cycle appears to be one involving thorium (160).

107. As already noted, in an FBR the thorium/uranium-233 cycle is less efficient than the uranium-plutonium cycle. Thus there would be an

overall loss in fuel utilisation, while thermal breeders at best are only likely to be self-sufficient. For this reason there is little enthusiasm to depart from the present proposed uranium-plutonium FBR in Britain, France, and Japan. As they have no significant indigenous reserves of uranium or thorium, only the uranium-plutonium FBR in the long run offers them a high degree of self-sufficiency in nuclear fuels.

108. Those advocating "proliferation-resistant" fuels see two advantages in thorium. First, the fissile material uranium-233 can be *denatured*, that is, de-enriched by uranium-238 to levels at which it could still be used as a reactor fuel but would be unsuitable for weapons. Plutonium can be similarly diluted as in mixed plutonium dioxide fuels, but true denaturing with a natural non-fissile isotope of plutonium is impossible since plutonium does not occur naturally. Thus, though plutonium may be separated from uranium-238 in oxide fuel mixtures by chemical means, separation of uranium-233 from uranium-238 requires genuine enrichment by diffusion or centrifuge methods—a harder and more expensive job. However, as pointed out in chapter 10, the extra cost may not be enough to deter the more ardent terrorist organisations.

109. The second point put forward by thorium cycle advocates is that the gamma radiation from the daughter products would at once discourage any hi-jack attempts on fuel systems. However, it has been claimed that uranium-plutonium fuels could be irradiated to achieve a similar aim.

110. Advocates make a third point. Because of the uranium-238 content of the denatured uranium-233 fuel, there would be significant amounts of plutonium in the spent fuel from the associated thorium cycle. In fact, there would be about 20 percent of that from the spent fuel of present LWRs (160). To cope with this, advocates of the denatured uranium-233 suggest that international fuel centres be set up to receive spent fuel and, after reprocessing, to export denatured uranium-233/thorium fuels, the extracted plutonium being burnt in FBRs within the fuel centre.

111. The merits of a thorium cycle of the type proposed are not obvious to us. It seems that international control, with irradiation before transport, would result in a similar level of security, no matter what the fuel. Nevertheless, we recognise the great importance of the present studies, and recommend that the results when available should be carefully appraised.

Safety

112. Subject to there being adequate quality control in design and manufacture, and to the plant being operated by suitably trained staff, experts now believe that the safety of nuclear plants is no longer an issue. This does not mean that there is no scope for improvement, but that, compared with other activities, nuclear power is extremely safe. Of far greater concern is the safeness of other large industries which can pose risks to the public from 10 to 100 times greater.

113. For the public the question of safety in the nuclear industry reduces to one of radioactive emissions from nuclear power plant sites. It is generally accepted that in normal operation, at least in the short term, these do not represent a significant danger, although in the long term, improvements (such as the storage of krypton-85 in reprocessing plants) will be necessary. The question of safety therefore becomes a question of accidents.

114. Many studies have been carried out in a number of countries on the safety of different reactor types and of the various processing activities in the fuel cycle. For the recent Windscale inquiry, case studies considered the consequences of a plane crash into a plutonium store or into a high-level waste storage tank, and the simple case of the loss of tank coolant. Those who made the studies concluded that for the location of the site, the consequences to the public were minor compared with the scale of the accident itself, and would lead at most to five delayed deaths. Even in accidents of this nature there is no chance of a bomb-like explosion. The danger to the public, as in other cases, comes from the release of radioactive substances. This does not mean to say that accidents involving criticality cannot occur.

115. If, by chance, sufficient fissile material should accumulate so that the total mass becomes critical, the magnitude of the resulting interaction would be limited, the material automatically blowing itself apart (that is *disassembling*). The danger would come from a sudden high flux of neutrons rather than from a physical explosion. The most likely place for this to occur is in a reprocessing plant, and considerable care is taken in the design of such plant to reduce the chance of an accident of this nature. We observed that warning devices are in continuous operation enabling the working area, at most a single building, to be immediately evacuated in the event of such an accident. In all types of establishments (military, research, etc.) about ten such accidents are known to have happened since the early 1940s. Nearly all of these were in the United States. Several workers were injured, and one worker was killed in each of the most serious accidents. No member of the public was ever at risk (171).

116. The real danger in nuclear power activities is that a normal type of industrial accident or explosion, or natural catastrophe, could lead to the escape of large amounts of radioactive material. There may be many accidents in which there is no release, and neither operating staff nor public are put at risk.

117. All reactor types have inherent safety features, some more than others. For example, some thermal reactors have low, and others high core power densities. To make all types equally safe seems to be simply a question of where and how the capital costs are distributed between the reactor proper and the emergency systems. As an example of this, we note various studies made on the safety of LWRs. In 1975 a report was published on this subject in the United States. The study, using a method of probabilistic-risk assessment, was made by Professor N. Rasmussen of the Massachusetts Institute of Technology. It is sometimes referred to as Wash-1400; we term it the Rasmussen report. It concluded that the risk was extremely low. This report attracted considerable criticism, partly because of the method used, but primarily because of some of the input data, and the neglect of certain fault conditions. All these aspects are discussed in greater detail in chapter 12.

118. In 1976–77 the Nuclear Installations Inspectorate of the British Health and Safety Executive (NII) carried out an independent study of the safety of the PWR system, and came to conclusions similar to those of the Rasmussen report. In a report to the British Secretary of State for Energy in July 1977 the NII stated:

> The Inspectorate consider that there is no fundamental reason for regarding safety as an obstacle to the selection of a Pressurised Water Reactor for commercial electricity generation in Britain.

and went on to say:

> Although there are some safety aspects about which present information and investigations are insufficient to allow final conclusions to be reached, and some areas where more work would lead to greater confidence, the Inspectorate are satisfied that these issues are not such as to prejudice an immediate decision in principle about the suitability of the PWR for commercial use in Britain (172).

This is of considerable significance, as up to the present Britain has operated commercially only gas-cooled graphite-moderated reactors of extremely low core power densities.

119. In the United States there is another probability-risk assessment study being done at present on the HTGR. Although a final assessment has still to be made, the study group concluded in a recent paper:

> The HTGR has worthwhile design options that should be considered since the reference power plant appears to pose a low risk to public safety. The low risk may allow additional benefits to be realised with the HTGR, including siting flexibility in densely populated areas, low potential damage to be covered by insurance, and reduced evacuation requirements (173).

120. In Britain new AGR plants are already being sited close to centres of population and hence the implication of the NII study for the PWR is that all reactor types at present in commercial use, if not already safe, can be made safe enough. In introducing the concept of "safe enough", we are conscious of the concern at present being shown in other large industries. We were informed by UKAEA safety experts, who are now actively engaged in many of the studies at present being made, that many large industries pose risks to the British public from 10 to 100 times greater than do the nuclear, and that at least 100 such establishments should be licensed as nuclear are. The present aim is to introduce existing nuclear standards into these industries. The industries involved with the transport and storage of chemicals are of major concern. It was claimed that the consequences of a "catastrophic" accident in a large chlorine storage plant could lead to 50 000 deaths, compared with the 10 000 (including delayed) deaths that could result from a fast reactor accident of comparable scale. The British Friends of the Earth expressed a similar concern to members of our Royal Commission about these large industries, and once the nuclear problem is resolved, intend to take the matter up.

121. The British Government in late 1977 announced that it would hold an inquiry into the fast reactor, focusing interest in reactor safety on the FBR. The NII had in late 1976 prepared a report on the safety of FBRs for the Secretary of Energy. It also contained answers to many questions on reactor safety generally put to the NII by the British Friends of the Earth, and, as well, a statement of the overall policy of the British Health and Safety Executive which is responsible for all safety matters (including nuclear) in all industries.

122. There is no such concept as absolute safety, there is always risk. The NII report states succinctly how they cope with this situation:

> No human activity is entirely free from features that are detrimental to health or involve risks to life, and it is never possible to be sure that every eventuality has been covered by safety precautions. The basic policy of the Health and Safety Commission is to eliminate these ill effects so far as is reasonably practicable. In some cases, where risks would otherwise be high, absolute duties and absolute requirements are imposed. These may take the form of quantitative limits or specified design requirements and have to be met, regardless of cost. These absolute duties and requirements do not eliminate risks completely, and for this reason, they do not remove the further statutory duty to achieve even safer conditions whenever and wherever this is "reasonably practicable" taking

account of known technology and costs. This policy is applied widely, for example in such diverse fields as the control of toxic substances, the limitation of the release of harmful or noxious wastes to atmosphere and protection against ionising radiation (171).

FUTURE GROWTH

123. The growth of nuclear power will depend on a number of factors including public acceptability, the demand for electricity, fuel supplies including services, oil supplies, etc. The technology for such growth already exists; further technological innovation may merely make it more acceptable. Certain developments such as the introduction of a worthwhile thorium cycle, sufficiently short doubling times for FBRs, the disposal of high-level waste will require time—longer than most would wish—but given public approval there is little doubt that these will come about.

124. After the oil crisis of 1973–74 demand for electricity levelled out and in certain cases decreased, but now electricity consumption is once again growing in most countries. In the United States in 1974, the growth rate was 0.2 percent per annum, and in 1975 and 1976, 2.6 and 6.2 percent respectively. However, it is not expected to return to the 1948–73 figure of 7.8 percent per annum; 5.3–5.8 percent is anticipated as more likely (163). A similar trend was observed in Canada, where we were informed by the Quebec Minister of Energy that rates of increase in consumption in the province had gone from 1 percent per annum in 1975 to 10 percent and 12 percent in the following 2 years. Likewise in Europe, after significant drops, rates of growth are again increasing. But in Britain over the next few years future growth is expected to be only between 3 and 4 percent per annum at most, and in France a little over 4 percent is planned. Sweden will try to restrain growth below a rate of 6 percent per annum till 1985 in the hope that lower growth rates will be realised after that date.

125. At the World Energy Conference meeting in Istanbul in September 1977, average annual growth in electricity demand from 1972 to the year 2020 was estimated at 4.2 percent per annum for OECD countries, and 5.1 percent for the world as a whole (15). Two different groups also gave estimates for world nuclear power growth for the same period:

Year	*GWe*	
	Estimate 1 (15)	Estimate 2 (166)
1985	303	...
2000	1543	1300–1650
2020	5033	3200–4300

During the same period electricity's share of the demand for secondary energy would rise from a present world value of 8 percent to nearly 20 percent, with nuclear power providing about 45 percent of this by the year 2000, and between 50 and 60 percent by 2020 (15, 166). These figures are in reasonable agreement with other estimates that have been drawn to our attention.

126. An immediate reaction to such estimates is that, with each of the present type of commercial reactors operating on a "once-through" uranium cycle needing approximately 5000 tonnes per GWe throughout its life, the known recoverable resources of uranium (about 4 million tonnes) would be fully committed by the early 1990s. Since advanced

reactor systems such as FBRs and those employing a thorium cycle are unlikely to be introduced in any numbers before the year 2000, further discoveries of uranium are essential.

127. However, known resources are merely a measure of the effort of exploration to the present, which has resulted in the greater part of them being located in North America (see chapter 3). There is, therefore, little doubt that the world's total recoverable resource is considerably greater than 4 million tonnes, and, as pointed out in the preceding chapter, the real problems are those of annual demand, and the throughput of associated fuel services. Because of this, scenario sets have been developed, for example, that presented at the 1977 World Energy Conference meeting (15), and that recently published by the OECD Nuclear Energy Agency (174).

128. The object of such scenarios is to estimate, for a particular growth pattern, annual, cumulative, and committed fuel requirements for any given year, and to determine likely demand on all aspects of the fuel cycle. Exploration and mining needs especially are assessed, and the size of the necessary enrichment, fabrication, reprocessing, storage, and disposal services estimated. The scenarios are defined in terms of various reactor strategies; that is, LWRs only, LWRs plus plutonium recycle, LWRs plus FBRs, LWRs plus HWRs (thorium cycle) plus FBRs, etc. The problem is complicated by possible policy decisions, the times at which advanced reactors may be introduced, the doubling times of FBRs, and so on. Nevertheless, they give instructive results. For example, for the situation presented at the World Energy Conference meeting (15), the OECD uranium needs for the year 2020 were estimated to be:

Reactor Strategy	Annual Demand 10^5 tonnes	Cumulative Requirements 10^6 tonnes	Commitment 10^6 tonnes
LWR (no recycle) … …	4.2	7.8	13
LWR + FBR (10-year doubling times) … …	0.8	4.6	5.3
LWR + FBR (24-year doubling times) … …	1.7	5.3	7

It was assumed that the breeders were introduced in 1993 in North America, and 1987 in Western Europe, the LWRs providing the initial inventories for the FBRs. Surprisingly, there is not a great difference between the cumulative requirements, although there is a very significant difference in annual demand. In fact, within another 10 to 20 years the latter would become negligible for the FBR case with a 10-year doubling time. These results illustrate present differences between the United States and European philosophies of the FBR. If there are adequate indigenous resources and the annual demand can be met, and because the cumulative needs for different strategies do not greatly differ in the middle term, the decision if and when to introduce the FBR can be postponed for many years. On the other hand, if there are no indigenous resources and the aim is to become highly self-sufficient in fuel supplies, the strategy in which the annual demand is a minimum would become attractive.

129. Once the FBR is introduced the magnitude of the resource ceases to be of concern in the long term. Even in the short term, it is of no great importance either, the restricting factors being the availability of supplies and services on the required time scale. In fact, those presenting these

scenarios conclude that over the time period considered "unprecedented levels of international co-operation" will be needed to meet the demands that could be placed on the uranium fuel supply industry.

130. The actual reactor strategy ultimately adopted will to a large extent be determined by public acceptability. In this regard, assuming that the question of safety is resolved, and that the necessary international co-operation indirectly solves the proliferation problem, there is still the question of waste disposal. It has been suggested that the introduction of fusion as distinct from fission reactors could go a long way towards solving the problem of waste disposal.

Fusion Reactors

131. In nuclear fusion, light atoms join together to form heavier ones, and in the process release heat, again in the form of kinetic energy of the reaction products. For example, a collection of interacting deuterium atoms (deuterium being a heavy isotope of hydrogen) can, through a series of interactions, lead to helium-4, the naturally occurring isotope of helium, plus neutrons and protons. The energy released appears as kinetic energy of helium-4 and the other particles, but unlike the fission case, there is no chain reaction.

132. For reactions to occur at a rate at which there is a useful energy output, it is necessary to raise the temperature of the deuterium gas to well over one hundred million degrees, over 10 times greater than the temperature in the centre of the sun. From such a hot gas there are large radiation losses, but once above a certain temperature sufficient heat is released in the fusion reactions to compensate for these. The gas then essentially burns. In very simplistic terms the generation of electricity by nuclear fusion can be summarised thus. A "match" is used to "ignite" the gas which can then "burn" at temperatures greater than several hundred million degrees in a "furnace" from which heat can be extracted to produce electricity through a conventional steam cycle. It may also ultimately be possible to convert the heat directly to electricity without the need of a steam cycle. The required technology for doing this is complex. Nevertheless, if it can be done the rewards are great. Only about a hundred or so kilograms of deuterium would be required per annum for a 1 GWe station and the reaction product is inert non-radioactive helium.

133. Deuterium is a naturally occurring isotope of hydrogen. In every 10 000 litres of water there is about 1 litre of heavy water, and more than adequate quantities can be extracted at negligible costs per unit of potential nuclear energy. The total quantity in the oceans is so great that the Fox report classed fusion reactors in with renewable resources (10). Unfortunately, the problems associated with a straightforward deuterium fusion reactor appear to be, at least for the moment, insurmountable. There is an alternative in which the reacting gas, instead of consisting solely of deuterium, consists of a mixture of deuterium and tritium, the third isotope of hydrogen. With such a mixture, the requirements for success are reduced by almost a factor of 100, although a high temperature of about one hundred million degrees is still necessary. The final reaction product is still helium, but with more neutrons of significantly higher energy being released.

134. Tritium does not occur naturally and must therefore be "bred". This is done by surrounding the reacting volume with a blanket of "fertile" lithium, the neutrons released in the fusion reactions interacting with the lithium to produce tritium and, incidentally, releasing more

energy. For a 1 GWe reactor about 260 kg of deuterium and 440 kg of lithium are needed a year, although a large lithium inventory (that is, the blanket) is also needed (103). Tritium is radioactive with a half-life of 12 years, emitting soft beta rays. In a 1 GWe reactor the inventory would correspond to about 400 kCi. Furthermore, as an isotope of hydrogen, it is a gas. Nevertheless, it is believed that releases, accidental or otherwise, could be adequately controlled, and the 400 kCi in such a reactor is to be compared with the 10 000 MCi in the core of a fission reactor (103).

135. There are many lines of research and development at present being pursued, including lasers as the "match", and magnetic confinement methods in which electrical methods are used to provide the initial heating. Major research in this area started in the late 1940s and early 1950s. It is hoped to demonstrate the feasibility of such reactors within the next few years. Machines are being built for this purpose at a cost of over $200 million each in the United States, Russia, and Britain, the last being a joint European project. If such experiments are successful (and there is every reason to believe that they will be), it is planned to have prototype reactors working by the end of the century.

136. Some of our members visited major laboratories in this field in the United States and Britain, and spoke to many people on the prospects of fusion power. The consensus is that, at the present rate of development, it will be at least 2020 before plant of the type required by utilities is likely to be in commercial operation. There are many technical problems to be solved, and, although earlier operating dates are conceivable, they could probably be achieved only at the expense of reasonably priced electricity.

137. Although fusion reactors appear to have a number of advantages over fission reactors, they do have problems of their own. Fuel costs will be negligible, but capital costs will be high. Furthermore, there will be high fluxes of high energy neutrons, and, although the lithium blanket will absorb these and act as a first biological shield, the induced radioactivity within the blanket and core of the reactor will make maintenance extremely difficult. There will be radioactive wastes, but of a different kind, and provided appropriate materials can be used for the enclosures to the reacting volume, the half-lives should be short, leading to the need to isolate the wastes from the biosphere for periods of less than a life-time rather than for 10 000 to 100 000 years.

138. In such a short summary we have hardly done justice to the potential importance of fusion, which in the long term could lead to solving the world's energy needs once and for all. We have taken the attitude that fusion is somewhat beyond our terms of reference because of the anticipated time-scales. Nevertheless, we believe that fusion developments should be closely followed in the hope that there will be more rapid progress.

Chapter 5. PUBLIC ACCEPTABILITY

INTRODUCTION

1. From the time of the early scientific experiments, there were hopes that energy from nuclear fission could be harnessed to serve mankind. But its first overwhelming use was in weaponry, so its further development was shrouded in secrecy, a secrecy made statutory in the United States by the Atomic Energy Act 1946.

2. In 1953 President Eisenhower delivered a major address at the United Nations, proposing a programme of "Atoms for Peace" and shortly after, a new United States Atomic Energy Act declassified much and various information. Many of those to whom we talked overseas recalled the early enthusiasm for the new technology which was believed to promise a safe, economical, and abundant source of energy. The general public seemed either to share this optimism, or to be content to dismiss nuclear power as an abtruse subject, best left to scientists and engineers to grapple with.

3. As the number of countries with nuclear power plants has grown (a growth coinciding with a world-wide upsurge of environmental concern) so have the writings for and against nuclear power and the demands for public involvement in power planning. Some critics have seen nuclear power as a focal point for discussing the wider issues of energy production and consumption and their effects on society. We have already considered this in chapter 3. We are concerned, here, with public perception of nuclear power itself, its risks and its benefits. On these issues there are such wide differences of opinion, even among eminent scientists, that a major American study says in its foreword:

> Where optimists see a front door to unlimited low-cost energy, pessimists see a back door to world-wide nuclear calamity, and neither perception is wholly unfounded. For more than thirty years both promise and menace have been strongly argued, and in the early 1970s the urgency of the debate was intensified as a consequence of heightened concern for energy supply, environmental hazard, and nuclear proliferation (12).

We do not intend to recount the history of the debate—that has been done by others (for example 111, especially its appendix C). We shall confine ourselves to what we observed, and discussed with many people, in North America and Europe, and to the evidence given us about public opinion in New Zealand.

UNITED STATES

4. The United States has a well developed nuclear industry based on LWRs for both the domestic and export markets. The nuclear industry, and the debate about it, are both well documented. Several States have held "initiatives" (or referenda) which give some indication of the public's opinion of nuclear power. Although the issues put to voters were more narrowly concerned with placing stringent restrictions on constructing and operating nuclear power plants, the vote seemed to have been widely

regarded as one for or against nuclear power itself. Large sums of money were spent on advertising. All the initiatives were defeated, and this was seen as a vote in favour of nuclear power (usually by about two to one).

5. The California Energy Resources Conservation and Development Commission (CERCDC) was set up in 1974 as an agency of the State government to reduce the exponential growth of electricity. Those of us who visited northern California met three of the five commissioners at Sacramento, and received much documentation on the work the CERCDC has already done. We met, too, some of the legislators and scientists, and were impressed by the effort being put into improving energy conservation.

6. In 1976 California prevented by law the construction of any more nuclear plants until the following conditions were met:

—The CERCDC and the legislature determine that the "United States through its authorized agency has approved and there exists a demonstrated technology or means for the disposal of high-level nuclear waste."

—The CERCDC and the legislature determine that the "United States through its authorized agency has identified and approved, and there exists a technology for the construction and operation of, nuclear fuel rod reprocessing plants."

—The CERCDC has "undertaken and completed a study of the necessity for, and effectiveness and economic feasibility of, undergrounding and berm containment of nuclear reactors" and has held public hearings to determine whether nuclear reactors should be required to be sited underground or contained by berms (143).

7. In the legislation, "technology or means for the disposal of high-level nuclear waste" is defined as meaning:

> a method for the permanent and terminal disposition of high-level nuclear waste. It shall not necessarily require that facilities for the application of such technology and/or means be available at the time the commission makes its findings. Such disposition shall not necessarily preclude the possibility of an approved process for retrieval of such waste.

However, it appeared to us that there were already difficulties over the interpretation of this definition.

8. In the United States we talked to representatives of the nuclear industry, the power utilities, the regulatory authority, scientists, environmental groups, and legislators. Both sides of the nuclear debate claimed to be receiving increasing public support, and contended that disseminating factual information to the public would consolidate their own position. We had an interesting meeting with Dr Alvin M. Weinberg, Director of the Institute for Energy Analysis, Oak Ridge, Tennessee. He had been one of the pioneers of nuclear power, but he was not now so optimistic because of antagonism to it. By means of what he calls a "Peace Treaty" he was trying to persuade anti-nuclear groups to go along with his aim for an acceptable nuclear future. He was very concerned about the opposition and felt that, if the nuclear industry could not satisfy those who honestly consider nuclear power is an abomination, it may lose out altogether.

9. Anti-nuclear groups were seeking a moratorium to allow the development of alternatives which stress conservation. They claimed some success, particularly with respect to President Carter's policy statement of April, 1977—success mixed with some disillusionment as it would seem that it was merely a "holding" statement to give more time in which to try to solve problems of proliferation and to further examine reprocessing.

10. Chapter 4 has already noted that the extensive building of nuclear power plants in the 1960s has been followed by a comparative lull, arising (as was suggested by legal consultants to the industry) not primarily from concern about the safeness of nuclear power, but from such factors as greater energy conservation after the oil embargo, economic recession, slowing population and economic growths, and uncertainties of politics and costs. The long licensing period was blamed for delay in ordering new plants. The length of this period comes partly from the complexity of the United States licensing procedure, and partly from the amount of public involvement in the hearings. The Administration is expected to introduce a Bill into Congress in 1978 to codify and simplify siting and licensing of nuclear power projects. In late 1977 the Deputy Secretary for Energy warned the AIF that the nuclear industry must change its own approach to licensing procedures, making an earlier start on the process by standardising design and by using sites which had been selected and approved in advance. The industry took this to mean that he did not expect to see any major changes in the NRC approach to licensing (144).

11. In May 1977, Westinghouse made a survey of the attitudes of the American people towards nuclear power based on in-depth, personal interviews of 2400 representative adults in their own homes by professionally-trained interviewers. This survey sought to find out what Americans knew about the energy situation today in the light of President Carter's initiative, and perhaps more importantly, what they wanted done. There were three main conclusions:

—President Carter's announcement of an energy program and the surrounding publicity have massively increased American concern with energy issues. It now ranks first with the American people.

—*Support for all solutions,* even when they contradict each other, has increased. Americans are more willing today than they were a few months ago to pay the costs and take the risks involved in various solutions.

—An increased majority of Americans today support the development of nuclear power. While they don't have much information about more complex issues, they back both the reprocessing of nuclear fuel and the development of a demonstration breeder reactor (145).

12. The Carter National Energy Plan will lead ultimately to an upsurge in the building of nuclear power plants. Although a move to more advanced technologies such as the fast breeder plants may be delayed, the Plan states that "because there is no practicable alternative the United States will need to use more light-water reactors to help meet its energy needs" (146).

13. Most people living near nuclear stations seem to be no more concerned than the millions of people living in San Francisco for which a large earthquake is predicted before the end of the century. We were told that over 70 percent of the people living near to the San Onofre plant favoured a nuclear programme.

CANADA

14. Nuclear power plants have generally been accepted in Canada. We were referred to a research report *Nuclear Power and the Canadian Public.* The overview to this report states:

> The study was designed to assess levels of public knowledge, perception and attitudes toward the use of nuclear power in producing electricity in Canada. Members of the population aged 18 years and over were scientifically selected from five regions across the country. Personal in-home interviews were carried out with over 2100 adults during March and April, 1976 (147).

The survey was the first to study Canadian public attitudes towards nuclear power at a national level. For most Canadians, energy problems ranked beneath their main present concern, inflation, but were expected to increase greatly in significance in the next 5 years.

15. The survey found that 44 percent of Canadians were uninformed about using nuclear power to produce electricity. The questions were directed only to the "informed" 56 percent of the population, as it would have been unfair to ask specific nuclear-related questions of "uninformed" people. Some results were: on opinions about the use of nuclear power for generating electricity—21 percent were opposed, and 68 percent in favour; on safety, opinion was somewhat divided—56 percent believed nuclear power plants safe, and 39 percent believed them unsafe; and on being asked to consider the sum of their knowledge and opinions to decide whether nuclear power was *worth* the risks or *not worth* the risks—about 56 percent said it was, and 20 percent said it was not, worth the risks, and 24 percent were undecided. Thus, though nuclear power seems to be a social issue of debate in Canada today, very few of the public are active either in opposing or supporting it.

16. On the building of nuclear power plants, 68 percent were in favour, 63 percent were in favour of having them in their province, and 40 percent were in favour of having them in their local area. In reply to another question, many people preferred rural locations (47 percent), or remote (30 percent).

17. Each of the 2100 sample was asked what kind of information about nuclear power was needed. Most responses were "tell all". More specific requests included information on safety and risks, on waste disposal, and on the way nuclear power is used to generate electricity. It is interesting to note that when the sample was asked to rank nine sources of information about nuclear power on a scale from "very reliable" to "very unreliable", the results indicated that scientists were viewed as the most reliable overall. We quote the full table from the research report:

Source of Information	"Very reliable" or "reliable" %	"Very unreliable" or "unreliable" %
1. Atomic Energy Control Board ...	65	12
2. Environmental conservation groups...	57	21
3. Federal Minister of Energy, Mines and Resources...	62	19
4. Newspaper reports	48	32
5. Provincial Ministry	61	21
6. Members of Provincial Parliaments ...	43	34
7. Scientists	74	11
8. Television news	67	16
9. Electric utility	58	23

Thus, if a nuclear plant was planned for a locality, Canadians felt that technical experts, the Provincial Government, and the general public should be the main ones to participate in a decision on the site.

18. The same group between April and July 1976 also studied 203 Canadian policy-makers. We were particularly interested in this study's comparison of the views of politicians, civil servants, academics, and environmentalists with those of businessmen—a group conspicuously

lacking among those who took part in our inquiry. The report showed that environmentalists knew more of nuclear power than did the other groups. The businessmen consistently showed most support for nuclear power, for example the summary of the study report states:

> A more general question about the construction of nuclear generating facilities in Canada reveals that 97 percent of the businessmen, 85 percent of the civil servants, 75 percent of the politicians, 59 percent of the academics, but only 5 percent of the environmentalists express support or qualified support for nuclear power. In the general population 71 percent support nuclear power (157).

BRITAIN

19. Nuclear plants have been operating in Britain since 1956, being welcomed by the public as a rapid and successful development of a technology—an achievement of which the nation could be proud. In England the Secretary of State can arrange for a public hearing when a nuclear construction site is being considered. During our visit to the Nuclear Installations Inspectorate (NII) we were told that hearings had been held in most cases, and that the objections raised had been concerned with general issues of loss of amenity and had not been specific to nuclear power. When construction was planned for the AGRs at present being built at Hartlepool and Heysham, there was so little public concern about the possible dangers of nuclear reactors that it was not thought necessary to arrange public inquiries. It is interesting that these two stations, in the north of England, were chosen as the first two "near-urban" sites (103).

20. As there had been no applications for construction licences for new nuclear power stations since the 1960s, there had been no local hearings at which opinions could be expressed. Early in 1974 a decision of the standing Royal Commission on Environmental Pollution to study the environmental problems of a greatly expanded nuclear power programme led to the Flowers report, which extended public knowledge of nuclear issues.

21. The inquiry at Whitehaven into the proposed extension of the Windscale reprocessing plant, concurrent with our own inquiry, has given a forum for the public debate in Britain of many of the energy issues prominent in so many of the submissions made to us. While we were in Britain the proceedings of the Windscale inquiry were being reported daily in the press, and many of those to whom we talked let us have their submissions prepared for that inquiry.

22. In chapter 9 we refer in detail to the local liaison committees set up by the CEGB and to meeting members of these committees at three nuclear power stations. A liaison committee is set up when construction begins, meets with senior station staff at least once a year, and is shown the reports of tests taken by the Department for the Environment. A committee is even more valuable as a direct link between the local authorities, the local people, and the power station. Inquiries, complaints, and misgivings can be, and are, expressed to its members. CEGB officials told us that they have no doubts about the acceptability of their nuclear plants at the local level, and our observations support this claim. They added, however, that they do not consider that they have been able to attain the same level of public acceptability of nuclear technology on a national scale, although they have adopted a policy of giving information and entering into debate. They do not consider that opposition to nuclear power has increased greatly in Britain.

23. In the past, organisations have been able to arrange visits to CEGB power stations and the general public is now being given the chance to visit stations on occasional open days. Immediately before our own visit, Hinkley Point station had held open days on two weekends with about 26 000 visitors moving through the station and showing a lively interest in its operation.

24. In London we heard the other side of the national debate from representatives of the Friends of the Earth, Dr P. Chapman of the Open University, Mr G. Leach of the International Institute for the Environment and Development, and Dr J. Davoll of the Conservation Society. Although their emphases vary, all these organisations contend that energy questions should be approached by analysing demand, whereas they see official planning as being preoccupied with energy supply and the expansion of generating capacity. They consider that energy conservation, better matching of energy type to end-use, and the development of renewable energy resources would provide better employment opportunities than would any kind of large centralised power plant. We found that many in these groups share with some American organisations an opposition to large power developments in general; and, though they consider that the various dangers of nuclear power are under-stated by its proponents, they acknowledge that other forms of power generation also have drawbacks as yet not fully investigated. Though they would not concede that nuclear power is inevitable in any country, most do not show intransigent opposition to the present level of nuclear industry in their own countries, seeming to regard it as an established, if to them undesirable, fact.

25. An independent national research survey commissioned in 1977 by *New Society* from the Opinion Research Centre produced some interesting results (148). It was based on a representative quota sample of 1081 adults, aged 18 and over, interviewed throughout Britain between 11 and 14 March, 1977. It showed a guarded approval for nuclear power; or at least a stoic acceptance. Most people thought that nuclear power was there to stay. Nearly two-thirds would accept a nuclear power station built within 10 miles of their homes. Seventy percent said they would trust the opinions of scientists the most. Only 5 percent would most trust newspapers and television reports, and 4 percent, the Government. A 70 percent majority also considered nuclear plants reasonably safe. But most people wanted to keep all options open. The public debates held on this nuclear question have obviously done little to educate the public. The "Don't knows" quite often held the balance of opinion. The survey found that women were more uneasy about nuclear power than men, an observation supported by our conversations with individual women, and with representatives of national councils of women in North America and Britain.

OTHER EUROPEAN COUNTRIES

Austria

26. The first nuclear power station in Austria was begun in 1971 but, soon after, public opposition hardened, as it had in West Germany. The Government then decided not to continue with its nuclear programme but to set up a public debate and to keep the present station out of operation until the reports from this debate had been discussed in Parliament and a vote taken. Thus, because of community antipathy the nuclear programme came to a standstill.

France

27. It would seem that French people in general had accepted the nuclear fission programme, but found the FBR programme something new and to be suspected. Most of the protests within France have been supported by foreigners, but, because there had not been any provision for any form of public debate, a home grown attitude of protest to the nuclear programme had begun to appear. Government appreciation of the need for good public relations is now leading to improved consultation—with all Ministers concerned, with local bodies, etc., and through the media. As a result the Government feels that there is more public understanding than in most other countries.

Sweden

28. Sweden, with a lack of fossil fuels, has developed substantial hydro resources and also relies heavily on imported oil. The main party in the present coalition was elected on a policy that no nuclear power stations over and above the five at present operating should be commissioned. An energy research and development commission was set up to formulate a new draft energy policy for parliamentary discussion in 1978. It was asked to examine and evaluate safety techniques and the environmental effects of nuclear power, as well as the management of radioactive wastes. Money was made available for research into using waste heat and developing renewable energy sources. Attempts are also being made to limit the growth of total energy consumption to 2 percent a year up to 1985, with an electricity increase of no more than 6 percent a year.

29. However, it was strongly held that the present Prime Minister would have to change his anti-nuclear stance and continue the nuclear programme to avert a growing energy production gap after 1985. In early 1978 two more nuclear power stations were approved.

Switzerland

30. Here also anti-nuclear opposition has appeared after an early enthusiasm and after the setting up of two nuclear power plants with a third almost built. A protest "sit-in" has led to one proposed site being abandoned. Public opinion polls have shown that about 50 percent of Swiss people support nuclear power, with the rest being divided between those who oppose it and those who are undecided.

31. Members of the Swiss Association for Atomic Energy linked the opposition to nuclear power with the increasing emphasis on promoting limited population growth and limited economic expansion, with the focus being on nuclear power, using as arguments safety, and the link with nuclear weapons. Opponents of nuclear power have demanded a 4-year moratorium, and a parliamentary commission has been set up to study this proposal. There is also an initiative which, if proceeded with, will lead to a referendum. While the proposed provisions for public acceptance of a new nuclear plant might not be completely impossible to meet, they would make any future expansion of nuclear power in Switzerland extremely doubtful. It must be noted that, in Switzerland, as in Scotland, public pressure has prevented drilling holes in rock as a preliminary investigation to find sites which might be suitable for the disposal of nuclear waste.

NEW ZEALAND

The Phillips Study (1975)

32. The only scientific sampling of national public opinion on nuclear power appears as a small part of a study of household attitudes to energy use and conservation made by Dr P. Phillips. This was a postal survey of a sample of 17 500 New Zealand households returning a 58.8 percent response rate. The questionnaire included the following item:

> Power Generation: A new power plant is planned in your area. A coal plant (a) and a nuclear plant (b) would produce power for roughly the same cost, but the coal plant would cause air pollution and there could be problems with disposing of the radioactive nuclear wastes. An oil fired plant (c) could be built which would have less impact on the environment but costs would be 50% higher and the fuel oil would have to be imported. I would recommend the building of (a) (b) (c) (circle one).

From the response to this item the report concluded:

> In the choice between power generation options, nuclear power was selected by 24% of respondents which placed it marginally behind oil with 24.7% and a poor third to coal with 45%. Support for the nuclear option varied between sub-groups within the sample but in no case rose above 35%. In general terms, most support came from the highly qualified, those with high socio-economic status and the high income groups. There was also a distinct difference between men and women with the latter markedly less in favour of nuclear power.

33. In response to two of 33 specific statements included in the survey to ascertain respondents' attitudes on a five-point scale, the most frequently endorsed answer was "undecided" when asked to comment on the statement that "Nuclear power will give us a clean, cheap, limitless source of energy". The second most popular was "disagree". To the statement "Nuclear power is completely safe", the popular response was "disagree", and the second choice was "undecided".

34. A parallel survey, using the same questionnaire on a sample of 500 members of the New Zealand Institution of Engineers, showed that:

> When presented with the same choice members . . . also placed coal first but were much more favourably disposed towards nuclear power than the general sample with almost twice as many selecting the nuclear option.

The Ericksen Study (1975)

35. Another study was put before us by Dr N. J. Ericksen (150). It dealt comprehensively with the subject, but is based on a sample of only 84 persons in Birkenhead and on 67 influential members of the Birkenhead community. It was intended only as a pilot or preliminary test study. Resources did not allow a comprehensive study to be made. Although the significance of the study as a measure of New Zealand public opinion is thus reduced, its thoroughness and depth gives it much interest. We appreciated Dr Ericksen's submitting it to us and appearing in person to discuss its findings.

36. From the responses to three questions designed to test attitudes to nuclear power at three different levels, the sample of 84 divided into three distinct groups. Most, 56 people (67 percent), opposed nuclear power as a source of electrical energy; and of these 56 people, 82 percent were strongly opposed to nuclear power. Of the 21 people (25 percent) who supported nuclear power, only 14 percent indicated strong support. The remaining 8 percent of the sample were neutral in outlook. The survey was designed to find out about beliefs and the desired participation in decisions about nuclear power, as well as about attitudes. The opponents

of nuclear power were found to be stronger in their opposition than the minority was in its support.

37. The survey of Birkenhead community influentials found a like proportion opposed to nuclear power, which again showed greater strength in its opposition. Safety factors (waste disposal and radiation) were the reasons most often given. A majority would be willing to take part in passive activities such as signing a petition, but fewer would organise or join a rally. A follow-up survey 16 months later found the same division of opinion on nuclear power with intensified attitudes and an increased desire for more governmental openness in nuclear planning. Evaluation of changing attitudes from September 1975 to February 1977 is of considerable interest, but unfortunately the sample by this time was so small that we cannot give a great deal of weight to any deductions from it.

38. This widespread questioning of whether nuclear power is suitable to New Zealand was also shown by the number of people and organisations who agitated for a public inquiry. Chapter 1 describes how our Commission arose from an undertaking to hold a public inquiry given in the election manifesto of the present Government. The FFGNP have stated that the certainty of a Royal Commission modified their own earlier intention to invite written submissions from the public (4). During our inquiry many have remarked that New Zealand is in an unusual situation in holding an inquiry before any substantive steps had been taken to introduce nuclear power. We have, therefore, considered that the expression of public opinion about nuclear power and the interplay of different assessments of its desirability, make up a very important part of this inquiry. Before considering the evidence of general public attitudes contained in the submissions, we shall discuss briefly the most publicised New Zealand expression of opinion about nuclear power—Campaign Half Million.

Campaign Half Million

39. The Campaign for Non-Nuclear Futures was formed in June 1976, and in 4 months collected 333 088 signatures to a petition opposing nuclear power reactors in New Zealand, either as nuclear power plants on land or as reactors on ships at sea. The organisers of the Campaign estimated that "while it had approximately 200 main co-ordinators, the number of actual signature-gatherers, speakers and supporters active in the campaign in some other way was around the 5000 mark" (27). It was pointed out to us that the signatories of the petition represent one in every seven New Zealanders over the age of 14. When we questioned the depth of knowledge about nuclear issues of those signing the petition, we were told that the publicity generated by the campaign led to increased willingness to sign from those who were approached in its later stages. While we are not convinced that all who signed the petition would be unalterably opposed to introducing nuclear power into New Zealand, under all circumstances, the size of the response shows a widespread concern and a lack of confidence in the technology.

40. What a petition, by its very nature, is unable to demonstrate is the depth of concern and commitment of the signatories and the reasons for their attitudes. We are therefore grateful to those organisations which made the effort, not only to ascertain their members' opinion for or against nuclear power, but also their reasons for this.

Community Organisations

41. The National Council of Women circulated a series of questions to its members and collated the replies, which express the views "of a very wide range of N.Z. women"(151). The council has 35 branches, each representing many organisations, and 29 replied to the questions. Of these, 23 rejected the development of nuclear power as a source of energy in New Zealand, 3 favoured it, and 3 did not know. Their reasons for and against nuclear power were summarised under five headings, and the submission comments that "it became clear from the number and quality of arguments put forward in support of the positions taken that those who reject the concept of nuclear power for New Zealand have given considerable thought and study to the matter". The reasons given for opposition to nuclear power covered accidents, pollution, weapons proliferation, cost, and dependence on non-renewable energy resources, all of which are discussed elsewhere in our report. The problem of the disposal of waste products with a long radioactive life was frequently cited as a reason for opposing nuclear power. The desirability of conserving energy was also strongly stressed.

42. Two women's organisations, which are affiliated to the National Council of Women at national level and whose opinions are incorporated in the NCW submission, also presented separate submissions. The New Zealand Federation of University Women reported on two surveys of the opinions of its members (152). The answer was a clear 5 to 1 majority against nuclear power. The Federation believes "the possible consequences to be undesirable and involving risks which far outweigh any benefits". The New Zealand Federation of Business and Professional Women's Clubs received replies to their questionnaire from 32 of their 38 clubs and reported that:

> The clubs were in the majority in favour of nuclear power development with certain reservations. Taken on membership however the percentage of individuals was 52% in favour 44% against and 4% abstained as they felt they had not sufficient knowledge to form an opinion. Members in favour and those against all felt that they need a lot more accurate information regarding nuclear power (153).

It was apparent from these three submissions that those supporting and those opposing nuclear power held completely contradictory opinions on such issues as cost, dangers, and effects on the environment—not a surprising result when many knowledgeable in the field express such divergent views.

43. The only body, other than women's organisations, to have actively canvassed its members' views was the Canterbury-Westland Young Nationals. After questioning 24 of their members, they concluded that ultimately the establishment of a nuclear power plant may well become advisable but there are big advantages in delaying that step as long as possible to wait for improvements in safety and efficiency (154).

44. Of the 141 submissions made to us, by far the most were opposed to nuclear power. The arguments included the use of indigenous resources, development of renewable resources, energy conservation, and the deferment or outright rejection of nuclear power. In this they are very closely identified with much of what we have read, and have discussed overseas. One significant difference, however, is that, in the absence of any nuclear industry in New Zealand, there is no strong pro-nuclear lobby here. This is in strong contrast to some other countries, especially the United States, where much money and expertise are spent on promoting nuclear power.

45. A significant area where New Zealand opinion differs from that in many countries is in the attitude of the trade unions. United States organised labour supported the nuclear industry in the various State initiatives, seeing it of importance in maintaining employment. In New Zealand the Federation of Labour has stated its opposition to nuclear power until it can be shown to be "safe and not harmful to the environment" (70), and the Public Service Association submitted that:

> Nuclear power should be deferred until proved technologically safe and free from political interference. Even if proved safe, it should not be introduced unless it can be shown that it is more economic, reliable and socially beneficial than any other available energy resource or combination of resources (119).

46. The difficulty of judging whether any process is "technologically safe" was discussed before us, and in some cases it was agreed that "publicly acceptable" would be a sufficient interpretation. But this raises the further difficulties of information, education, and the expression of public opinion.

INFORMATION AND EDUCATION

47. In a section of its submission called "The Measurement of Social Acceptability", the Commission for the Environment stated:

> An informed public judgement on the hazards of nuclear energy requires the existence of readily available information on the subject . . . It is also desirable that such information should be widely discussed and debated to highlight and crystallise the major points at issue (23).

Several submissions advanced this point of view, and some described specific aspects on which more information is needed.

48. It has been alleged that information on the adverse effects of nuclear power has been kept secret. It is generally agreed that its military origins were not conducive to an early exchange and dissemination of information. However, in recent years the trend has been reversed. Not only are the technical documents, such as the United States Nuclear Regulatory Commission (USNRC) regulations and the Rasmussen Report on Reactor Safety, of formidable size, but there are also many more articles, magazines, and books dealing with aspects of nuclear power. Some books have been published during our inquiry, and, while overseas, we heard of still more in the course of preparation. Unfortunately, much of the writing is identified with one side or the other of the nuclear controversy, and so is regarded with some suspicion by those of the opposing view. This, though a natural outcome of the polarisation of opinion, is not helpful for those who still seek factual and objective information.

49. We had hoped that our inquiry would help disseminate information and provide a forum for the nuclear debate in New Zealand. We believe that something of this aim has been achieved. We have already expressed our appreciation of the fine series of papers by the DSIR and our hope that they will receive wider circulation. In this chapter we have outlined some of the concern about nuclear technology which was given public expression in our hearings. We were encouraged by the communication established by those who took a continuing part in our inquiry and by the spirit of co-operation which we saw growing there. As well, official decisions have been made during our inquiry which may, in some measure, alleviate the more pressing anxieties and allow a more extended study of the whole question of energy than appeared likely at the start of our hearings.

50. We have been most disappointed with the limited interest shown by large sections of the public. Although some who have appeared before us have claimed to represent many people, and although those who did appear have done so conscientiously and thoroughly, the number of people actually attending the hearings has been small, and most of those have been presenting submissions. By and large, public attendance at our hearings was slight. We realise that this is not uncommon with formal hearings and had hoped that the news media would make the main issues clear to a much wider public. Unfortunately, with a very few exceptions, we do not consider this has, in fact, happened (see chapter 1). We hope that our report, especially its "overview", will bring a simple and essentially non-technical account of nuclear matters as they affect New Zealand to those who are interested and concerned.

51. Widespread information becomes more important in the light of the assertion, so often made, that decisions about nuclear power should not be left entirely to the experts. We heard much comment on the need for public education, discussion, and involvement in decision-making.

52. The Public Service Association (PSA) recommended:

> An advisory body of scientists and informed lay persons, balancing pro and anti-nuclear power groups . . . Its function would be to hold a series of public meetings on nuclear power, throughout New Zealand. Its meetings should be widely publicised. It should then report back to Government and to the public, and Government should consult the records of the meetings, the report and public response to it, as a guide when deciding on their power policy (119).

We have studied with interest the interim report of a similar programme in Austria and noted the difficulties encountered in finding suitable participants and in obtaining full and objective reporting. There seems to be grave danger that such a scheme would tend to polarise opinion and that only the sensational aspects would be widely reported. From what we have learned of the Austrian experience, and also of the limited success of the attempts of the Ontario Royal Commission on Power Planning to involve the public in formal discussion meetings, we cannot recommend any such programme.

53. We must make it clear that this was only one of several PSA recommendations about education for rational energy use, and about participation in the nuclear debate. Their basic contention was that "an educated population is a safeguard for democracy, and energy and nuclear power are definitely areas in which widespread education is needed" (119). This we accept.

54. Several submissions referred us to the 1974 Swedish community discussion programme on energy options. The Church and Society Commission of the National Council of Churches went further and recommended:

> In the New Zealand study programme we envisage, groups would enrol (administered perhaps by the Continuing Education Departments of the Universities) for say, 6–10 evening meetings in their own localities to study the implications of three courses for New Zealand's energy development, including the full range of possible directions . . . As there would be non-expert participation in discussions about alternative technologies, in weighing the risks and assessing the benefits, prior to the study programme there must be clarification of the relevant complex issues so that they can be presented to the non-expert in the clearest possible way (35).

55. We are aware of three such community discussion programmes in New Zealand within the past decade, and we note that one on mental health is planned for 1978. Also, after submissions had been presented, environmental organisations asked publicly for a similar discussion programme based on the Government's projected goals and guide-lines for energy policy. Though we have some reservations about how deeply such programmes penetrate all sections of society, we see advantages in them. We recommend that if a discussion programme is implemented, it should be based on small groups and not be a structured formal debate; include nuclear power as one option among many in the total energy scene, and not as a topic to be considered alone; and it should not include a formal final report, but should aim at increasing the community's awareness of energy matters.

56. If public information and discussion can be achieved, there remains the further matter of public involvement in decision-making. We have considered the possibility of referenda on nuclear power, and we made inquiries when overseas. In the light of what we learned, and considering the fact that the countries where a public vote has been held on nuclear matters are those where such votes occur much more often in political life than they do in New Zealand, we cannot recommend that such a complex matter as nuclear power should be decided by referendum. With the FFGNP report already published, and now ours, we consider that the general licensing process referred to in other parts of our report will, together with the normal democratic process in New Zealand, give adequate opportunity to further involve the public with nuclear questions.

PART III

Chapter 6. THE NZED PROPOSALS

INTRODUCTION

1. The attitude of the NZED to the need for a nuclear power programme has changed considerably since we began our inquiry in November 1976. At that time the departmental policy as stated in the 1976 report of the PCEPD was that:

> nuclear power must be regarded as one of the main imported fuel options for thermal generation beyond 1990 . . . At the present it would still appear to be necessary for a decision in principle on nuclear generation to be made in 1977, or very soon thereafter (38).

2. The reasons given by the NZED for needing an immediate governmental decision in principle authorising a nuclear power programme were based on the following premises, each of which has been a matter for debate:

(a) The forecast for electrical demand showed that 49 774 GWh per annum would be needed in 1990, rising probably to 80 400 GWh per annum by the end of the century (4, 39).

(b) There were no clear indications that alternative indigenous energy sources would be sufficiently developed in time to provide the power needed (38).

(c) Nuclear power generation was a commercially proven technology which could supply the 1200 MW shortfall likely to occur in 1990 (*Evidence* p. 85).

(d) A decision in principle would not be an irrevocable commitment to nuclear power. Such a commitment would not need to be made for another 5 years (40). (The difficulties of the concept of a "decision in principle", and the changed meaning now given to it by the NZED, are discussed later).

3. The NZED was much criticised during our inquiry for wishing to start a nuclear power programme before being able to show that New Zealand's indigenous power sources could not make up the expected shortfall in electricity supply. In particular, the DSIR criticised the NZED for not having pursued a much more vigorous geothermal programme, while others thought that the importation of coal should have been thoroughly investigated if indigenous sources were insufficient.

4. It emerged that NZED policy was one of predominate dependence on commercially proven energy sources. The department said:

> Over the past 20 years . . . we have tended to stay with conventional proven sources of energy because they are commercially available and we are not in ourselves a research and development organisation . . . we are geared to buy what is on the market . . . (*Evidence* p. 104).

It became quite obvious that although the NZED had a watching brief on unorthodox methods of electricity generation, and called on other State departments for resource assessment, research, and development, it followed a cautious orthodox policy when new generating capacity was needed.

5. This is an understandable attitude in an agency responsible for actually providing New Zealand's electric power needs. Other institutions or other State agencies having no such operational responsibility can much more comfortably recommend the advantages of as yet unproven resources or of technologies still in the developmental stage. However, there have been shortcomings in indigenous resource assessment and exploitation which it is hoped the new Ministry of Energy will remedy.

6. The initial rather rigid attitude of the NZED changed and grew more flexible as our inquiry progressed. The department must take credit for the genuine attempt to meet some of the objections raised to its initial case, and to modify its stand.

7. In its later submission 128, the NZED revised its forecast of electricity demand to take into account a more realistic contribution by the end of the century from previously unconsidered indigenous sources. The demand could be met, but this was unlikely because of environmental and feasibility restrictions. It concluded, however, that nuclear energy must still be considered as an option as it may well be needed *after* the year 2000, and consequently the groundwork which would permit a move to nuclear power must be laid well before that date.

8. The 1977 CRPR report presented to Parliament in September confirmed this thinking. Its predictions of load demands considerably reduced those given in the 1976 report. Indeed, there was a difference of opinion within the CRPR on the amount of the reduction. The majority report gave a deferment in load growth of 2 years compared with the 1976 estimates; the minority report gave a 5-year deferment (41).

9. In the 1977 PCEPD report, the nuclear power station was not included as one of the works needed to satisfy load growth in the next 15 years, thus giving a breathing space in considering the need for a nuclear power programme. The PCEPD still regards nuclear power as an energy option which cannot be disregarded. It thinks that the time before a decision must be made will allow "for a better evaluation and further technical progress with conservation measures and with alternative means of electricity production" (42).

10. In line with its policy of keeping its options open, the PCEPD recommended that: "The appropriate Government departments should therefore continue to keep in touch with the situation overseas and to develop expertise and understanding of advances in nuclear technology" (42). The official policy is thus quite different from that existing when our Royal Commission was appointed.

11. Much time was spent in the presentation and cross-examination of the NZED proposals. Because of changed circumstances many matters raised may not now be immediately relevant, but New Zealand may well have to face them again before long. Thus it is of more than historical interest that we here examine the machinery of departmental decision-making, the reasons given for the need for a nuclear programme, and the way such a programme would be implemented.

ESTIMATED DEMAND

12. The amount of new electric generating equipment needed to meet expected future demand is determined from the demand forecasts of a series of committees comprising representatives from State departments and electrical supply authorities. An updated forecast for 15 years ahead is produced each year.

13. Forecasts start from information given by the 61 electrical supply authorities each of which prepares for its own local region a forecast for 5 years ahead, taking account of the many factors which may cause changes in domestic, industrial, and commercial electricity use. The 61 five-year forecasts are examined for consistency by a Policy and Finance Utilisation Committee (PFUC), which combines them into a national forecast.

14. The CRPR extends the PFUC 5-year forecast out to 15 years. Before 1976 the CRPR forecasts assumed an unrestricted supply of electricity in normal weather, and took account of the long-term economic trend.

15. In 1976 the Treasury gave the CRPR an economic forecast, and the New Zealand Institute of Economic Research gave its views on economic conditions, both in the medium term. Besides these, the CRPR had an independent forecast by the Department of Statistics, and took into account some 16 factors which were likely to reduce future electricity demand. Full details are given in the 1976 report of the CRPR.

16. The PCEPD submits to the Minister of Electricity the necessary additions to generation based on the CRPR report. This is then the "Power Plan" for the year. Authorisation for any particular project is still subject to independent reviews by the Treasury, the Ministry of Energy Resources, and the Government.

17. The CRPR has published the following forecast guidelines in its annual reports:

(a) . . . the ultimate object of the whole [forecasting] process is to produce, in the long term, an adequate supply of electricity without excessive expenditure of resources (43).

(b) . . . [the CRPR] understands it to be Government policy to provide for an adequate supply of electricity to facilitate the achievement of its social and economic objectives (43).

(c) . . . We believe that the committee must endeavour to produce the best possible estimates of future requirements; it is for others to decide whether the country can afford to meet these requirements (39).

18. The accuracy of the CRPR forecasts has been studied in the report of the FFGNP (4) and in submissions presented to us. The forecasts have usually been over-estimates, and the DSIR pointed out:

> It seems that the CRPR sees its task as one of not underestimating future electricity requirements, since developments based on underestimates would be difficult to accelerate, whereas over-development can readily be slowed down to more closely match the demand (44).

19. Electricity generation figures over the past 40 years show an almost constant annual increase of 7.2 percent, that is, they double every 10 years. As has been repeatedly pointed out to us, this exponential (compound interest) growth cannot proceed indefinitely when the resources on which it depends are finite.

20. The greater complexity introduced into forecasting in the last two years, and the slowing down of economic growth, have reduced the forecast percentage increase in energy demand, thus:

Table 6.1

PROJECTIONS OF AVERAGE ANNUAL PERCENTAGE INCREASE IN TOTAL ENERGY DEMAND IN NEW ZEALAND

Period of Increase	Year of Projection		
	1975	1976	1977
1977–81	8.6	7.3	–
1981–86	6.2	6.0	5.6
1986–91	6.1	5.4	5.1

THE NZED SUBMISSIONS

21. References to nuclear power generation first appeared in official reports in 1957 the year after Calder Hall, the world's first commercial nuclear power plant, started operation in Britain. The Combined Committee on the New Zealand Electric Power Supply concluded that:

> New Zealand has better sources of power available to meet its needs for some time to come. This is indeed a fortunate circumstance for this country which can thus reap the benefit of further experience in this very new and promising field (184).

But by 1964 an appendix to the Power Plan stated that in 1968 or 1969 investigations into timing of a large thermal station using either coal or nuclear fuel must start. In 1968 the Power Plan included a 250 MWe nuclear unit scheduled for commissioning in 1977, but noted that the nuclear programme "could be significantly affected in the event of early large scale discoveries of natural gas". After the Kapuni (1959) and Maui (1969) gas fields were discovered, and large amounts of coal were confirmed in the Huntly area, the projected commissioning date for New Zealand's first nuclear power station was put back in a number of steps from 1977 to 1990. The 1975 Power Plan initiated the concept of a decision in principle on the introduction of nuclear power to New Zealand.

22. The 1976 Power Plan forecast for the year 1990–91 an electrical power requirement of 10 026 MW, and an energy requirement of 49 774 GWh. Estimates of electricity generation from hydro, geothermal, natural gas, and coal, and a consideration of the state of development of wind and solar power generation, led the PCEPD to consider that nuclear power should be commissioned in 1990. They saw no way in which the forecast power requirement could be met other than by a 2 × 600 MWe nuclear power station.

23. The Power Plan pointed out the lack of precise knowledge of the extent of our indigenous energy resources, of the rate at which they could be economically used, and of the optimum amount which could be allocated to power generation. It stressed that high priority should be given to obtaining this information, but concluded that "there are no clear indications that any such [alternative indigenous energy] resource[s] will be sufficiently developed in time to significantly delay the introduction of the first nuclear stations"

"Decision in Principle"

24. In its first submission (40) the NZED spelled out what it meant by the "decision in principle" for a nuclear power programme that it was seeking from the Government, and gave a detailed timetable of the steps it would take when the Government gave its approval. The NZED argued that the great amount of preparatory work needed before a new complicated technology could be introduced into New Zealand inevitably meant very long lead times. A nuclear licensing authority would have to be set up to formulate safety standards; and, because nuclear power generation was a contentious issue, the department wished to receive assurances that it was an acceptable means of generation. However, it was never made clear to whom this means of generation was to be acceptable.

25. The precise meaning of a "decision in principle" and its implications were not at all clear to us, and indeed the meaning the NZED attached to the phrase altered during our inquiry. In its first submission the NZED contended that a decision in principle was not an irreversible commitment to nuclear power. Such a commitment would not be sought from the Government until 5 years after an approval in principle was received. According to the NZED, even at this stage the Government might decide not to make a commitment to nuclear power. Many of those opposed to the introduction of nuclear power did not accept this contention. They argued that the existence of a group of highly trained experts, together with plans for a licensing and regulatory body, would constitute a powerful argument for the continuation of a nuclear programme. We think this is a valid point.

26. In the light of the changed power-demand forecasts for the early 1990s, the NZED in its later submission 128 modified its first stand. It saw no clear indication that New Zealand could become self-sufficient in indigenous energy without excessive economic or environmental cost. The NZED therefore considered that nuclear power must continue to be investigated as an important energy option.

27. The level of activity which the NZED considered to be the minimum needed to maintain nuclear power as an energy option differs substantially from the detailed timetable of the "decision in principle". One would need, as it stated in its submission 138:

(a) to monitor world activity in unresolved areas (e.g., waste-disposal facilities, the development of multinational fuel-cycle centres, uranium availability, cost escalation);
(b) to study other developments in nuclear energy (e.g., new technologies, standardised designs);
(c) to establish the viability of reactor sites in New Zealand;
(d) to investigate the disposal of radioactive wastes, including spent fuel, in a New Zealand context;
(e) to send staff overseas for training in nuclear technology in order to maintain a small core of staff with a suitable depth of knowledge and experience;
(f) to actively promote public understanding and discussion of the issues associated with nuclear power and energy generally.

28. Mr K. D. McCool (Chief Engineer—Development) in cross-examination after presenting the NZED final submission stated quite clearly what was now meant by the term "decision in principle", a meaning that was not at all apparent earlier in our inquiry.

The Chairman . . . Do I understand that you no longer seek a decision in principle, or do you consider that what you ask in the final paragraphs of your submission really amounts to what you originally meant when you sought the decision in principle.

Mr McCool . . . I think the point I am making is that the decision in principle is no longer an urgent requirement. The decision in principle was really an acceptance of the fact that nuclear power technology was something that the country was prepared to proceed with (*Evidence* p. 2484).

29. The MER in its final submission merely said that it was essential for the relevant State departments to keep up-to-date with nuclear technology; but did not itemise what it considered a desirable level of activity. It did not believe "that the case against nuclear power is such that it should be rejected completely, as an approval in principle could be warranted at a later date" (45).

The Scope of the Proposal

30. In its first submission the NZED gave a detailed 15-year timetable of activities up to the commercial operation of the first nuclear power unit (40). The first 5 years were to be taken up with activity governed by the "decision in principle". The governmental approval to construct the station was scheduled for the end of the fifth year. According to the NZED there was no irrevocable commitment to nuclear power until this point.

31. In the first 5 years $4.9 million were to be spent, including the salaries of the staff, some of whom would have to be recruited overseas. A project consultant was to be appointed in the first year to advise and assist in all phases of the first nuclear station. During this time a project team of about 40 engineers and scientists would be assembled within the NZED. Two-thirds of these would be sent overseas for training, or possibly recruited overseas. They would work with specialists in State departments, especially the MWD and the DSIR, as well as with private consultants in New Zealand.

32. The NZED would be responsible for investigation and design studies, and would in the first 5 years have to carry out planning and implementation in manpower and nuclear aspects; to carry out site studies leading to the selection of a specific site; to go through the environmental impact reporting procedures to the audit stage; to comply with town and country planning and water rights requirements; to prepare specifications for the reactor system, fuel, and the turbogenerators; to call tenders and evaluate them; and to carry out a continuing training programme for scientists and engineers.

33. A licensing authority independent of the NZED would be set up by first appointing a head, key experienced staff, and a consultant. Their preparatory work could include: legislation on liability and licensing; siting criteria; safety criteria, codes, and standards; preliminary safety analysis report procedures which would describe how designers are to meet the safety criteria; quality assurance and control requirements, and audit procedures.

34. To give it effectiveness and independence the licensing authority should be adequately staffed to carry out its own work as early as possible. Overseas experts would certainly be needed at first, but there would be a need for a strong New Zealand influence on the authority. The NZED estimated that 15 to 20 people would be needed by the start of construction of the first station. These matters are discussed in more detail in chapter 13.

35. Under cross-examination the NZED admitted (*Evidence* p. 83) that a nuclear power programme would not end with the building of the one station forecast for 1990. Its nuclear power programme would comprise several stations, but the exact number was said to be impossible to determine at present. It would not be realistic to contemplate setting up a licensing authority or to retain the highly trained staff needed both in the infrastructure and in the nuclear power plant itself if the country had one station only.

36. It would follow then, that a final governmental commitment to one nuclear power station would inevitably and eventually lead to New Zealand's having several stations. As Mr K. D. McCool stated under cross-examination, "Our programme in a sense is a preparation for a longer term involvement in a succession of nuclear power stations" (*Evidence* p. 83).

Problems Raised by the Proposal

37. The NZED founded its proposal to introduce nuclear power by 1990–91 on the forecast of electricity demand for that time. NZED forecasts were often criticised, for example, by Professor R. H. Court for the Environmental Defence Society (28) who would not agree that the NZED was forecasting at all but only formulating self-fulfilling plans, and by those who considered that too much reliance was placed on the extrapolation of previous exponential-type trends. Because electricity use depends on unquantifiable social and economic factors, no great precision can be expected in long-term forecasting. An accurate forecast of electricity demand for 1990 would need a perfect forecast of the nature of New Zealand society between 1977 and 1990.

38. Uncertainties in forecasting are introduced by: changes in population which depend on migration and fertility rate; changes in the economy and the future levels of economic activity; possible extent and effect of changes in electricity prices; the extent to which natural gas will replace electricity; the acceptance of the need for conservation, and the economics of conservation.

39. As it is not known how these factors will vary in the next 25 years, it is not surprising that estimates of electricity demand for the year 2000 vary widely. The FFGNP report (4) gives 12 graphs of the growth of electricity demand to the year 2001. The forecast figures for that year range from 19 444 GWh per annum to 124 000 GWh. From somewhere within this range a figure or sub-range of figures must be chosen as the present "best" estimate.

40. The NZED, after considering possible changes in domestic commercial, and industrial electricity demand, and allowing for economic growth continuing in the medium term, concluded "that for planning purposes it is prudent to allow for the possibility that 60–70 000 GWh of generation could be required in the year 2000 bearing in mind all the uncertainties inherent in the long term" (53). In arriving at this conclusion, the NZED studied three scenarios of future electricity use. These were not forecasts but models to illustrate the effects of different assumptions on levels of future electricity use.

41. Two basic scenarios, "Static" and "Normal Growth", were devised and assumptions made about growth of electricity use in the domestic, commercial, industrial, and large industrial sectors which included the forest-based and metal-smelting industries. In each scenario it was

assumed that: (a) the population growth was based on the low fertility and the 5000 annual net immigration projection of the Department of Statistics; and (b) that the growth of commercial and industrial consumption was calculated from a relation based on assumed growth in GDP. There was no certainty that the assumptions for each scenario were economically consistent. The "Static" scenario assumed no change in GDP per head, but a growth in population. The "Normal Growth" scenario assumed moderate growth in the economy with no large-scale technical innovation. ("Electrified Transport" scenario was the same as "Normal Growth" with electrification of part of transport energy needs added.) Projections of electricity use to the year 2000 for the three scenarios are shown in figure 6.1. The detailed figures and notes are given in appendix C.

42. The DSIR, in attempting to circumvent the uncertainties of long-term forecasting, used a different approach (46). It accepted the Power Plan estimate of demand for 1991–92 as the best available at present, and considered the energy resources that could be developed by the year 2000. This led to the conclusion that "resources could be found to supply an additional 4.5 GW of generating capacity between 1992 and 2000, giving a growth rate of about 4.25 percent per annum in that period". The DSIR stressed that it was not recommending any particular growth rate but "trying to assess the ability of indigenous energy resources to provide electricity to the end of this century without the introduction of nuclear power during that period".

43. In all the criticisms of NZED forecasts and forecasting procedures, there was no submission which demonstrated a feasible alternative. It was suggested by Peet and Williamson that the logistic curve fitted the historical data of electricity use better than the exponential curve (47). Although intuitively this curve gives a more sensible shape to extrapolated demand, there is no *a priori* reason why any particular mathematical function should fit the data and be used for long-term forecasting.

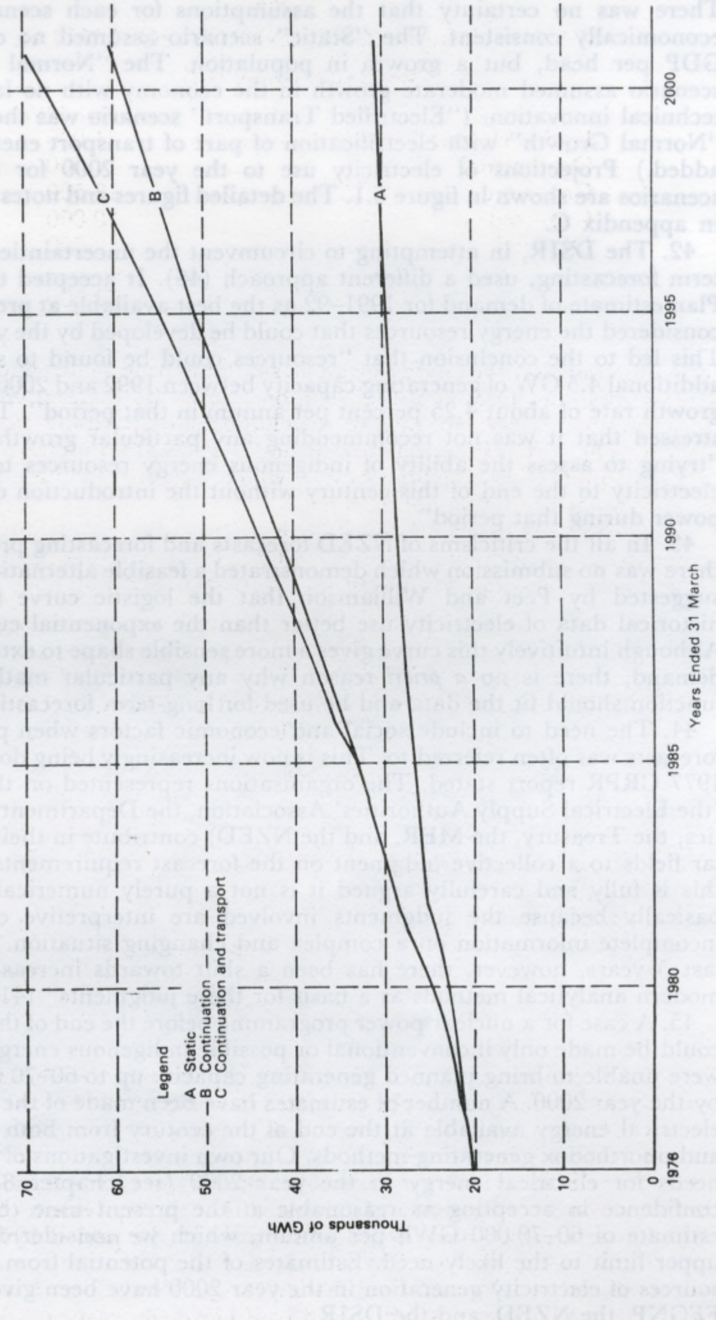
44. The need to include social and economic factors when producing forecasts was often referred to. This is now increasingly being done, as the 1977 CRPR report stated. The organisations represented on the CRPR (the Electrical Supply Authorities' Association, the Department of Statistics, the Treasury, the MER, and the NZED) contribute in their particular fields to a collective judgment on the forecast requirements. "While this is fully and carefully argued it is not a purely numerical process, basically because the judgments involved are interpretive ones with incomplete information on a complex and changing situation. Over the last 5 years, however, there has been a shift towards increased use of modern analytical methods as a basis for these judgments" (41).

45. A case for a nuclear power programme before the end of the century could be made only if conventional or possible indigenous energy sources were unable to bring planned generating capacity up to 60–70 000 GWh by the year 2000. A number of estimates have been made of the potential electrical energy available at the end of the century from both orthodox and unorthodox generating methods. Our own investigations of the likely needs for electrical energy in the year 2000 (see chapter 8) give us confidence in accepting as reasonable at the present time the NZED estimate of 60–70 000 GWh per annum, which we consider defines an upper limit to the likely need. Estimates of the potential from orthodox sources of electricity generation in the year 2000 have been given by the FFGNP, the NZED, and the DSIR.

Figure 6.1

PROJECTIONS OF ELECTRICITY USE TO THE YEAR 2001 (SCENARIO APPROACH)

(*Source:* NZED submission 128)



46. The FFGNP gave the following as the maximum annual energy potential:

Table 6.2

MAXIMUM ANNUAL ENERGY POTENTIAL

(*Source:* FFGNP Report, 1977)

	Annual GWh
Hydro-electric	34 000
Geothermal	11 000
Coal-fired	13 500
Gas-fired	10 000
Oil-fired	2 000
	70 500

It pointed out that the energy given as available from hydro and geothermal sources, and from coal-fired stations, could be realised only with a substantially accelerated rate of development of partially investigated sources. The FFGNP expected unorthodox generation methods to make small but increasing contributions on which a figure could not be placed because of lack of firm information.

47. The NZED listed the possible electrical energy contributions from various sources additional to the 48 460 GWh per annum shown in the 1976 Power Plan and excluding any from a nuclear station, as (53):

Table 6.3

ELECTRICAL ENERGY SOURCES ADDITIONAL TO 1976 POWER PLAN

(*Source:* NZED)

	GWh per annum
Coal-fired	6 000
Expanded hydro development	13 400
Small hydro	3 000–4 000
Expanded geothermal	7 000
Unorthodox sources	5 500
	34 900–35 900

The NZED concluded that, while full development of the above indigenous resources would enable the projected demand of 60–70 000 GWh per annum to be met, such development was unlikely because of environmental and feasibility restrictions.

48. The DSIR reviewed the resources that could be made available for electric power development and suggested that the equivalent of up to 4.5 GW of generating capacity could be supplied in the period 1992 to 2000 from the following (46): 2.5 GW additional hydro-electricity and geothermal combined; 1 GW coal-fired station in the North Island; and 1 GW coal-fired station in the South Island based on open-cast coal. In each of

these three estimates, a total potential of at least 60–70 000 GWh per annum of generation capacity is indicated for the year 2000. Thus these recent DSIR and NZED estimates confirm the findings of the FFGNP that there is the potential to provide 70 000 GWh per annum from conventional energy sources. However, as the report of the FFGNP pointed out:

> From an environmental viewpoint, however, this is hardly comforting since it means that the comparison is no longer between a nuclear programme and possible alternatives, but between a nuclear programme and total commitment of all alternatives. In terms of resource utilisation such a plan would close an alarming number of options for succeeding generations (4).

49. The NZED, with its recent experience of the effects of environmental restrictions on electricity generation is pessimistic about meeting a target of 60–70 000 GWh per annum by the end of the century. It argues that New Zealand must continue to consider nuclear energy along with imported coal, as options for electricity generation. Even if it were found that nuclear power was not needed before the year 2001, it may well be needed after that date. The present departmental view has been summarised thus:

> The NZED believes that it is necessary to continue with the groundwork that would permit a move to nuclear power in the event that it is required. It seems clear that effective preparation for a nuclear option will not be possible without a large measure of public acceptance that such a policy is in New Zealand's best interest (53).

Chapter 7. ELECTRICITY GENERATION IN NEW ZEALAND

INTRODUCTION

1. To appreciate the need or otherwise for nuclear power it is essential to have a clear understanding of the overall characteristics of the present and the likely future power system. In this chapter we summarise the present methods of production and discuss the extent to which indigenous resources may cope with future demand. In doing this we comment on various associated environmental aspects, though many of these are considered in greater detail in other chapters.

2. Electricity was first transmitted in New Zealand in 1885 when the Phoenix Quartz Mining Company built a small station near Skippers on the banks of the Shotover River, Central Otago. The electricity was used for lighting. However, it was not until 1888 that the first public electricity system was introduced by a private company at Reefton, Westland. For the next 27 years various local bodies and private companies undertook generation from both steam and small hydro plants.

3. The first State-owned power station was opened at Lake Coleridge, Canterbury, in 1915, and from then on the State assumed responsibility for electricity supply. At first the Public Works Department (now MWD) was responsible for design, construction, and operation. It was not until 1945 that a separate department called the State Hydro-Electric Department was established. By 1958 it was obvious that not all our electricity could be generated from hydro resources and the name was changed to the New Zealand Electricity Department. In 1968, along with certain amendments, the role of the NZED was consolidated in the Electricity Act. In essence the NZED was required to provide "an adequate economical supply of electricity and the promotion of measures for economy and efficiency in the use of electricity".

4. An amendment to the Electricity Act in 1976 gave the NZED a new duty:

> To undertake or promote measures to achieve greater economy and efficiency in the use of electricity as a means of reducing the future rate of growth of electricity requirements.

In 1977 the NZED stated that:

> The amendment more clearly defines the department's role in conservation activity, having the dual effect of influencing future growth patterns and reducing immediate expenditure on fuel involving, in the case of oil, a high cost in overseas funds (48).

5. Even more recently, it has been fully recognised that the supply of electricity cannot be considered in isolation. Thus in 1977 a new State department, the Ministry of Energy, was established to carry out the functions of the former NZED, the Mines Department, and the MER. The relevant divisions of the MWD, which in the past have been responsible for construction, will continue to give the appropriate support services.

Figure 7.1 (a)

NEW ZEALAND ELECTRICITY DEPARTMENT SYSTEM, 1978
(NORTH ISLAND)

(*Source:* NZED)

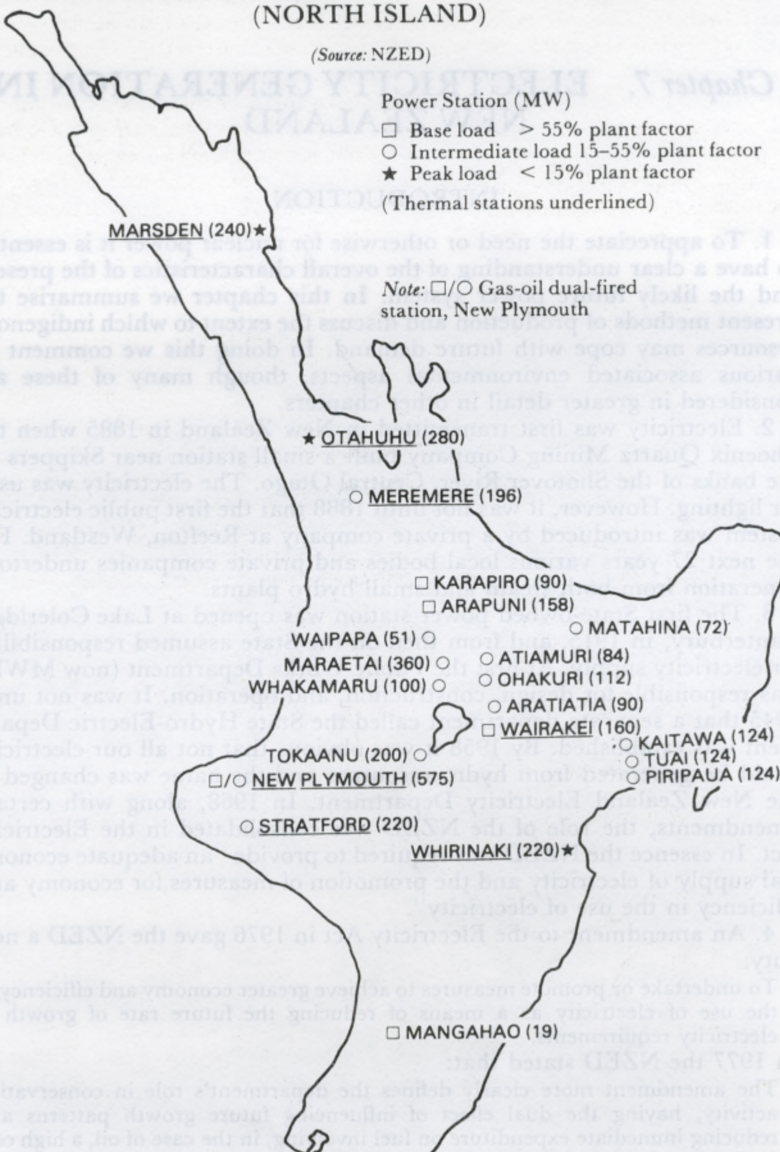
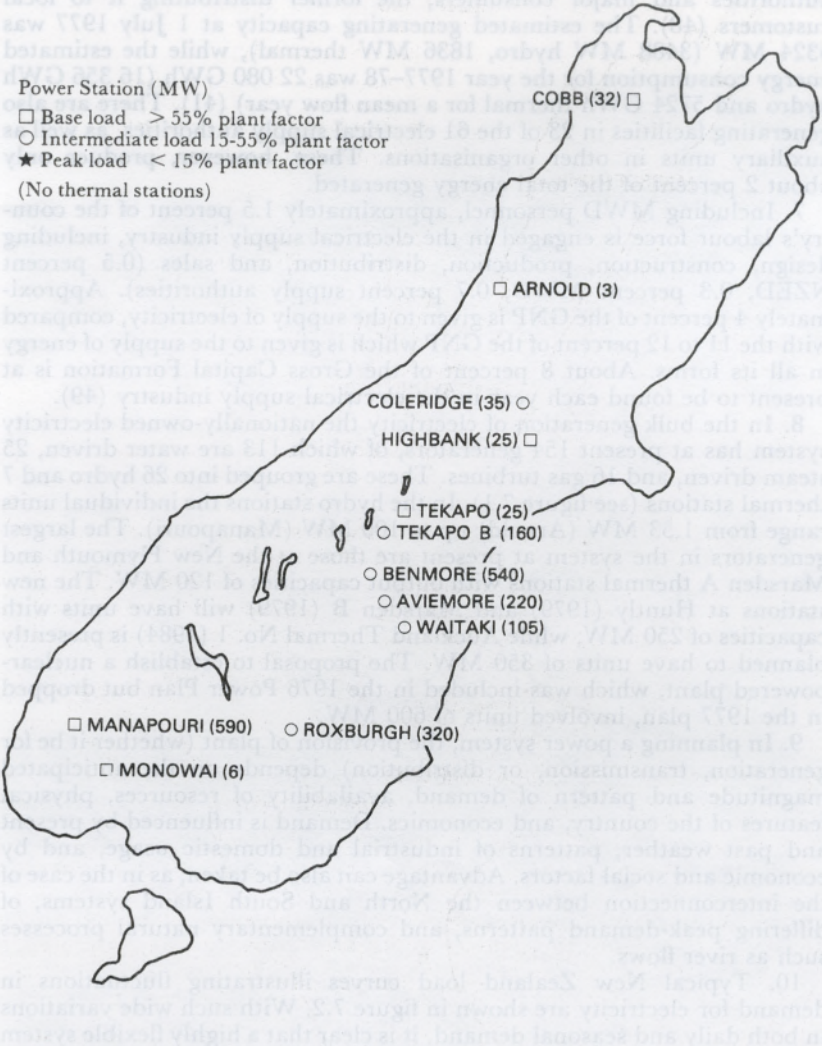


Figure 7. 1 (b)

NEW ZEALAND ELECTRICITY DEPARTMENT SYSTEM, 1978 (SOUTH ISLAND)

(Source: NZED)



THE PRESENT POWER SYSTEM

6. At present the NZED operates 33 stations (see figures 7.1 (a) and (b)). The energy generated is transmitted over a route of about 13 000 kilometres of extra-high-voltage transmission lines to the 61 supply authorities and major consumers, the former distributing it to local customers (48). The estimated generating capacity at 1 July 1977 was 5324 MW (3488 MW hydro, 1836 MW thermal), while the estimated energy consumption for the year 1977–78 was 22 080 GWh (16 356 GWh hydro and 5724 GWh thermal for a mean flow year) (41). There are also generating facilities in 23 of the 61 electrical supply authorities, as well as auxiliary units in other organisations. These, however, produce only about 2 percent of the total energy generated.

7. Including MWD personnel, approximately 1.5 percent of the country's labour force is engaged in the electrical supply industry, including design, construction, production, distribution, and sales (0.5 percent NZED, 0.3 percent MWD, 0.7 percent supply authorities). Approximately 4 percent of the GNP is given to the supply of electricity, compared with the 11 to 12 percent of the GNP which is given to the supply of energy in all its forms. About 8 percent of the Gross Capital Formation is at present to be found each year in the electrical supply industry (49).

8. In the bulk generation of electricity the nationally-owned electricity system has at present 154 generators, of which 113 are water driven, 25 steam driven, and 16 gas turbines. These are grouped into 26 hydro and 7 thermal stations (see figure 7.1). In the hydro stations the individual units range from 1.53 MW (Arnold) up to 100 MW (Manapouri). The largest generators in the system at present are those at the New Plymouth and Marsden A thermal stations with output capacities of 120 MW. The new stations at Huntly (1979) and Marsden B (1979) will have units with capacities of 250 MW, while Auckland Thermal No. 1 (1984) is presently planned to have units of 350 MW. The proposal to establish a nuclear-powered plant, which was included in the 1976 Power Plan but dropped in the 1977 plan, involved units of 600 MW.

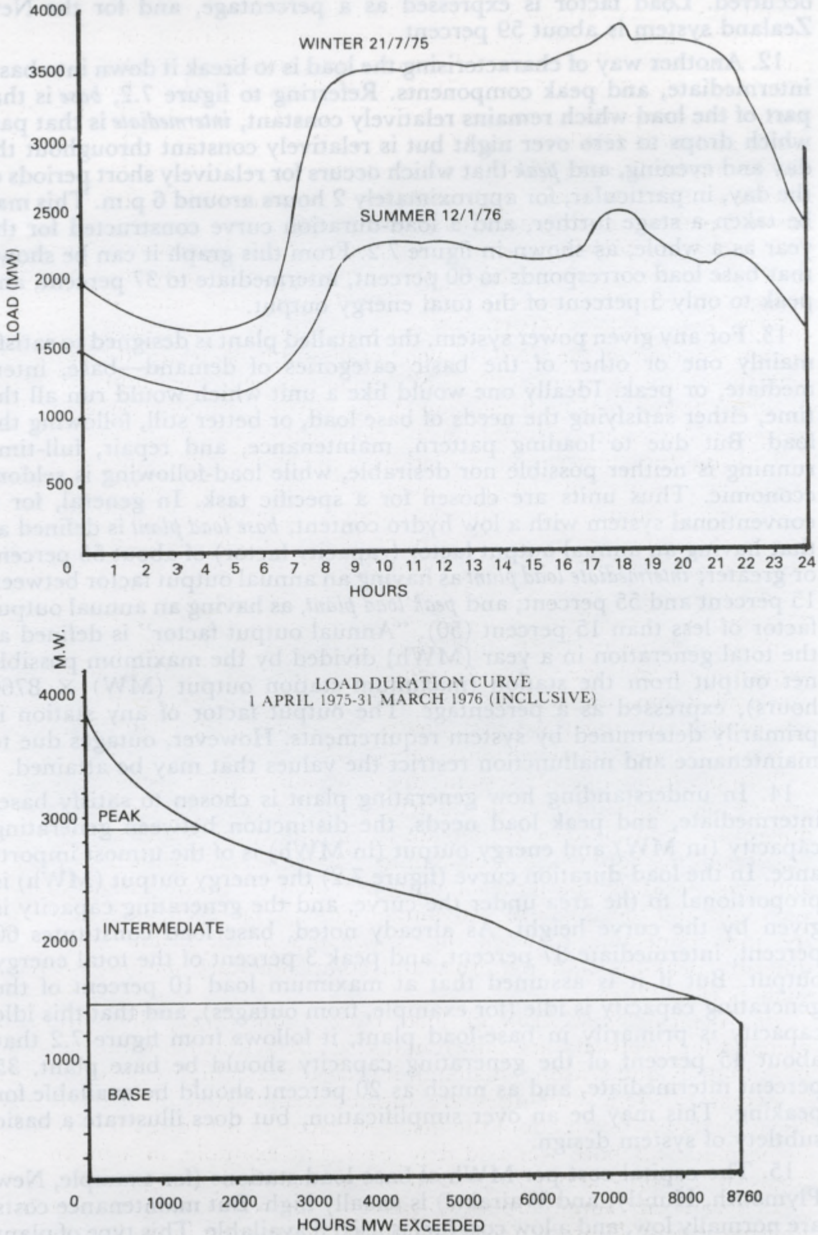
9. In planning a power system, the provision of plant (whether it be for generation, transmission, or distribution) depends on the anticipated magnitude and pattern of demand, availability of resources, physical features of the country, and economics. Demand is influenced by present and past weather, patterns of industrial and domestic usage, and by economic and social factors. Advantage can also be taken, as in the case of the interconnection between the North and South Island systems, of differing peak-demand patterns, and complementary natural processes such as river flows.

10. Typical New Zealand load curves illustrating fluctuations in demand for electricity are shown in figure 7.2. With such wide variations in both daily and seasonal demand, it is clear that a highly flexible system is necessary. The difficulties are further complicated by the fact that, because about 70 percent of the installed capacity is hydro, allowance has to be made for both wet and dry years. For example, in a mean year, hydro will supply about 75 percent of our electrical energy, but in a dry year it can only supply about 65 percent, the rest having to come from thermal plants. Thus the generating units chosen must be such as to give a flexible, reliable, and supportive system.

Figure 7.2

LOAD CURVES FOR TOTAL NEW ZEALAND SYSTEM

(*Source:* Wong and Hewlett (50))



11. The nature of the demand can be characterised by the concept of a "load factor". This is defined by the New Zealand power-planning authorities in discussing the annual load as the ratio of the average half-hourly load for the year to the maximum half-hourly demand that has occurred. Load factor is expressed as a percentage, and for the New Zealand system is about 59 percent.

12. Another way of characterising the load is to break it down into base, intermediate, and peak components. Referring to figure 7.2, *base* is that part of the load which remains relatively constant, *intermediate* is that part which drops to zero over night but is relatively constant throughout the day and evening, and *peak* that which occurs for relatively short periods of the day, in particular, for approximately 2 hours around 6 p.m. This may be taken a stage further, and a load-duration curve constructed for the year as a whole, as shown in figure 7.2. From this graph it can be shown that base load corresponds to 60 percent, intermediate to 37 percent, and peak to only 3 percent of the total energy output.

13. For any given power system, the installed plant is designed to satisfy mainly one or other of the basic categories of demand—base, intermediate, or peak. Ideally one would like a unit which would run all the time, either satisfying the needs of base load, or better still, following the load. But due to loading pattern, maintenance, and repair, full-time running is neither possible nor desirable, while load-following is seldom economic. Thus units are chosen for a specific task. In general, for a conventional system with a low hydro content, *base load plant* is defined as that having an annual output factor (capacity factor) of about 55 percent or greater; *intermediate load plant* as having an annual output factor between 15 percent and 55 percent; and *peak load plant*, as having an annual output factor of less than 15 percent (50). "Annual output factor" is defined as the total generation in a year (MWh) divided by the maximum possible net output from the station (maximum station output (MW) × 8760 hours), expressed as a percentage. The output factor of any station is primarily determined by system requirements. However, outages due to maintenance and malfunction restrict the values that may be attained.

14. In understanding how generating plant is chosen to satisfy base, intermediate, and peak load needs, the distinction between generating capacity (in MW) and energy output (in MWh) is of the utmost importance. In the load-duration curve (figure 7.2) the energy output (MWh) is proportional to the area under the curve, and the generating capacity is given by the curve height. As already noted, base load constitutes 60 percent, intermediate 37 percent, and peak 3 percent of the total energy output. But if it is assumed that at maximum load 10 percent of the generating capacity is idle (for example, from outages), and that this idle capacity is primarily in base-load plant, it follows from figure 7.2 that about 45 percent of the generating capacity should be base plant, 35 percent intermediate, and as much as 20 percent should be available for peaking. This may be an over simplification, but does illustrate a basic subtlety of system design.

15. The capital cost per MWh of base-load stations (for example, New Plymouth, Huntly, and Wairakei) is usually high. But maintenance costs are normally low, and a low cost fuel is used if available. This type of plant is relatively inflexible unless designed, at extra cost, to be capable of load cycling. The capital cost per unit of energy output is usually lower in intermediate plants, but maintenance and operational costs are normally

higher (for example, in Marsden and Meremere power stations). Peaking stations (for example, the gas turbine plants at Otahuhu, Stratford, and Whirinaki) have low capital costs, but also low efficiencies, high fuel costs, and possibly high operational and maintenance costs. In general, base-load plant should be designed to be capable of changing its function, and is relegated to intermediate load duty as it ages. Hydro stations may be designed to perform any of the basic functions. Because of this, the present New Zealand system differs somewhat from more conventional overseas systems in having some overlap in function design.

16. The New Zealand electricity system is fully interconnected, the 33 power stations feeding into a common transmission system with the two Islands linked by the 500 kV DC transmission system. Power is transmitted at 220 kV, 110 kV, 66 kV, and 50 kV through approximately 13 000 kilometres of transmission line route to about 130 substations, from which it is supplied by the electrical supply authorities to the consumer. The NZED, in selling to the supply authorities, sets rates for both maximum demand and total energy use, thus ensuring that optimal use is made of the generating capacity available. The supply authorities commonly use remote control of water-heating systems and space heating to smooth demand, and thus maximise the load factor.

17. The North Island and South Island power systems are supervised from control centres respectively at Whakamaru and Islington, the object being to optimise the use of water and fuel and to ensure effective transmission under normal and emergency conditions. Senior engineering staff at the NZED head office in Wellington co-ordinate this work and lay down policy guide-lines.

18. Changing patterns of consumption, due to either technological innovation or social change, could have marked effects on future growth and development. As already noted, the rate of growth in consumption is uncertain, two schedules, rather than one, being presented by the CRPR in their 1977 report. However, in planning, the PCEPD have based their recommended programme for development on the more rapid of the two, corresponding to an estimated generating capacity of 11 087 MW and a generating capability of 47 664 GWh per annum for the year 1991–92 (42). If this programme is fulfilled, the system will then consist of 38 hydro and 12 thermal stations (counting Marsden A and B separately). These will be supplemented by 112 MW from about 40 small auxiliary hydro plants. The greater dependence on thermal plant implicit in the plan is of considerable importance. Of the total 47 664 GWh generated in 1991–92, for a mean flow year, 21 976 would come from thermal plant. For a dry flow year this figure would be 25 830 GWh. It appears that little change in annual load factor is anticipated over the next 15 years, although the output factors for both existing and new plant, especially thermal, could change significantly from one year to the next.

19. Irrespective of the date when the present power plan is completed, whether this be 1991–92 or say 1993–94, the prime concern of our inquiry is with developments beyond that date. Our terms of reference relate to the introduction of nuclear power and are therefore orientated towards the introduction and type of further base-load plant. The NZED proposal for a nuclear power programme implied that on completion of the present plan, base-load plant should be added in steps of 600 MW with commissioning periods of about 2 years (50). This raises the inter-related questions—Is there an alternative to a nuclear power programme? and, To what extent can indigenous resources satisfy future needs?

INDIGENOUS ENERGY RESOURCES

20. The main indigenous energy resources which may be used to produce electricity are coal, natural gas, hydro, and geothermal. There are other possibilities, most of which, however, depend on as yet unproven technologies. These include: solar, wind, tidal, waves, biomass, and oil shale.

21. The rate of utilisation of any natural resource at a particular time may be limited by constraints other than the size of the resource. Society may decide that it will not accept the environmental consequences of exploitation. The public reaction to the optimal use of Lake Manapouri and certain features of the Clutha plan for hydro-generation are examples. The weight given to environmental objections can, of course, change with circumstances and with time. Again, the shortage of trained manpower may also limit the rate of exploitation. The Secretary of Mines pointed out (*Evidence* p. 154) that there is a world-wide shortage of trained and experienced underground coal-mining staff to take positions of responsibility within the next 10 years. New Zealand shares in the shortage, and thus a greatly increased use of indigenous coal for electricity generation, even if desirable, may not be practicable in the near future.

22. Other environmental factors such as the production of waste heat, or of oxides of sulphur, nitrogen, and even carbon, produced in the burning of fossil fuels, can all influence the social acceptability of a particular method of electricity generation. Problems of this nature may be sometimes alleviated by present or future technological innovation (such as the reticulation of hot water, the use of scrubbers, fluidised bed combustion, etc.). These aspects will be dealt with in other parts of our report. The magnitude of a resource only is discussed in this section.

23. As well as its absolute magnitude, efficiency of use of a resource must also be considered, in particular the matching of the resource to its end use. Relevant aspects are discussed in chapters 4 and 8. We summarise here several of the more important points. In fossil-fuelled conventional electricity plants, after allowing for transmission losses, only about 30 percent of the energy content of the fuel is usefully used at present. However, the direct use of the fuel does not always lead to an improvement. In the case of Kapuni gas, the net efficiency associated with the production and domestic use of electricity is about 27 percent, while for the direct use of the gas for similar purposes it is about 44 percent, an improvement of 63 percent. However, the present use of coal for space heating is only 18 percent efficient (see chapter 8).

24. The use of combined cycle plant with Maui gas to produce electricity will raise the overall efficiency from about 30 percent to 35 percent, while further technological developments in dual system operation could result in major changes by the beginning of the next century. Such developments could include improvements to the present type of combined cycle plant, the successful development of magneto-hydrodynamic (MHD) plant to a level that can be used in public utilities, and similar developments in the area of fluidised bed combustion. There is at present a joint United States - Soviet project on MHD, and the possibilities of fluidised bed combustion are being vigorously pursued in the United States. We were in fact told during our visit to the United States that fluidised bed plants of between 5 and 50 MW were already being used by private organisations for the co-generation of electricity and

heat. In this latter type of application, efficiencies of total fuel use of up to 85 percent may be achieved (see chapter 8).

25. By comparison, the present use of our hydro resources is already highly efficient. Not only does the turbo-generator convert well over 90 percent of the potential energy to electricity, but the utilisation of the associated water flows is also high, there being little by-passed down spillways. For example, in 1976–77, the overall utilisation in the North Island was over 99 percent and that in the South Island 97.4 percent (48).

Coal

26. No definitive figure can be given for New Zealand's coal reserves. The updating of reserve estimates is carried out from time to time, and this, together with new mining techniques, makes estimates of recoverable coal of temporary value only. Reserves are usually quoted in an international system of four categories of decreasing order of accuracy: "measured", "indicated", "inferred", and "speculative" (51). Accuracy limits of the last two are plus or minus 50 percent. A revised estimate by the MER in 1974 of coal resources in New Zealand, based on information obtained by the Mines Department and the DSIR, gave the recoverable reserves in the "measured", plus "indicated", plus "inferred" categories as 940 million tonnes (5).

27. The need for a greater knowledge of our coal reserves has been recognised by governmental approval for the Mines Department to step up exploration in the Waikato and in Southland. However, to prove the coals presently classified as "indicated" or "inferred" up to the "measured" category would entail many years' work, and an expenditure of about $40 million (5).

28. At present no attempts are made to include the social acceptability of mining operations in the estimates of recoverable reserves. It is interesting to note the suggestion of the Secretary of Mines for reserves in future to be multiplied by a factor (ranging from 0 for "unacceptable" to 1 for "acceptable") which would take account of social acceptability and give a more realistic figure (32). It is proposed to publish results for each coal deposit after approval of the social-acceptability factor by the Commission for the Environment. The estimates would show the amounts of coal "measured", "indicated", and "inferred" in the ground. They would also show how much could be technically and economically extracted and exploited, and the probability that the mining operation would be socially acceptable. The amount of coal that it is believed could actually become available would finally be given.

29. The efficiency of extraction also affects the estimation of reserves. In underground mining, efficiency ranges from 10 to 75 percent, though for opencast mining it may be 90 percent (*Evidence* p. 156). Changes in mining technology could increase estimates of coal reserves, just as changes in social acceptability of mining operations may alter estimates one way or the other.

30. When the New Zealand coal reserves are considered in the light of the needs of a large coal-fired power station, they are seen to be quite modest. A 1300 MW station in its 30 years of operation at an average 57 percent output factor needs about 100 million tonnes of coal. Therefore, nine only such stations would use all our coal reserves, both opencast and underground. Planning for a coal-fired station can be done only in terms of "measured" coal, and less than 25 percent of the resource is in this category.

31. Over and above the present commitments to new mines for the Huntly power station, the Mines Department cannot before 1990 open any new large underground mines for power generation supply. There are also limitations on the amounts available from opencast mines. The department could supply 1 to 2 million tonnes of opencast coal a year from 1987. This would require a new mine, north of Huntly, which would put about 1800 hectares of farm land out of production for 30 years and cause pits of about 300 metres deep which may not be environmentally acceptable (52).

32. The amount of coal that can be committed to electricity generation should be determined only when New Zealand's overall energy needs and resources have been considered. The matter cannot be settled in isolation. When coal is at present used for metallurgical purposes, and may in the future be needed as a replacement for liquid fuels as well as for the production of liquid fuels, it is clearly a valuable resource which should not be squandered.

33. The NZED places an upper limit of 3000 MW for the North Island for coal-fired generation of electricity for the year 2000 (53). The ultimate upper limit for coal generation has been placed considerably higher by the DSIR. The realisation of the DSIR estimate, however, depends on a number of constraints which include completion of a great deal of exploration, and the proving of reserves, as well as social and environmental problems. Subject to the successful solution of these problems, the coal reserves which might become available for thermal electricity generation are (46): Waikato coal, 2 GW; Waikato peat, 1–2 GW; and South Island coal, 2–3 GW. (The equivalent powers indicated correspond to plant running at 70 percent output factors.) These reserves are additional to those already committed by the existing power plan.

34. The use of imported coal to conserve our own very limited coal reserves was suggested to us several times. The NZED had done no serious study of the possibility (*Evidence* p. 141) but is now investigating imported coal which might meet its future needs (42).

35. The PCEPD reported in 1977 that:

> A 1200 MW power station would consume about 3 million tonnes [of coal] per annum and this would require major shipping facilities. The coal which has been investigated has an energy content slightly higher than that of New Zealand coal and has a relatively low sulphur content. On the information available, the generation cost per kWh from imported coal would be only marginally higher than from indigenous coal.
>
> Although imported coal would not bring the environmental disadvantages of using local coal, it would involve substantially increased overseas costs, most of which would be vulnerable to fuel price increases, and uncertainties concerning the reliability of fuel supply.

The Secretary of Mines also pointed out that ships of about 50 000 tonnes would be needed to transport the coal, together with a deep water port and transport to get the coal to the power station.

36. There are other New Zealand coal reserves on the West Coast of the South Island and an intermediate-type plant is planned for Buller at some time beyond the present power plan (42). However, though the Waikato and Southland coals have low sulphur content, much of the West Coast coal does not. Thus development of electricity generation could be limited there.

Natural Gas

37. Without the large assured market for natural gas in electricity generation, New Zealand's gas fields would not have been developed as they are now. Natural gas was discovered at Kapuni in 1959, and on the Maui field in 1969. The gas resource is estimated to be 490 PJ for Kapuni and 6370 PJ for Maui (54). One PJ yields 100 GWhe at 33 percent efficiency, and hence if all available gas reserves were given to electricity generation at the maximum calculated deliverability, 30 100 GWh per annum could be generated to the year 2000 (44). This is to be compared with the 1976–77 demand of 20 915 GWh per annum and the "forecast" 47 664 GWh per annum for 1991–92.

38. Under present plans the output is expected to increase up to 1989, and then to fall slowly, with a cut-off date in the year 2008. The extent to which natural gas is made available for electric power will depend on policy decisions relating to alternative uses. The direct use of natural gas in domestic or industrial markets utilises this important resource at a significantly higher efficiency than that achieved through conventional electricity generation. The use of combined cycle plant may modify this situation, perhaps even to the extent of making electricity generation preferable to the direct use of gas in domestic applications (see chapter 8).

39. The Natural Gas Corporation expressed the opinion that electricity generation from gas should be kept to the minimum compatible with the economics of an adequate market (55). The MER in its 1977 annual report said that, as a result of a 1976 interdepartmental study of gas allocation, the Minister of Energy Resources was to offer the Natural Gas Corporation specific annual quantities of Maui gas for a rolling period of 15 years. The report says:

> The quantities offered the Corporation increase from 13 percent of the gas the Crown contracted to purchase in 1978–79 to 20 percent in 1985–86 and even greater quantities in later years. This compares with an expected 10 percent that would be available for general use. The quantities are to be reviewed annually by the Minister in consultation with the Corporation and the New Zealand Electricity Department (18).

40. The increase in use of gas for other than electricity generation depends on the availability of capital and manpower, on technical developments, and on the economics of substitution. The use of gas in the domestic sector is inhibited at present by the high cost of gas appliances, and the limited extent of reticulation. The substitution of gas for electricity is dealt with at greater length in chapter 8.

41. As a petrochemical feedstock, natural gas would provide a wide range of materials both for import substitution and as a valuable source of export income. Transport fuels may be replaced by natural gas in various forms, but each of the many options must be evaluated in terms of an overall national energy policy.

42. The discovery of further gas fields in the New Zealand area would have great economic benefits. The DSIR, on geological grounds, considers (44) that there is a reasonable probability of discovering by the year 2000–01 further resources equivalent to 2.5 times the known reserves in the Maui and Kapuni fields.

Hydro

43. The expected hydro energy (mean year) generation for 1977–78 is 16 356 GWh, out of a prospective total electric energy generation of 22 075 GWh. These figures include the New Zealand Aluminium Smelters' requirement.

44. There are a number of undeveloped hydro sources in both the North and South Islands. The MER estimates that as well as the schemes given in the 1976 Power Plan, an additional 4000 GWh per annum from the North Island and about 15 000 GWh per annum from the South Island are possible (5). This takes no account of small hydro schemes of less than 50 MW for which there has been no systematic review. These could probably generate a further 3000 GWh per annum.

45. There are many constraints on the realisation of this hydro potential, the main ones being: the completion of engineering investigations; the solution of soft rock and seismic problems at a number of sites; and, the evaluation of the social, safety, environmental, and economic aspects of each site.

46. Within the North Island, the prospective schemes will be the last major ones to be developed. In the South Island, the Clutha, Waitaki, and Rakaia schemes involve multi-purpose plans for water use which could affect the amount of water available for power generation. The high bedloads of shingle in West Coast rivers also pose engineering difficulties.

47. Added to these are the constraints imposed by the social acceptability of individual schemes. These constraints are usually based on environmental grounds. If any scheme had to be abandoned or restricted in size for environmental reasons, there would be a corresponding reduction in the energy available, and this energy could not necessarily be replaced by alternative schemes.

48. The MWD submitted to us a programme for the development of hydro and geothermal resources up to the year 2000 which it considered to be feasible only if the assumed resources of manpower, time, and finance could be made available (56). This programme, along with possible accelerated geothermal development, is given in table 7.1, the relevant submission having already been presented as an appendix to the 1977 CRPR and PCEPD reports. The hydro programme would produce 4000 GWh per annum from the North Island and 9400 GWh per annum from the South Island. The figures are not precise since in no component of the programme is investigation of site complete, and in many cases little has been done beyond reconnaissance. It was noted that, as North Island hydro has very little storage capability, alternative sources of energy have to be available to meet dry seasons. South Island hydro could meet North Island needs only with additional transmission across Cook Strait.

49. The possible advantages of small hydro schemes, which are not included in the MWD's suggested programme of hydro development, were mentioned to us several times, especially by Professor J. T. Salmon, who pointed out that there were 108 rivers in New Zealand with some potential (30). The NZED has been reluctant in the past to become involved in small hydro schemes, doubtless because financial and manpower resources were fully committed to major hydro development. However, though the potential of small hydro is not great in terms of total electricity needs, proposals to assist supply authorities with investigations and construction are being discussed with the Government (53).

Table 7.1

POSSIBLE PROGRAMME FOR FURTHER HYDRO AND GEOTHERMAL DEVELOPMENT TO THE YEAR 2000 AD

Note: Stations listed in appendix V of the 1976 Power Planning Report are not included.

(*Source:* MWD Submission 104)

	Annual Energy Production (GWh/year) At 2000 AD	Potential Additions Beyond 2000 AD
North Island Hydro—		
Kaituna	270	—
Mohaka	1 000	—
Wanganui	1 600	—
Rangitikei	700	200
Other	430	600
Sub-total	4 000	
South Island Hydro—		
Upper Clutha II	2 190	—
Lower Clutha	610	1 670
Lower Waitaki	3 600	400
Buller	3 000	1 000
Sub-total	9 400	
Geothermal (North Island)—		
Seven stations completed	7 000	5 600
Total	20 400	

Geothermal

50. The Wairakei geothermal station has proved to be one of New Zealand's most reliable electricity generating plants. It has been in service 85 percent of the time to generate 80 percent of the energy that could be generated if it were run at maximum rating. Wairakei first fed electricity into the grid in 1958 and was completed in 1964 operating at 150 MW. Since then, it has generated 16 percent of the electric power produced in the North Island. A 150 MW geothermal station at Broadlands is in the power plan, scheduled for commissioning in 1983–84.

51. The efficiency of a geothermal station is only about 10 percent. Ideally, a geothermal plant should be used to produce hot water for industry as well as electricity. This is done to some extent at the Tasman Pulp and Paper plant at Kawerau, and hot water is used for lucerne drying at Broadlands. The distances of the bores from possible industrial users hinder an extension of the scheme.

52. The DSIR estimates that, in addition to the present Wairakei and proposed Broadland stations, there is 1390–2160 MW available from other known geothermal sources in 13 places. It considers that, subject to

technical studies being completed, certain environmental and safety questions being solved, and a more aggressive investigation programme, it would be possible to produce from 0.5 to 1 GW by 1991. An extra 2 GW could also be produced, part in 1991–2000 from known sources, and the remainder after 2000 from various future developments (46).

53. The major environmental problem raised by the use of geothermal steam has been associated with arsenic and other toxic constituents in the waste hot water. Experiments have been carried out at Broadlands both on the removal of these substances and the reinjection of the waste water back into the ground. Successful experiments together with other studies suggest that the problem is solved (57). However, we believe that there is need for an early practical demonstration on site of the adequate disposal of waste geothermal waters.

54. The DSIR considered that geothermal generation could have made a greater contribution to New Zealand's power requirements than it has done. It was critical of the NZED for not pursuing this option more vigorously. The NZED argued that the PCEPD would not consider geothermal as an option until wells had been drilled and the field measured (*Evidence* p. 87). There does not appear to have been NZED pressure for increased exploration and proving of new fields.

55. The MWD view of the geothermal potential that can be realised by the year 2000 is somewhat more conservative than that of the DSIR. It considers that seven stations producing 7000 GWh per annum would be a realistic estimate of what can be done (42). Much of the DSIR estimate is made up of contributions from sources which are still in the "indicated" and "inferred" categories rather than "measured".

Unorthodox Sources of Electricity Generation

56. Besides energy sources which are at present being used for producing electricity, there are a number of other indigenous resources which in principle could also be used. Economics or technological factors may make exploitation on a large scale not viable. It is conceivable, however, that in the not too distant future, electricity could be produced in New Zealand from solar radiation, wind, waves, urban wastes, and plant material. The FFGNP discusses these and concludes:

> Some of these sources have very considerable power potential. However, no firm evidence has been produced that they will be harnessed to a sufficient extent by the end of this century to permit them to be classed as viable alternatives to nuclear power station generation (4).

57. The DSIR considered that wind, solar energy, and urban wastes may contribute to New Zealand's electric power generation either directly, or indirectly through substitution. Although likely to be valuable the contribution is not expected to be large—an estimated 0.5 GW by the end of the century. Nothing is expected from waves unless developments overseas show the way. Electricity generation from burning plant material is estimated as less than 0.5 GW (46).

58. Because these unorthodox energy sources were mentioned to us on many occasions, we shall discuss briefly their extent where it is known. Other aspects of the use of these resources are treated elsewhere in our report.

Solar Energy

59. The sun's energy is unlimited, but there are two distinct disadvantages to its use: the energy is diffuse, and it is intermittent needing some form of storage.

60. The maximum intensity of solar radiation received at the surface of the earth is about 1 kWm^{-2}. But in New Zealand, even for a surface having the optimum tilt and orientation, only 170 Wm^{-2} would be received as a daily average. For a 10 percent conversion of this energy to electricity, which is a probable value, it follows that large areas would be needed for the direct conversion by photovoltaic methods. Nevertheless, there is considerable interest in this possibility in the United States, although present indications are that capital costs could be high, and that there is unlikely to be any significant contribution to electrical energy requirements before the end of the century.

61. The direct use of solar energy to run conventional steam cycles is also being considered in several areas in the United States, and deserves watching. It is questionable whether New Zealand has either the appropriate land areas or insolation necessary to ever make such applications viable.

62. Solar energy would most likely be applied in New Zealand to water heating and space heating. Since these come under the heading of conservation techniques, they will be discussed in the next chapter.

Wind Power

63. From an analysis of the wind records of the Meteorological Service, Dr N. J. Cherry has estimated that the potential installed capacity for wind-power generation in New Zealand is in excess of 20 000 MW (58, 59). Sites with a high average wind speed include the west coast of the North Island, Cook Strait, Foveaux Strait, the Otago-Southland coast, Banks Peninsula, Rakaia Gorge, and coastal areas that are elevated and exposed to winds from the west or south.

64. The natural variability of wind complicates the use of wind power. Although there have been proposals to connect wind generators into the national grid (59), most schemes entail a complementary system with storage. It seems feasible to use hydro-electric storage lakes for this purpose.

65. Utilising the potential for wind-power generation means solving technological problems of windmill design, and of systems analysis to integrate such a scheme into the NZED network. The economics of wind-power generation and its integration would need to be investigated more exhaustively than they have been so far. Environmental considerations are by no means negligible. It has been pointed out that the generation of 5 percent of New Zealand's energy needs for the year 2000 would require 350 × 2 MW wind generators operating at 55 percent plant factor (42). Each generator would have a tower height of 55 metres and a rotor diameter of 80 metres.

66. Although windmill development would be an imported technology, local research and development is appropriate in some areas. The NZERDC has funded two major projects on wind energy: one to measure and analyse wind conditions at a number of sites, and the other to investigate the integration of wind-power generation into the supply system.

Wave Power

67. There is a considerable amount of interest and activity overseas in the development of wave energy systems, especially in Britain where a number of the approaches were noted by members of the Royal Commission. Averaged over a year, there are about 80 kW of power in each metre of wave front approaching Britain from the Atlantic. The total power available is close to 120 GW and it is believed that a very large fraction of this could be converted to electricity. There are, however, large variations (by a factor of 10 or more) in the wave-front energy due to storms, seasonal changes, etc. Because of this, some kind of storage system is necessary, and the conversion structures must be steel-stressed. Also, it has been estimated that in Britain the cost of electricity from wave power could be five times or more than that from nuclear sources (60).

68. The properties and magnitude of wave power on New Zealand coasts is being investigated at present. The NZED is supporting a programme of wave measurement to assess the potential (42). By comparison, the small tidal range in this country is not considered to be adequate for electricity production.

Biomass

69. Wood or woodwaste has been suggested as a renewable resource that could be used for the generation of electricity. Troughton and Cave give 19.66 GJ per tonne as the energy content of dry radiata pine, and quote the annual dry matter production at 15 tonnes per hectare (61). If a 1200 MW thermal power station operated at 70 percent output factor and 35 percent thermal efficiency, a pine forest of 260 000 hectares would be needed to supply the wood fuel (3). This corresponds to about 2 percent of New Zealand's arable land.

70. Forestry need not compete with agricultural land. However, according to the NZED, 40 percent of the present forest area and 10 percent of the land area thought suitable for forestry development (at the 1974 Forestry Conference) would be needed to fuel a 1000 MW station (53). With the present high value placed on sawn logs, and on the pulp and paper industry, direct competition for forest products from the electricity industry may not be in the national interest.

71. Combined timber milling and energy farming may be possible in some areas. There are also areas set aside for forestry which are not ideally suitable for exploitation by the pulp and paper industry. Based on scheduled planting rates until 1980, Northland, Gisborne, and Canterbury could support a total generation of 1800 GWh by the year 2000; ultimate capacity could be from 5000 to 7000 GWh.

72. Both the economics and social acceptability of growing timber for fuel in electricity generation present problems, the former being discussed later in this chapter.

73. The most serious energy problem that New Zealand will have to face towards the end of the century is the provision of a substitute liquid fuel for transport. Present technology can produce methanol and ethanol from biomass. Whether it will be appropriate to use large areas to produce fuel for electricity generation rather than liquid fuel for transport is a question that must be faced.

FUTURE DEVELOPMENT

74. Table 7.2 summarises the basic characteristics of the fully completed 1977 Power Plan (42, 38).

Table: 7.2

THE COMPLETED 1977 POWER PLAN

(Source: PCEPD Reports 1976, 1977)

Station	Fuel	Generating Capacity in MW	
North Island—			
Meremere	coal	196	
Huntly	gas/coal	960	
Auckland No. 1	gas	1 340	
Auckland No. 2	gas/coal	1 005	
New Plymouth	gas/oil	575	
Wairakei	geothermal	160	
Broadlands	geothermal	150	
Marsden A	heavy oil	240	
Marsden B	heavy oil	240	
Gas turbines, Otahuhu	light oil	280	
Gas turbines, Whirinaki	light oil	220	
Gas turbines, Stratford	gas	220	
			5 586
Hydro			2 331
South Island—			
Hydro			3 505
Total			11 422
Possible Generating Capability GWh			49 000

75. The main points to note are the predominance of the thermal plant in the North Island, and its absence in the South. However, as already noted, a 240 MW intermediate coal-fired plant is being planned for Buller. The individual generating capabilities have not been indicated since these could depend on weather patterns and changes in demand characteristics. However, from the PCEPD 1976 report it is apparent that, for the anticipated load pattern, a system of this nature is capable of producing about 49 000 GWh a year.

76. Both Auckland No. 1 and No. 2 are scheduled as base-load stations, and Huntly is scheduled as an intermediate-load station, although it could also be used for base-load operation if need be. If present intentions are followed, no further gas (or oil) base-load plants will be built beyond the completion of this plan, although it is conceivable that additional plant for either peak or intermediate application could use these fuels.

77. It is notable that, apart from the use of relatively small amounts of oil, this system relies entirely on the use of indigenous resources. For developments beyond this plan, possible contributions from the further use of such resources are summarised in table 7.3 which is taken from a NZED submission (53) with the addition of the South Island coal which was considered to be also possible by the DSIR (46).

Table 7.3

POSSIBLE ELECTRICAL ENERGY CONTRIBUTIONS IN THE YEAR 2000 FROM VARIOUS SOURCES;
(additional to those shown in table 7.2)

(*Source:* NZED submission 128 amended and modified)

Note: By way of comparison the 1200 MWe nuclear station shown in the 1976 Power Plan is expected to produce 7400 GWh per year when it is fully commissioned.

Energy Source or Generation Technique.	Annual Energy Contribution in GWh	Comment on Limitations on Development, Enviromental Impact, ect.
Coal—		
North Island	6 000	Commitment of coal for stations beyond those already in plan in doubt.
South Island	6 000	
Expanded Hydro Development ...	13 400	Increased allocation of resources to hydro development required. Lack of public acceptance may inhibit some of the proposed schemes.
Small Hydro	3 000—4 000	Full development would probably requre more than 50 small hydro stations.
Expanded Geothermal ...	7 000	A number of schemes each requiring enviromental clearance. Proof of enviromental solutions not finalı Possible land subsidence/conflict with tourist industry.
Wind	Possibly 3 400	Technical feasibility and economics yet to be demonstrated.
Energy Farming	1 800	Large land areas involved need to be fully investigated.
Refuse	350 (in Auckland)	Overall potential not great.

78. The table shows a total of about 41 to 42 000 GWh per annum, which means that by the year 2000, 90 000 GWh per annum could conceivably be generated from indigenous sources. This is considerably more than the 60 to 70 000 GWh which the NZED has stated it would be prudent to plan for. However, from the point of view of planning a power system (for reasons given in the preceding section and summarised in table 7.3) the sources listed in table 7.3 can, for the moment, be regarded only as speculative. Again, there are economic factors and load matching to be taken into account.

79. The MWD has stated that the capital costs for the development of the hydro and geothermal sources shown in table 7.1 (up to 2000 only) are \$940 per kW and \$620 per kW respectively at 1976 values (56). The comparable cost for nuclear power is \$770 per kW, interest and decommissioning costs being ignored in all cases (62). On taking into account all costs, the NZED has stated that the new geothermal would cost 1.6 cents per kWh, and the new hydro 2.5 cents per kWh (53). The costing refers to base-load type operation, and for comparison the NZED gives 1.9 cents per kWh for coal, 2.9 cents per kWh for nuclear, and 3.1 cents per kWh for oil (62). In a letter to the Royal Commission in reply to some of Treasury's criticism, the NZED stated that capital costs for the individual schemes in the MWD hydro programme cover the range 1.87 to 3.12 cents per kWh. The approved small hydro schemes are expected to cost about the same as that for the new major State schemes, but it is believed that further developments of small hydro could be more expensive (53). In the absence of storage, wind (if technically feasible) could be competitive with nuclear (53), but wood-fired power stations could be relatively expensive, in the range 4 to 5 cents per kWh. This, presumably, is associated with the fact that, due to furnace design, a small unit size of 60 MW is dictated at present (53). On the other hand, more recent studies have shown that, even with reinjection of waste water, the Broadland's geothermal costs could be less than the 1.6 cents per kWh given by the NZED, being in fact nearer 1.4 cents per kWh (57). It follows that, apart from the use of wood and perhaps small hydro, direct economic factors are not in themselves an impediment to the further use of indigenous resources. In fact the further use of hydro, geothermal, and coal is to be preferred to the use of imported nuclear or oil fuels. A discussion on the economics of nuclear, coal, and oil plants is given in chapter 14.

Load Matching

80. The problem of load matching is a highly technical subject. Not only must the consumption pattern be taken into account, but among other factors a merit order of operation and minimum plant factors must be assigned to the individual elements of the system. There are, however, a number of general comments that can be made. The completed existing power plan will presumably match the then existing load. Assuming that a further 21 000 GWh is needed for the year 2000, corresponding to the upper limit of 70 000 GWh suggested by the NZED, one reaches the requirement of about a further 14 000 GWh for the North Island and about a further 7000 GWh for the South, if, as assumed, present geographic patterns of consumption persist. From tables 7.3 and 7.1 we have for the North Island: geothermal, 7000; coal, 6000; major hydro, 4000. Thus, with the development of these resources alone, the North Island needs could be met. Furthermore, assuming that base plant must supply 60 percent of the load, this could be covered by geothermal, and by "fine

tuning" of the system. Similarly, in the South Island with 9400 GWh of major hydro and 6000 GWh of coal, there appears to be no major problem. In the absence of the coal, however, there could be difficulties, although these could be alleviated by a second Cook Strait cable costing \$160 million for a capacity of 1200 MW (53), and the development of small hydro. If the accelerated hydro and geothermal programme put forward by the MWD is vigorously pursued (which incidentally could lead to over-capacity in earlier years), and if there is a significant but by no means full exploitation of the remaining Waikato coal fields, it would seem to be possible to provide the 70 000 GWh for the year 2000 which would match our needs. This assumes no great environmental objections, and that the necessary resources of manpower and finance will be made available (see chapter 15). The South Island base-load requirements would still have to be met by hydro. Whether there is any great objection to this is uncertain, but it has been stated by Wong and Hewlett:

> The aim now is to build future hydro stations wherever possible for low load factor operation to complement the base load operation of future large thermal stations which cannot perform the load cycling role as easily as hydro (50).

81. Whether or not this statement is relevant to the South Island power system, it is of considerable importance to the aims of our Royal Commission. Taken at its face value, it implies that future hydro plant is not to be used for base-load purposes, and is not therefore an alternative to nuclear. We accept this, believing that the appropriate alternatives are either geothermal or coal with the former being preferred for reasons already given. We note with interest that accelerated programmes for both geothermal investigation and coal exploration were included in the 1977 Budget.

Beyond 2001

82. Developments beyond the year 2001 are uncertain. Tables 7.1 and 7.3 show that there would still be about 25 000 GWh a year left, over and above the 70 000 assumed for the year 2000. It is, of course, doubtful whether wood will ever be regarded as a suitable fuel, and the use of wind has still to be proved. Further, stations like Auckland No. 1 and Huntly would have to be replaced as base-load plant by about 2010, and Auckland No. 2 not long after.

83. The DSIR has considered a number of possibilities including other major hydro schemes, the full development of the Otago-Southland coal fields, developments in geothermal technology, and possible future petroleum discoveries (46). Major developments in solar energy and wave power are also possible. Again, a slower growth in the use of electricity in this century could lead to consumption rates of less than 70 000 GWh a year by 2000 leaving known reserves to be carried into the next century. On the other hand, economic, environmental, and social factors could restrict the further use of indigenous resources. Taking everything into account, we are forced to agree with the following two statements made by the NZED that: "Even if nuclear power is not essential before the year 2000 it may well be required beyond that date" (53); and that:

> There is as yet no clear indication that by utilising indigenous energy supplies New Zealand can become self sufficient in energy without excessive economic and environmental cost. Until this is the case nuclear power must be considered as a possible option for the future, and investigations into its utilisation must continue at a level commensurate with its potential importance (63).

Chapter 8. ELECTRICITY CONSUMPTION IN NEW ZEALAND

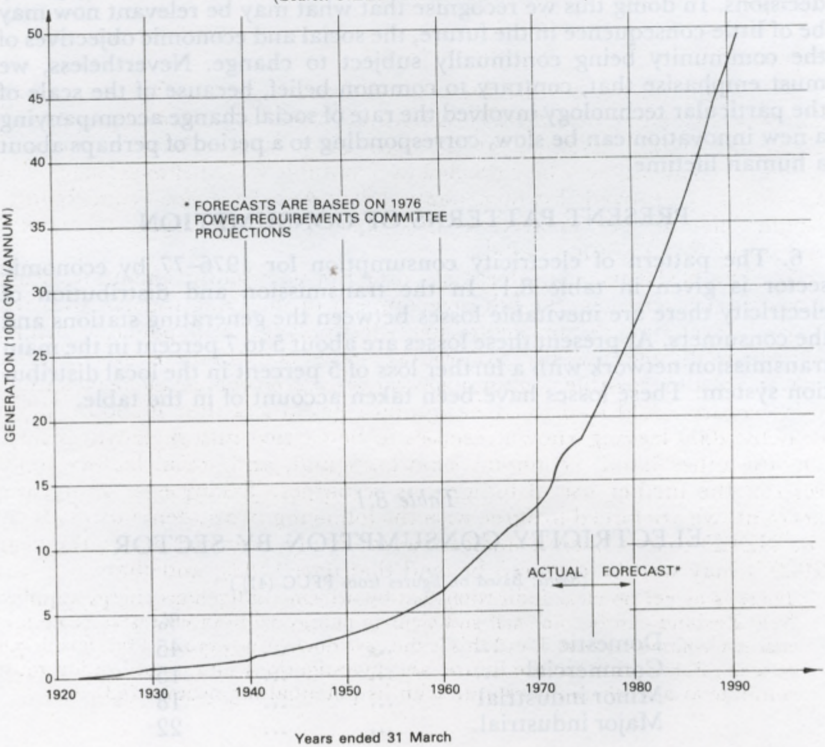
INTRODUCTION

1. Since the commercial acceptance of electricity as an energy source at the beginning of this century there has been an extremely rapid increase in its consumption. From the 1930s to the present day the growth in demand for electricity has doubled about once every 10 years (see figure 8.1). Departures from this rate of growth have occurred but these have produced little more than an oscillation about the basic 10-year doubling time.

Figure 8.1

NEW ZEALAND ELECTRICITY GENERATION 1920–1991

(*Source:* NZED submission to FFGNP)



2. Public awareness of this pattern of exponential growth has come only with the realisation of an impending oil shortage, the necessity for generation by means which, it is feared, might irrevocably affect the environment, and the alleged inevitability of nuclear generation with all its peculiar ethical and social problems.

3. Although an ever accelerating increase in growth is unlikely to continue indefinitely, we do not know when there will be a flattening in the growth curve. It is generally accepted that our present pattern of electricity consumption will eventually turn out to be part of a logistic or "S-shaped" curve rather than a simple exponential. However, we can say little about the ultimate shape of this curve which will be determined by population and industrial growths, social and economic standards, and the possible substitution of some other energy source for electricity.

4. Presumably because it has been clean, convenient, cheap, and relatively safe, electricity has largely displaced its competitors (oil, gas, coal, and wood) from the lighting, cooking, and water heating markets, and is now making major inroads into the space heating field. Within industry it has become the major supplier of mechanical power. However, the electronics field including communications and computers is the only market for which electricity cannot be replaced by some other energy source.

5. In this chapter, with these points in mind, besides discussing the general pattern of consumption, we speculate on the ultimate size and nature of the market for electricity. In this way we arrive at a measure of the adequacy of the various estimates already made for future needs, and test the hypothesis that future growth patterns can be controlled by policy decisions. In doing this we recognise that what may be relevant now may be of little consequence in the future, the social and economic objectives of the community being continually subject to change. Nevertheless, we must emphasise that, contrary to common belief, because of the scale of the particular technology involved the rate of social change accompanying a new innovation can be slow, corresponding to a period of perhaps about a human lifetime.

PRESENT PATTERNS OF CONSUMPTION

6. The pattern of electricity consumption for 1976–77 by economic sector is given in table 8.1. In the transmission and distribution of electricity there are inevitable losses between the generating stations and the consumers. At present these losses are about 5 to 7 percent in the main transmission network with a further loss of 5 percent in the local distribution system. These losses have been taken account of in the table.

Table 8.1

ELECTRICITY CONSUMPTION BY SECTOR

(Source: Based on figures from PFUC (41))

	%
Domestic	45
Commercial	15
Minor industrial	18
Major industrial	22

7. "Commercial" includes public services such as hospitals, universities, etc.; "major industrial", the forest-based, and metal-smelting industries; "industrial", manufacturing, mining, food processing, farming, and construction. (Food processing accounts for about 5 percent and farming about 2 percent of the total electricity consumed.) It is also interesting to note that public lighting accounts for only 0.6 percent and traction about 0.3 percent of the total (53). Much of the electricity used in public transport (for trolley buses, etc.) is produced by the local authority concerned and is not accounted for in the table. The quantities involved, however, are believed to be relatively small (*Evidence* p. 2255).

8. The most rapidly growing sector over the past 10 years has been the major industrial, the growth being about 21 percent in 1976–77 (41). In fact, as pointed out by the Friends of the Earth (64), from 1969 to 1976 the major industries were responsible for 42 percent of the increment in consumption. However, the PFUC does not anticipate any significant change in this sector's percentage share of the total over the next 5 years (41), while the scenarios of the NZED, referred to in chapter 6, actually imply a relatively large decrease by the year 2001 (65).

9. In the domestic sector the average consumption for each household is about 8000 kWh with close to 90 percent of all households being equipped for both electric cooking and water heating. On the other hand, only about one-third of all houses are heated solely by electricity, corresponding to half the existing homes in the North Island and 20 percent in the South. The typical electricity consumption for an average all-electric home in the middle region of New Zealand is summarised in the following table (53):

Table 8.2

TYPICAL ELECTRICITY CONSUMPTION FOR AN AVERAGE ALL-ELECTRIC HOME
(Middle region of New Zealand)

(*Source:* NZED submission 128—Summary of table 2)

	kWh per annum	%
Water heating	4 000	39
Space heating	2 000	19
Cooking	1 200	12
Lighting	700	7
Appliances	2 400	23
Total	10 300	

Although the energy consumption in space heating given in the above table is not one of the highest items, it could conceivably become the highest, possibly up to 10 000 kWh per annum, if widespread whole-house resistance heating became popular (see paragraphs 20 ff).

10. Overall, on a national basis, about 60 percent of domestic electricity is used at present for low-grade heat (in the ratio of about 3 for hot water and 1 for space heating), and about 12 percent for high-grade heat, that is for cooking (33). The ratios are probably similar for commercial buildings although, with this sector also including public services such as hospitals, etc., the percentage used for low-grade heat could perhaps be nearer 50 than 60 percent.

Table 8.3

HEAT USE IN INDUSTRY
(GWh per year)

(*Source:* NZED submission 128)

Note: That the total electricity use for all purposes in the South Auckland area for the industries surveyed was 450 GWh, and that in the Hutt area was 50 GWh.

	Heat at Temperature					
	Up to 90°C	Up to 120°C	Up to 150°C	Up to 180°C	Up to 240°C	Up to 240°C and above
South Auckland (Penrose, Otahuhu, Panmure, Mt. Wellington, Wiri)						
Total heat demand	126	244	345	429	746	1049
Heat supplied by electricity	22	23	23	23	23	98
Lower Hutt (Gracefield)						
Total heat demand	70	111	134	231	231	256
Heat supplied by electricity	0.9	1.0	1.1	1.1	1.1	7.7

11. Table 8.3, based on recent surveys of the industrial sectors, implies that only 5 percent of electricity consumption of those sectors goes into low-grade heat (that is less than 120ºC) and about 16 percent into high-grade heat (greater than 240ºC). The lack of an intermediate category suggests that the use of electricity for high-grade heat is probably "non-substitutable". It is also interesting to note that the total process heat used in industries of the type surveyed corresponds to over twice their total electricity consumption. Whether these observations are true for all industry is uncertain, but the survey included freezing works, pulp and paper manufacture, sawmilling, textile manufacture, glass and steel manufacture, chemical works, and food and beverage processing (53).

12. Using these considerations, and table 8.1, we have estimated in table 8.4 the pattern of electricity consumption in terms of end-use rather than of economic sector. Our estimate assumes that the pattern of consumption in the commercial sector is the same as that in the domestic sector and that the use of electricity for the production of heat in all industry is adequately represented by table 8.3.

13. According to this analysis 48 percent of the electrical energy at present consumed in New Zealand is "fixed", that is, essentially non-substitutable. In fact, assuming that industrial high-grade heat is also fixed, this figure becomes 54 percent with only 46 percent being used in a way which would readily permit replacement. This is an interesting observation. For a practical situation, if we assume that half the domestic and commercial buildings obtain half their hot water from solar panels, that half the high-grade heat for cooking is provided by gas, and half the space heating by either gas or heat pumps, the total saving is only 15 percent. This is considerably less than the 50 percent or more suggested to us in several submissions.

Table 8.4

ELECTRICITY CONSUMPTION IN TERMS OF END USE

(*Source:* Royal Commission on Nuclear Power Generation)

	%	%
Low Grade Hot Water		30
Domestic	21	
Commercial	7	
Industrial	2	
Space Heating		9
Domestic	7	
Commercial	2	
High Grade Heat		13
Domestic	5	
Commercial	2	
Industrial	6	
Fixed (Lighting, appliances, etc.)		48
Domestic	13	
Commercial	4	
Industrial	31	

THE POTENTIAL MARKETS FOR ELECTRICITY

14. Many submissions pointed out that electricity should be little different from any other consumable item. Like any such item it should follow an S-type curve, a "saturation" level* being determined by the size of the market and the activities of other competitors within it. In the case of electricity, in terms of normal commercial expectancy, the rate of market penetration has been relatively slow. The result has been that the real growth characteristics have become confused by concurrent population growth, technological developments, and increases in standards of living, all of which have continually tended to increase the market size. The potential market for electricity, a premium fuel, should be almost the entire energy field. However, over any period the market can be limited by both economic and technological factors, while the fraction of the potential available can be controlled by both pricing and policy decisions.

15. The apparent rapid growth of electricity in the past has been largely due to its suitability as a substitute for other fuels. It should follow therefore that both present and foreseeable markets should already be reasonably well defined and identifiable, thus permitting planning as distinct from forecasting. Unfortunately, this does not appear to be the case, a point emphasised by the second submission of the Campaign for Non-Nuclear Futures (66). The domestic sector has been extremely well researched, even down to the consumption by individual household appliances (33, 53), but the same cannot be said to be true of other sectors. It was, however, apparent from cross-examination during our

*That is, not a true saturation as growth could still occur after the curve had passed through a knee.

hearings that this deficiency is well recognised, and present and past research by both the NZED and NZERDC is going a long way towards filling this need. Subject to these restrictions, we attempt to estimate for ourselves an upper limit for the consumption of electricity in the various economic sectors for the year 2000. The prime object in doing this is not so much to produce our own forecast for that year but more to understand the limitations and appreciate the inherent assumptions in the many forecasts that have been brought to our attention during our hearings.

Domestic Sector

16. The basic components of the domestic sector are well defined—water heating, lighting, cooking, appliances, and space heating. The market for the first three is close to saturation, and the use of appliances is also approaching saturation. There appears, however, to be enormous scope for space heating (and perhaps cooling) (53). To obtain an estimate of a possible upper limit for the domestic sector in the year 2000, we assume that all houses are all-electric, with space heating provided solely by electricity.

17. In 1976 there were 1.03 million housing units in New Zealand (see appendix C). Ignoring demolitions (which are about 2000 a year (51)) by the year 2001 this could increase by about another 700 000, corresponding to 28 000 new units a year, which is close to the average over the past 5 years. From table 8.2, a typical all-electric house uses about 8000 kWh per annum for water heating, lighting, cooking, and appliances implying a total consumption of about 13 600 GWh by the domestic sector for these purposes alone in the year 2000. At present the average (as distinct from the "typical") all-electric house uses about 2500 kWh per annum for space heating (53). The MER has pointed out:

> In the past the growth rate in heating consumption per household is estimated to have been in the range 1.5 to 3 percent per annum, giving a doubling time of between 23 and 46 years. This growth rate is expected, without conservation, to continue at the lower end of the range so that the average consumption after about 40 years will approach the amount consumed by the larger domestic users today (33).

18. Choosing the fastest growth rate referred to in this statement, the average all-electric house could use 5000 kWh per annum by the year 2001 corresponding to a total of 8500 GWh for the postulated 1.7 million housing units. It follows that the total consumption for all purposes in the domestic sector for the year 2000 could be about 22 000 GWh. Since, however, the average of 2500 kWh for present day space heating is weighted towards the North Island (as pointed out previously), 22 000 GWh could be an underestimate for all houses all-electric. Furthermore, it has been pointed out on a number of occasions that the present incidence of high-comfort space heating in New Zealand is relatively low. O'Malley has stated:

> The study revealed that the incidence of high comfort space heating was not high. Moreover, it is highly income related—much more so than other forms of consumption. It is also particularly sensitive to fuel pricing, perhaps because the substitution alternatives are more numerous, or because the running costs are more noticeable. Clearly it means that energy consumption could potentially continue to increase faster than real income (67).

19. For an increase in real GDP of 3.5 percent per annum the real GDP per head will have increased by 1.81 by the year 2001 (see appendix C). We could therefore have underestimated the real demand for 2001 by allowing for only a factor of 2 increase in space heating by then. Since the problems inherent in resistance space heating were emphasised on several occasions, especially by the Friends of the Earth (64) and Ecology Action (Otago) (3), we believe that further discussion on this matter is warranted.

20. Shaw and Stephenson in their NZERDC report on heat pumps express the opinion that a suitable level of thermal comfort in New Zealand could correspond to temperatures of 20°C (68°F) in living areas and 15°C (59°F) elsewhere. They concluded that to reach these conditions a fully insulated average New Zealand house (the average being over all climate regions and housing types) needs about 11 000 kWh per annum, and a house uninsulated except for ceilings, about 19 000 kWh per annum for space heating (68). These figures are irrespective of the form of heating, being the actual heat values over and above any thermal gain from solar input, people, appliances, cooking, etc., necessary to maintain the appropriate temperature difference between inside and out. In an attempt to obtain an upper limit to the domestic space heating market we assume that all houses are fully heated to the comfort level defined above, with new houses being fully insulated and existing houses uninsulated (except for ceilings). For the 1.03 million houses existing in the base-year of 1976, 20 000 GWh would be needed for their space heating in the year 2000. Allowing for a 20 percent increase in size of an average new house (the average three-bedroom house is at present only 102 square metres (68)), the addition of another 700 000 houses would require a further 9000 GWh, giving a total of 29 000 GWh for space heating for that year. If this heat was to be provided by electrical resistance methods only, the then total domestic electricity consumption for the year 2000 could be 43 000 GWh, over twice the present consumption for all economic sectors.

21. If, however, such levels of thermal comfort were desired, the relative economics would almost certainly lead to refitting of existing houses to levels of insulation comparable with those of new houses. That is, the space-heating need for the year 2000 could drop to about 20 000 GWh rather than being 29 000 GWh. Furthermore, at these levels of heating it is quite probable that heat pumps would be economic, reducing this figure further to 10 000 GWh (for a coefficient of performance of 2, see paragraph 39), a value little different from the originally estimated value of 8500 GWh. This means that on an overall national basis, conservation techniques (discussed in detail later) are more likely to achieve the house warmth required than the direct use of more electricity in purely resistance heating devices.

22. One other aspect that should be taken into account is a possible increase in summer air-conditioning. However, it has been pointed out by Shaw and Stephenson (68) that in North American conditions air-conditioning systems usually only operate at temperatures above 24°C. In Auckland a daily average of more than 24°C comes only on 0.2 days a year. Shaw and Stephenson thus consider domestic air-conditioning unwarranted.

23. It therefore appears that our original estimate of 22 000 GWh, or from the above discussion, say 23 500 GWh per annum, is a reasonable estimate for the domestic sector in the year 2000. We are not saying that

all houses will be or should be all-electric by that year, nor that all existing houses should be refitted or even that those houses with a high space-heating load should use heat pumps. We are merely remarking that there appear to be sound economic incentives why the domestic load should not exceed 23 500 GWh per annum in the year 2000, and pointing out the potential impact that resistance space heating could have. We believe furthermore, that because of the large demands that could be made on the energy sector as a whole, the question of space heating deserves further investigation with, as the Friends of the Earth have asked (64), emphasis being placed on the general criteria for thermal comfort.

Commercial and Industrial Sectors

24. The individual components of the non-domestic sector cannot be as readily identified as those for the domestic. There are, however, exceptions. The major consumers buy their electricity in bulk from the NZED, the greater part of which is for specific well-defined purposes. Again, electricity use in the transport sector is specific. There are uncertainties, if any, only in the commercial and minor industrial sectors. Within the former the pattern of consumption could still, by the year 2001, be similar to that within the domestic sector. However, as noted by the NZED: "The general trend . . . towards increased automation of process will be a significant if small contributor to an increased use of electricity in commerce" (53).

25. In the case of the industrial sector, as implied in the previous section, consumption is essentially for "fixed" purposes. That is, apart from its use for the production of small quantities of specialist process heat, its primary use must be in the area of plant and machinery. This means, in particular, that any question of "saturation" hinges on the extent to which further appliances may be used in the future. We assume, of course, that electricity will not for economic reasons be used for the general production of process heat. On the other hand, as with the commercial sector, automation could be important. The NZED stated:

> Analysis has shown that electricity consumption per unit of industrial output is rising . . . This continuing trend is interpreted as being the result of the automation of process, the increased use of plant and machinery and improvements in working conditions (53).

26. In a sense this statement stresses that the mode of consumption is not well identified. However, the NZED has also shown for past patterns of consumption (excluding the large forest-based and metal-smelting industries) that there is a strong relationship between the rate of growth of electricity consumption in the non-domestic sector and the rate of growth of real GDP. This is shown in figure 8.2. A mathematical model using the data from 1958 to 1976 has been developed to fit this relationship, and the fit is good (53). This model is discussed in detail in appendix C and considered again later in this chapter.

27. The nature of the model, and the data in figure 8.2 on which it is based, are such that for a constant rate of change in real GDP the rate of growth of electricity in the non-domestic sectors, excluding the large industries, decreases with time, the change being in fact about 0.12 percent a year. That is, for example, for a growth rate of real GDP of 4 percent a year for all years, the model gives the present (1978) growth rate for electricity at 6.6 percent but 7.8 percent for 1968. If the model should be applicable to future growth patterns, then for the same rate of change

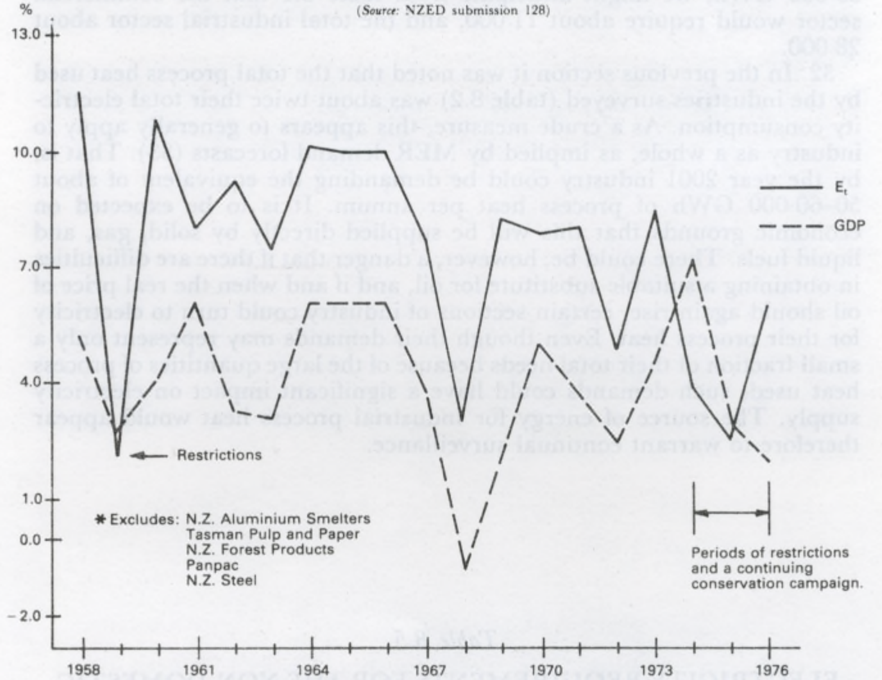
of GDP, the corresponding growth rate of electricity will be 4 percent by 2001, implying a saturation level, that is zero growth, in about 60 years.

28. Higher and lower rates of change in real GDP give higher and lower growth rates for electricity, and again since the rate of change of real GDP actually fluctuates from year to year, so does electricity consumption. Table 8.5 gives predictions on this model for the year 2000, corresponding to the requirements of 6500 GWh (including an anticipated 10 percent for transmission losses) in the year 1976 for the non-domestic sector (excluding the large forest-based and metal-smelting industries).

Figure 8.2

PERCENTAGE MOVEMENT IN NON-DOMESTIC ELECTRICITY CONSUMPTION* (E_t) AND REAL GROSS DOMESTIC PRODUCT (GDP)

(*Source:* NZED submission 128)



29. Whether the model will still be valid by the year 2001 is of course questionable. However, table 8.5 does give an indication on past patterns of behaviour of the sensitivity of electricity growth to changes in the rate of growth of real GDP. As a reference point, the OECD has implied that for about the next decade the average rate of economic growth in New Zealand could be in the range 3.3–3.5 percent a year (69).

30. If we assume that the ratios implicit in table 8.1 are still relevant to the year 2000, then for a 3.5 percent rate of change of real GDP a year, we would expect from table 8.5 that for the year 2000 the major industries would consume 15 500 GWh, transmission losses included. This is, of course, a completely arbitrary assumption and is merely applying the same model to the forest-based and metal-smelting industries as to the

commercial and other industrial sectors. However, the value obtained is in surprising agreement with information received during our hearings and, in particular, values arrived at for the year 2000 in the NZERDC "Continuation" scenario (6). If past, but not necessarily present, intentions for development are realised, consumption in the major industrial areas for the year 2000 could be of this order: forestry, 7000 GWh; aluminium smelting, 4000 GWh; New Zealand steel, 1000 GWh; other, including transmission losses, say 3500 GWh.

31. Thus for a constant 3.5 percent of change in real GDP per annum, the electricity needs for the commercial and both industrial sectors could be 39 000 GWh per annum by the year 2001. An 0.5 percent change in the rate of growth of real GDP either way could either increase or decrease this estimate by about 3300 GWh, that is, by about 8.5 percent. Of the 39 000 GWh, we might anticipate from table 8.1 that the commercial sector would require about 11 000, and the total industrial sector about 28 000.

32. In the previous section it was noted that the total process heat used by the industries surveyed (table 8.2) was about twice their total electricity consumption. As a crude measure, this appears to generally apply to industry as a whole, as implied by MER demand forecasts (33). That is, by the year 2001 industry could be demanding the equivalent of about 50–60 000 GWh of process heat per annum. It is to be expected on economic grounds that this will be supplied directly by solid, gas, and liquid fuels. There could be, however, a danger that if there are difficulties in obtaining a suitable substitute for oil, and if and when the real price of oil should again rise, certain sections of industry could turn to electricity for their process heat. Even though their demands may represent only a small fraction of their total needs because of the large quantities of process heat used, such demands could have a significant impact on electricity supply. The source of energy for industrial process heat would appear therefore to warrant continual surveillance.

Table 8.5

ELECTRICITY REQUIREMENTS FOR THE NON-DOMESTIC SECTOR FOR THE YEAR 2000

(Excludes large forest-based and metal-smelting industries)

(*Source:* Royal Commission on Nuclear Power Generation)

Rate of Change of Real GDP per annum %	Electricity Requirement GWh
4.0	25 600
3.5	23 400
3.0	21 500
2.5	19 500
2.0	17 900
1.0	15 000
0.0	13 000

Transport Sector

33. In reply to a question about the needs of a possible electrified public transport system, the NZED was uncertain but gave an estimate of 5 to 7 percent of our present total electricity consumption if most cities had suburban electrified trolley bus services (*Evidence* p. 2255). That is, the requirement could be about 1000 to 1400 GWh a year. For the year 2000 it could perhaps be double this, but if such services should become at all viable it could well be that the local authorities involved would generate their own electricity, as some do now. It is unlikely that such a demand would have any significant effect on the national system. Again, it was stated by the NZED that electrification of the North Island main trunk railway would need only about 200 GWh per annum (53). Thus public transport in general is unlikely to be of serious concern.

34. But it was pointed out by the NZED in considering their "Electrified Transport" scenario that if the entire New Zealand transport system, including private vehicles, should be electrified by the year 2000 the demand on the electrical system for battery charging could amount to 24 000 GWh per annum ((53) and appendix C). For this to happen there would have to be a major and early breakthrough in batteries. Although this appears to be unlikely, there is considerable research going on in several countries, including Britain and the United States (*Evidence* p. 2221). Furthermore, owing to the relatively rapid turnover of new vehicles, there is unlikely to be any great capital restraints on the rate of market penetration. Such a possibility must be therefore considered seriously. However, a more plausible figure for the year 2000 could be 12 000 GWh, corresponding to half rather than all the market being captured. All in all we do not see this as a major problem which would require either the greater use of our limited indigenous resources or the immediate introduction of nuclear power. In principle, the oil displaced from the transport sector could be used in either existing or new oil-fired power stations to give the necessary electricity. The overall load factor of the generating system would be improved, owing to night battery-charging, and there would be a net increase in the efficiency of primary energy use. (Present efficiencies in the transport sector are only about 20 percent, while electrification could result in efficiencies of nearer 30 percent.) The capital cost of new oil stations, if needed, is relatively low, and the construction time relatively short compared with nuclear, thus enabling a rapid response to market demands (see chapter 14).

CONSERVATION AND SUBSTITUTION

35. In their 1977 biennial report, the California Energy Resources Conservation and Development Commission gave the following (partial) interpretation of energy conservation (their italics): " . . . energy conservation means doing *better* with the limited energy resources available —*not doing without* the valuable and necessary functions that energy can provide" (71).

36. We appreciate, as the Commission for the Environment pointed out to us, that energy conservation can be perceived in a much broader context than this, realising "economic, social, and environmental benefits well beyond those directly associated with energy use" (72). However, for the purposes of this chapter we find the California Commission interpretation adequate and confine this part of the report to certain specific aspects.

In particular, we discuss space heating, water heating, and the possible generation of combined heat and power. Other aspects will be touched on later.

37. In general, if the cost of a conservation technique to save 1 kWh is comparable with or less than for 1 kWh of delivered electricity, a strong economic incentive will exist to adopt it. However, this cost may be primarily due to a large initial capital cost which inhibits the growth of the technique. Interest-free loans can help in such cases, as in the State-sponsored home-insulation scheme. The prices of delivered electricity set at 1 April 1977 averaged over the main centres were:

Table 8.6

THE AVERAGE DELIVERED PRICE OF ELECTRICITY
(As at 1 April 1977)

(*Source:* Based on MER submission 129, tables 1 and 2)

	$/GJ
Domestic—	
Water heating	2.02
Other	2.55
Commercial	5.25

Details for the commercial sector were not given. In the long term the incremental cost of generation is expected to lie in the range 3.5 to 4 cents per kWh, and thus significant increases in these costs can be expected (33).

Space Heating

38. In general an insulation level which can save up to 60 percent of energy consumption for space heating can be readily attained in the timber-frame housing construction most commonly used in New Zealand. Other types of construction could be brought up to the same standard in time (33). The present cost of the saving is 1.8 cents per kWh, and from table 8.6 is clearly worthwhile. Over the past 2 years approximately 100 000 existing homes have been partially insulated, and mandatory requirements for a given level of insulation in all new buildings were introduced in the 1977 Budget.

39. The potential use of heat pumps was strongly advocated in the Ecology Action (Otago) submission (3). The heat pump is the essence of a refrigerator. It transfers heat from one body at a lower temperature to another at a higher temperature. The quantity of heat transferred plus that generated by the pump itself is greater than the energy dissipated by the pump motor. A figure called the coefficient of performance (COP) is defined as the ratio of the heating energy delivered to the input energy required for pumping. In applications to space heating, heat is transferred from some source such as air, water, etc., from outside to inside a building. In a typical New Zealand climate, a heat pump can achieve a seasonal COP of between two and three (53). That is only one-half to one-third of the electricity would be needed to provide the same amount of heat with electric resistance heating. A main domestic disadvantage is the relatively high capital cost. For present rates of consumption the cost of saving in an insulated house would be 12 cents per kWh, and 6 cents in an

uninsulated house (33). The cost decreases with heating needs and for a building requiring 8000 kWh of heat per annum, the cost of saving is 3.6 cents per kWh (33). It follows that there could already be a major market in the commercial (and perhaps industrial) sector, and in view of previous discussion significant inroads into the domestic market could occur by the end of the century. It is also possible that in the commercial sector the pumps could be used in their dual role of heating and cooling.

40. There are difficulties with air-source heat pumps in that in very cold weather supplementary heating may be needed. If this is of the conventional electric resistance, much of the advantage of heat pumps in reducing increased winter power demands may be lost. Because of this there is considerable interest, especially in the United States, in assisting heat pumps with solar panels which would boost the temperature of the input air. In spite of this problem, a recent Electric Power Research Institute (EPRI) study in the United States has shown that heat pumps are now cheaper than electric resistance or oil furnace systems, with only natural gas furnace systems being superior. There are still problems of reliability with some manufacturers' equipment, but further improvements are possible with corresponding reductions in maintenance costs (73).

41. Other possible improvements relevant to space heating lie in building design associated with the direct use of solar energy. Many passive techniques are well known and others may be developed. All should be inherent in architectural design. We can only comment that greater attention should be paid to these aspects in future.

42. The potential savings in space heating needs have already been discussed in paragraph 21. As implied there, initial savings will be more apparent than real, such techniques being used to increase thermal comfort rather than to save electricity. However, we would recommend that at least large users of space heat, especially those in the commercial (and perhaps industrial) sector should even now be encouraged to use heat pumps. Not only does it appear to be economic to do so, but it will take a considerable time to develop the necessary labour force for servicing. If there is no good servicing, a reputation for unreliability could well develop leading to wholesale and most undesirable rejection of the technique, if and when the domestic sector's needs warrant the use of heat pumps.

Water Heating

43. There are three methods of reducing electricity consumption in this area. The first is reduction in the thermostat setting from say 74°C (165°F) to 54°C (130°F), giving a daily saving of over 1 kWh per cylinder. There is probably little point in doing this, however, if insulation is improved with flock being replaced by a suitable alternative. The resulting annual saving if this were done would be about 550 kWh for 74°C (165°F) and 210 kWh for 54°C (130°F), the cost of the savings being 0.2 cents per kWh and 0.6 cents per kWh respectively (33). A third method of saving energy is to install solar heaters.

44. To save 2000 kWh a year per household (note present average annual consumption of about 4000 kWh) by the installation of solar hot water heaters, the thermostat setting of the hot water system must be set to give water at 52°C (125°F). As previously implied, most household hot water heaters are probably set to give water at temperatures higher than

60°C (140°F). At 60°C the savings drop to 1500 kWh and for higher temperatures the savings would be less still. In Auckland the savings appear to be as low as 1250 kWh per annum (53). However, the situation is not clearly understood and trials being made by the MWD and by the Housing Corporation should clarify the problem. The estimated cost of saving for an annual saving of 2000 kWh is 4.5 cents per kWh for new houses and 4.8 cents per kWh for old houses (33), although there may be existing houses in which the cost could be significantly more. From table 8.6 the present economic viability is therefore questionable. In the long term the situation could be different. For an annual average saving for a household of 1500 kWh, to be pessimistic, there could be a potential overall saving of about 1500 GWh by the year 2001. It is assumed that most new and about half the existing houses would be equipped with solar heaters.

45. Taking into account all the types of conservation techniques so far discussed (excluding improvements in architectural design), the MER has estimated an upper limit of about 10 percent for a possible reduction in the projected domestic demand for the year 1990, that is about 1400 GWh (33).

Combined Heat and Power Generation

46. In combined heat and power generation both heat, at a desired temperature, and electricity are simultaneously produced. The heat can be produced by back pressure and extraction steam turbines delivering steam at temperatures of 200–300°C, or from the exhaust gases from gas turbines which can supply gas at 500°C for drying purposes or to raise steam in waste-heat boilers (1). The exhaust of diesels and gas engines fuelled with natural gas can also be used. Overall fuel utilisation efficiencies of up to 85 percent can be reached (53). The actual ratio of electrical to heat energy produced will depend on many factors, including the system used and the required temperature of the output heat.

47. In Britain 20 percent of industrial power needs are supplied by such systems (1). There appears to be considerable scope for their introduction into New Zealand. As an order of magnitude estimate of the electrical energy that might be available, we note from paragraph 32 that by the year 2001 industrial process heat could be running at a level of about 60 000 GWh per annum. Assuming that about one-third of this could be supplied by combined heat and power generation systems, and that the ratio of heat output to electricity generated is about 4 : 1, this gives an electrical generating capability of 5000 GWh per annum. This is a significant amount when compared with the estimated total electrical needs for industry of about 30 000 GWh per annum by that year. Obviously a careful and detailed study is warranted. However, the technique appears to be capital intensive, and as noted by the NZED:

> While the use of this technique with large installations may be in the national interest because of the efficiency of fuel use achieved, the return on capital invested may not meet the investment criteria of the companies concerned. Government action may be necessary to encourage investment in capital intensive conservation measures of this kind (53).

48. The concept may be extended to large thermal power stations. In such stations only about one-third of the energy input is converted into electricity. The remainder is waste heat normally in the form of hot water and is disposed of in cooling towers, cooling ponds, or discharged into

natural waters. If the heat is discharged at an appropriate temperature it can be used in the hot water reticulation systems sometimes called "district heating". This is a well established technique of energy distribution in Europe and North America (59). In Sweden, for example, about one-third of the waste heat from thermal power stations is used for domestic and other heating.

49. During our hearings we were presented with a very favourable appraisal of the possible introduction of such schemes into New Zealand (59). On balance we were not convinced, especially when we realised that the viability of such schemes is still in question in Britain even with its much higher housing densities (74). Again, any such scheme as heat pumps, is more likely to introduce apparent rather than real decreases in electricity consumption, higher levels of thermal comfort being sought. Nevertheless, we support further studies in this area and understand that such are being done. We also recognise that district heating would compete with heat pumps and natural gas, as well as resistance heating, and should be judged accordingly.

Substitution

50. The NZED has commented on the lack of detailed market projections of natural gas, stating that "This lack of information on the expansion plans of the gas industry presents a difficulty in electricity forecasting and planning" (53). That there should be uncertainties is perhaps not at all surprising when the MER comments:

> . . . the substitution in households of natural gas for electricity . . . is economically justifiable only if at least 50 percent of the households in a reticulated area are prepared to accept gas for two out of the three uses—space heating, water heating, or cooking. (The relative benefits of this would be eroded somewhat if combined cycle electricity generation and/or the widespread use of heat pumps becomes possible) (33).

51. Again, although the direct use of natural gas is certainly preferred to its use as a power station fuel, the gains in efficiency are not at present as high as often stated. For 100 units of raw Kapuni gas the net heat that can be supplied in a household through electricity is 27 units, and by direct use, 44 units: that is, there is an overall improvement of only 60 percent and not 200 or more as often believed. In industrial applications the corresponding figure is 52 units (33). There is a 31 percent loss before use from losses by flare, station use, treatment, and distribution. For household use, the MER gives the following efficiencies (33):

electricity	100 percent
gas cooking	59 percent
gas space-heating	60 percent
and gas water-heating ...	72 percent

with a weighted mean for gas of not much more than 60 percent. With the use of Maui gas there could be an improvement but in terms of being a substitute for electricity, the overall efficiency of natural gas is unlikely to be greater than about 50 percent.

52. The delivered cost of household gas at 1 April 1977 was about 1.1 cents per kWh (33), and even if this is only used at about a 60 percent efficiency, there is from table 8.6 an apparent economic gain in substituting gas for electricity. The corresponding figure for the commercial sector is 1.5 cents per kWh. However, the capital cost of gas appliances, etc., is

relatively high, and in terms of the substitution, cost-savings for a typical house are 2.7 cents per kWh for space heating and 2.5 cents per kWh for water heating (33), higher than the costs of delivered electricity given in table 8.6. Nevertheless, the NZED notes that "given 100 percent acceptance for space heating, cooking, and water heating, in high density developments the situation is very favourable" (53). State-sponsored loans will also help.

53. In industry with its need for process heat, natural gas will be used as a substitute for oil rather than for electricity.

54. The extent to which savings in electricity use can be made by replacing it with natural gas will of course depend on a number of factors. In its scenarios (appendix C), the NZED pointed out that the adoption of gas for water heating and cooking in 300 000 additional houses would reduce electricity consumption by about 1600 GWh per annum, while the substitution of gas space heating to gain high levels of thermal comfort in the same number of houses would result in a further reduction of about 3600 GWh per annum, a total saving of 5200 GWh. This corresponds to about a quarter to a third of all houses in the North Island using only gas for these purposes by the year 2000.

55. Another relevant factor is the size of the resource. The total of reserves for the Kapuni and Maui fields was given in chapter 7 as 6800 PJ, about 1.9 million GWh. This corresponds to about 60 000 GWh a year over a 30-year life. Assuming as an upper limit that 20 percent of this would be available for domestic and similar types of use in the commercial sector (see chapter 7), the total amount available is 12 000 GWh per annum which, used at a 50 percent efficiency, gives an upper limit for electricity savings of 6000 GWh per annum. Significant, but not as large as may have been anticipated. New discoveries could, of course, radically alter this estimate.

56. The use of coal as a substitute for electricity in the domestic area is to be questioned for many reasons. At present its efficiency of use in space heating is only 18 percent (33). That is, on present practices, coal is better used for electricity production. This very low efficiency could no doubt be raised but, as pointed out by Shaw and Stephenson, the seasonable efficiencies for the use of fossil fuels in space heating are only likely to be at best in the range 50–65 percent, even though under optimum conditions 80 percent may be reached (68). The use of oil as a substitute for electricity is not to be considered at the moment " . . . assuming of course as we must for planning purposes at this stage that major oil reserves are not discovered on shore or off shore New Zealand which could be brought into production [by 1990]. Such an event would significantly change our energy options" (75).

FUTURE GROWTH

57. From the discussion already given, it is apparent that the growth of electricity depends on many factors. These include economic activity, industrial developments, technological innovation, population and/or housing growth, the existence of alternative energy supplies, the desire for high levels of thermal comfort, the acceptance of the need for, and the economics of, conservation. A basic question is, to what extent can growth be controlled? Apart from certain elementary regulations (such as mandatory insulation for new houses, and tax incentives for conservation) tariff and pricing policies are apparently the only useful methods. These can make alternatives attractive and lead to increased efficiency in the use

of the generating system as a whole. To what extent growth can be curbed in an absolute sense, however, is open to question. While the cost of energy as a whole has increased markedly in the past few years, it is still a relatively small proportion of total business and household costs (67). Thus consumption is likely to be relatively insensitive to price changes, for example as illustrated by recent rises in electricity prices.

58. From the late 1940s to the early 1960s the real price of electricity was approximately constant. Then it fell owing to long periods between reviews, and to price control. An appropriate price level was restored by increases in April 1976 and April 1977, so that 1977–78 costs are now being met with a small margin of revenue for capital (53). However, it was claimed by the NZED in cross-examination that the effects of the first price change on total consumption were only short term, and that little other effect was to be expected from the second (*Evidence* p. 2223). In view of the discussion in the preceding sections, this is probably understandable. With relatively low levels of use in discretionary areas such as space heating, and the cost savings of alternatives still being somewhat higher than electricity, little change was to be anticipated. With further increases in price, there may be more positive, though still small, results.

59. The Treasury has prepared demand forecasts based on three different pricing situations: (a) a 20 percent real price increase in 1977 with no future real price changes; (b) a 20 percent real price increase in 1977 with 5 percent real price increases per annum to 1985 and then no real change thereafter; and (c) a 20 percent real price increase in 1977, a 10 percent real price increase in both 1978 and 1979, and a 5 percent real price increase per annum to 1985, and then no real change thereafter (76).

60. These forecasts have led to projected electricity demands in 1991–1992 of 40 698 GWh, 39 370 GWh, 38 780 GWh respectively. Irrespective of the relevance of these estimates for the year 1991–1992, it follows that for an over 50 percent change in real price between the extremes of these forecasts there is only about a 5 percent change in consumption. Thus it appears that pricing in itself is unlikely to have great effects on demand, even if the prices approach marginal costs. If, however, a relatively cheap and abundant substitute existed, they could have very significant results, leading perhaps to a 25 percent reduction in consumption, corresponding to half the substitutable component being replaced by, say, natural gas (see table 8.4).

61. On the other hand, the form of the bulk supply and retail tariffs to different classes of consumer can convey important information to the consumer on the cost of consequences of his consumption and thus perhaps prompt conservation measures. Also peak coincidence, time of day, and seasonal tariffs can lead to more efficient use of the generating system as a whole (53).

62. Inevitably, much of the debate on nuclear power has centred on the reliability of demand forecasts and the merits or otherwise of low energy and high energy societies. We recognise that these aspects are both complex and important but, unfortunately, subject to emotional overtones. However, we feel that we must try to set bounds on the rate of growth in electricity consumption in order to estimate a possible date for which nuclear power may be needed, and the subsequent rate at which nuclear plants may have to be introduced.

63. To evaluate the sensitivity of various projections of consumption to basic assumptions, we take as a first estimate 68 000 GWh per annum for the year 2000. We arrive at this figure thus. We have previously estimated

a plausible upper limit for domestic consumption of 23 500 GWh per annum for 2000, which with 10 percent added for transmission losses, gives about 26 000 GWh per annum. For a 3.5 percent per annum growth rate in real GDP, corresponding to the upper limit of the OECD value for New Zealand for the next decade, we obtained 39 000 GWh per annum for the commercial and total industrial sectors. To these estimates we add a further 3000 GWh (that is about 5 percent of the total) for demands by the public transport sector, giving a total of 68 000 GWh.

64. If the growth rate in real GDP should be 4 percent rather than 3.5 percent, and the number of new houses 800 000 rather than 700 000 (that is, a building rate of 32 000 a year), the total would increase to 73 000 GWh. This we regard as an upper limit, recognising that we have completely ignored major developments in the transport sector and neglected possible, but unlikely, demands for electricity for industrial process heat beyond the type of demand at present made. It is important to realise that this estimate is in almost every way consistent with past patterns of growth. It is, however, quite inconsistent with the so-called "historical" growth pattern of 7.2 percent a year, corresponding to a 10-year doubling time, which gives for the year 2000 a consumption of 124 000 GWh (4). It is apparent that the market potential for such a figure exists.

65. If all houses were all-electric and heated to high comfort without the use of conservation techniques (that is, with resistance heating only used), then for 1.83 million houses by the year 2001 domestic consumption, according to our previous estimates, would be about 52 000 GWh per annum, transmission losses included. If we assume, furthermore, that the transport sector is completely electrified, another 26 000 GWh would be needed. Adding 43 000 GWh for the commercial and industrial sectors (for a 4 percent per annum increase in real GDP), we obtain a total of 121 000 GWh, near enough to the "historical" projection for the year 2000. Since we have previously identified in general terms all components of the energy sector, the "origins" of the difference between the "historical" estimate and our upper bound appear to lie in the transport sector and the potential for resistance heating in the domestic sector. Irrespective of the validity of our upper bound, these simple estimates clearly identify the impact that these two sectors could have on electricity consumption. Since, however, we believe our estimate of 26 000 GWh for the domestic sector to be more plausible than the 52 000 GWh, it also raises the question of the relevance of past concepts of "historical" growth corresponding on average to a 10-year doubling time. Before discussing this we attempt to set a lower bound to the electricity generated by the national system in the year 2000. Again, we try to be consistent with past patterns of consumption.

66. Known reserves of natural gas could provide 6000 GWh per annum of useful heat in the domestic and commercial sectors. Since half of this could be used for high comfort heating, to be consistent with previous arguments, this could replace only 4500 GWh rather than 6000 GWh per annum of electricity. The installation of solar hot water heaters could save about 1500 GWh per annum, while a reduction of transmission losses from 10 percent to 9 percent consistent with the NZED predictions (appendix C) could save about another 1000 GWh a year. Combined heat and power generation could perhaps reduce the NZED load by a further 3000 GWh, and "in house" production of electricity by local authorities for public transport could give a further decrease of 1500 GWh. This

reduces our initial estimate of 68 000 GWh for the year 2000 to 57 500 GWh. It was also noted by the NZED in their scenarios that the major industries, instead of requiring about 16 000 GWh as estimated, may only need 10 000, including transmission losses. Since we may have already accounted for a fraction of this by the use of combined heat and power systems, any corresponding reductions that can be made may be nearer 4000 GWh. Add to this the possibility of a 5 percent reduction in absolute demand due to price increases, and we obtain a lower bound of about 50 000 GWh. Thus for the year 2000, we estimate that electricity consumption could lie in the range 50–73 000 GWh.

67. It is doubtful that further discoveries of natural gas would lead to a lower bound in the time scales involved. On the other hand a decrease in the rate of growth of real GDP could. Changes in population are not explicitly accounted for, as these are implicit in housing-growth and GDP values. Again it is to be noted that no direct allowance has been made for heat pumps etc., since, at least in the domestic sector, the effects of these will be more apparent than real. There could, however, be associated savings from the commercial sector. The value for the upper bound could be invalidated by major developments in the transport sector. But, as already noted, in the short term, the appropriate action would appear to involve oil-fired rather than nuclear-powered stations.

68. The most likely demand to be met by the NZED could be about 60 000 GWh per annum, although planning should take into account an upper limit of about 70 000. The Treasury estimate a figure of about 60 000 GWh (76), while the NZED scenarios (see appendix C) also imply 60–70 000 GWh. At first sight it is not surprising that our estimate should be about the same as that of the NZED, since their model for the commercial and industrial sectors formed a large part of our analysis. We have, though, investigated in a somewhat different way the sensitivity of the estimates to various assumptions.

69. In terms of past behaviour the NZED model for the non-domestic sectors gives an exceedingly good fit. Although other similar models no doubt exist, the NZED model is remarkable in that it relates present to past growth rates and has been developed from a pattern which changes relatively rapidly with time (see figure 8.2). Eighty percent of the changes in electricity growth in the non-domestic sector (ignoring the large industries) can be attributed to changes in rate of growth of real GDP. The general characteristics of the model were summarised in paragraph 29 and further details are given in appendix C. Of considerable significance is the fact that, for constant rate of change in real GDP, it leads to the logarithm of energy consumption being a quadratic rather than a linear function of time. In their second submission to us, the Campaign for Non-Nuclear Futures (66) presented a number of mathematical models of consumption over the past 20 years, which had been developed at their request by the Applied Mathematics Division of the DSIR. Two of these, one with and one without Comalco consumption, were quadratic fits to the logarithm of the total energy consumption, and are similar to that obtained from the NZED model. In fact the NZED model yields values surprisingly close if Comalco is included. (This is discussed in detail in appendix C). One of the most important aspects of these models is that they imply that the so called "historical" rate of growth corresponding to a constant doubling-time is simply an approximation to the true situation, its applicability being limited to a given period in time. At any instant in time, changes in consumption can be adequately represented by a

constant doubling-time, but this time will gradually increase over a period of years. (This is also discussed in appendix C). This is, of course, obvious from figure 8.1, where the rates of growth in the 1920s and 1930s were considerably faster than they are now. If models of the NZED type are to be believed, they will be significantly less by the end of the century.

70. Of course, even a model of the NZED type, like any such model, cannot be said to be exact. The real pattern of past consumption is undoubtedly a complex function of time, which even if known would not necessarily apply to the future. Such models can only give a guide and any associated forecasts must be tempered by both judgment and planning. Because of this it is obvious that the greater the detailed identification of the sources of consumption the more reliable the forecasting is likely to be. It appeared to us that the NZED is well aware of all these matters, the situation being summarised in the 1977 CRPR report, thus:

> Firstly, the committee uses no single or simple formula, but takes into account all the information available to the parties represented and consulted, before making a collective judgment on an appropriate level of forecast requirements. While this is fully and carefully argued it is not a purely numerical process, basically because the judgments involved are interpretive ones with incomplete information on a complex and changing situation (41).

71. The consequences of a mistake were emphasised to us by Hydro-Quebec (77). They pointed out that if one planned for a 3 percent growth rate a year, and demand warranted 6 percent, it would take 15 years to bring the system up to the necessary level. Nevertheless, in view of the discussion in this chapter, we are prepared to accept that the likely range for electricity consumption for the year 2000 is 50 000–70 000 GWh, and present planning should be based on the assumption that it could be the upper limit of 70 000 GWh. Consistent with this we might expect doubling-times closer to 20 rather than to 10 years by the end of the century, with perhaps consumption by 2020 being no more than twice that in the year 2000. This is discussed in some detail in chapter 15. However, a great deal of further study is necessary before any definitive growth rate can be estimated.

PART IV

Chapter 9. ENVIRONMENTAL CONSEQUENCES

INTRODUCTION

1. The generation of electricity, whether by means of nuclear or fossil fuel, hydro, or by one of the unconventional methods, affects the physical and social environment, usually (but not always) to its disadvantage. Some generation methods may also affect human health, either insidiously as a consequence of emanation of detrimental discharges, or directly in the event of accidents. This health aspect is discussed in chapter 11.

2. Environmental effects differ with different methods of generation, but the choice of method and siting of a power station represents a compromise between many options and factors. A comparison of the environmental effects of nuclear and other types of power stations was presented in the FFGNP report under the following broad divisions—impacts on land use, on water resources, on air quality, on noise, and on social conditions (4).

3. In the present chapter we define the environmental significance of the nuclear alternative or option in electricity generation in New Zealand. In this context the site chosen, and the consequences thereof, would be expected to be of fundamental significance.

SITING

4. When commercially operable (as distinct from experimental or military) nuclear reactors were first installed overseas they were sited in fairly remote places, in partial admission that the new technology was potentially hazardous. Now, after two decades of experience in the nuclear generation of electricity, siting decisions relating to future units in Britain, for example, tend to favour near-urban siting. Thus, from the Flowers report:

> It is Government policy [in Britain] that future commercial reactors should all be acceptable in principle for "near urban" siting . . . The safety of the public is considered to derive more from high standards in the design, construction, and operation of nuclear power stations than from remote siting. We agree and would go further. Because of our views on the desirability of using the waste heat . . . for district heating we should wish to see nuclear stations developed that could be sited sufficiently close for this purpose to areas where a large enough heat load exists; this would dictate siting within about 30 km of the urban areas involved. The need for transmission cables would also be reduced and hence their adverse effects on amenity . . . We acknowledge, however, that urban siting would present some conflict with security considerations. . . .

5. The consensus, however, among organisations holding an attitude of guardianship to the environment (e.g., Friends of the Earth) was that any nuclear station in New Zealand should be situated in a sparsely-populated region (2). It was submitted by both the Department of Lands and Survey (85) and the Department of Internal Affairs (86) that, in the search for a relatively remote site, national parks and reserves should be excluded. It seems most unlikely that a national park would be selected as a site. Another constraint on siting is introduced by the need to minimise risks to the nation's primary industries—especially agriculture. Analyses of prevailing wind records in relation to land use and occupancy would be needed to minimise the danger of radioactive contamination of agricultural and pastoral land in the event of an accidental release from a nuclear station. This danger is further considered later in our report.

Seismic Considerations

6. Most nuclear reactors in the world are built in areas where the seismic risk is considerably lower than it is in most parts of New Zealand. A country with a record of earthquakes and volcanic eruptions must pay great attention to geology in selecting a site for a nuclear station. Although no part of New Zealand can be considered as free from the possibility of a large earthquake, the level of seismicity varies considerably over the country.

7. The Geological Society of New Zealand, though not saying that a suitable site for a nuclear power station could not be found here, was "not very enthusiastic" at the chances of finding one (*Evidence* p. 1907). However, there are nuclear reactors in Japan and California, both earthquake prone regions. There, geological factors dominate site selection, and strict codes of site selection and reactor construction are enforced (44).

8. "Base isolation", a system of construction in which the movement of a structure is effectively isolated from the shaking ground in an earthquake, was presented to us as being capable of being used in constructing a nuclear plant. This type of technique has been used in bridge building, but much study is still needed to determine its suitability for reactor buildings (56).

9. As an added safeguard some reactors have been built underground. In a recent Japanese review, underground siting was given as the first goal, and it is expected that underground plants will be realised there in 1990. In New Zealand, underground siting is feasible but suitable sites may be hard to find (44).

10. The NZAEC made the following recommendations based on the report of its working group on seismic effects on nuclear installations (87):

(a) There should be established New Zealand criteria in design and standards for materials, manufacture, testing, and surveillance using United States codes and standards as a guide for judging the safety of reactors in respect of earthquake risks.

(b) The New Zealand licensing authority should assess the risk of surface faulting after consulting with scientists familiar with New Zealand conditions.

To define New Zealand's requirements for reactor suppliers, there should be specified for any reactor site, a safe shut-down earthquake (SSE), and an operating base earthquake (OBE). These are defined thus. An SSE is that earthquake which is based on an evaluation of the maximum earthquake potential considering the regional and local geology and seismology, and specific characteristics of local sub-surface material. It is that earthquake which produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems, and components are those necessary to assure:

(i) the integrity of the reactor-coolant pressure-boundary;
(ii) the capability to shut down the reactor and maintain it in a safe shut-down condition;
(iii) the capability to prevent or mitigate the consequences of accidents which could result in potential off-site exposures comparable to any agreed guideline exposures.

An OBE is that earthquake which, considering the regional and local geology and seismology, and local sub-surface material, could reasonably be expected to affect the plant site during the operating life of the plant. It is that earthquake which produces the maximum vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional.

11. The NZAEC further recommended that the SSE be defined as sufficiently severe and infrequent that the probability of its occurring during the life of the reactor with consequent release of radioactivity, could not be considered to add significantly to the risk of such a release from non-seismic causes. It also recommended that instruments should be installed to record tectonic information at prospective nuclear sites. This should be done as early as possible because large earthquakes are relatively uncommon, and valuable information would be got from recording even one at a site.

12. At present it is not known whether there are any sites in New Zealand which are geologically and seismicly suitable. There is a need for a general decision on the order of safety that would be needed in a nuclear plant in New Zealand. If seismic risks are to be no greater than any agreed criteria, then the level of risk decided on can be translated into seismic terms. Though it is essential that adequate safety standards are adopted, unrealistically low SSE values would effectively prohibit the building of any nuclear power station. This may at some future date be found to be an undesirable restriction.

Environmental Considerations

13. Various Governments have made laws and regulations to help protect New Zealand's environment. Any works development must meet the requirements of the Town and Country Planning Act, the Water and Soil Conservation Act 1967, and the Clean Air Act 1972. The requirements of these, together with environmental impact reports, would certainly and prominently feature in any public debate on a projected nuclear installation.

Engineering Considerations

14. The NZED specified certain requirements of land, water-supply, access, public health and safety, hydrology and geology, etc., and social impact (40). *Land*: about 40 to 60 hectares of flat land would be needed; if coastal, above high-tide level without danger of flooding.

15. *Water-supply* must be adequate for condenser cooling. A nuclear station of the type likely to be used in New Zealand is expected to use 50 percent more cooling water than a similar fossil-fuelled power plant. There are two cooling methods. The "once-through" or "direct" method takes cooling water from the source (river, lake, estuary, sea) pumps it through the condensers and returns it to the source. The "closed-circuit" method distributes the water through cooling towers in which the heat rejected by the condensers is dissipated. The NZED stated that a 1200 MWe nuclear station having a "once-through" cooling system would need a throughput of about 60 cubic metres a second. As New Zealand has no rivers which could supply such quantities without suffering harmful effects from thermal pollution, "direct" systems would only be considered for use at open coastal sites, or where cooling ponds of adequate size (estimated at 600 hectares) could be constructed.

16. *Access* to the site for some of the plant items would present difficulty where maximum loads for road transport are set at 200 tonnes. The transport weight of the pressure vessel for a 600 MWe BWR is over 400 tonnes. The same component for a PWR weighs 230 tonnes, and the PWR steam generator, 320 tonnes. The calandria and end shield of a 600 MWe CANDU exceed 200 tonnes. Transportation of fuel to and from a nuclear power station would also depend upon very rigidly specified safety requirements.

17. *Public health and safety* must be recognised in determining a site. Remoteness has only limited effect on safety though the density of the population surrounding prospective station sites must be a factor in site evaluation. There are two broad categories of safety criteria for siting nuclear power plants. In the first category (as in the United States, Canada, Japan), sites are chosen on the basis of limiting the radiation dose from a maximum credible reactor accident to a given value at the boundary of the site, that is, the criteria as in the Code of Federal Regulations (88). The second category applies to Britain where sites are graded in four classes depending only on density and distribution of surrounding population. Site-rating factors are computed from a system of weighting derived from the dispersion of radioactive iodine downwind in stable air conditions (89).

18. *The hydrological, meteorological, and geological* conditions at a site can all be significant for construction and safety. Some aspects of these are referred to again later.

19. *Impacts on society* must also be considered. These include access to and enjoyment of the countryside, and avoiding visual intrusion or change in land use. Fossil-fuelled stations which need tall stacks and large fuel-storage areas can be less pleasing than nuclear stations which have minimal storage structures and only a small stack or none at all. The latter tend also to be more aesthetically pleasing as buildings, though they are inevitably large and with their transmission lines dominate the immediate surroundings.

Communication with Local People

20. We cannot stress too strongly the importance and need for frank and open communication with the local people at every stage in any proposed nuclear power programme. The NZED has in the last few years made moves to explain to the public the relevance of the Clutha scheme, the Huntly station, and the proposed Auckland Thermal No. 1 station. A nuclear programme demands even greater efforts because of the widespread public distrust of a new and unknown technology. The record of the British CEGB in its relations with the public, both nationally and locally, presented us with a model worth careful study. We were able to observe and assess this when members visited the nuclear stations at Oldbury, Hinkley Point, and Heysham in September 1977.

21. The CEGB stressed that:

> Initial communication with local people at the outset of site investigations can set the tone for what is to become a long association, and the degree of rapport that is achieved can strongly influence their attitudes and eventual acceptance of nuclear power. An important objective of the CEGB is to establish a basis for mutual confidence and frank communication which can be continued and developed throughout the life of the station (90).

The communication with the public starts before beginning the search for a site. Local planning authorities and any other organisations with special interests are informed, and public statements are made in the national and local press and on radio and television. As part of the site investigations, CEGB staff discuss with local authorities, societies, and individuals the need for nuclear power, and the merits of specific sites. Representatives of the community have been assembled as liaison committees, closely identified with the CEGB staff. The recent applications of this policy have proved very effective. It should perhaps be pointed out that the policy was first implemented at a time when world-wide objection to nuclear power did not exist. But without full communication from the local to national level, public acceptance of nuclear power is not possible. Consulting local people is an important aspect of siting a nuclear station.

Environmental Comparisons: Hydro and Nuclear

22. In its final submission (No. 134) the MWD replied to an earlier request for comment on the comparative environmental effects of a hydro and a nuclear development. This was sought to provide a measure of the effects of a nuclear station in terms of more widely known effects of hydro. A comparison was made between the Upper Clutha Scheme F hydro development and a 1200 MWe nuclear power station. The comparison was limited to the topics discussed in part 6 of the FFGNP report, that is, those associated with the siting of the facilities and excluding other matters such as costs, and consequences of structural or operational failure.

23. The MWD said that the two developments were not equivalent in terms of either power or energy production. The Upper Clutha Scheme F has an installed capacity of 1515 MW and an estimated energy production of 4670 GWh per annum. A 1200 MWe nuclear station (assuming a 70 percent output factor) has an energy production of 7350 GWh per annum.

24. The MWD stated that the environmental differences could be expressed in broad terms as follows:

Impacts on Land Use

(1) Occupation of Land by Power Stations—
(a) Nuclear:
With once through cooling—300 ha.
With pond cooling—900–1050 ha.
(b) Clutha:
Power stations, canals and lakes—1850 ha.
Additional for: temporary use during construction; lake reserves; relocated roading; and transmission facilities—400 ha.

Comment: It is likely that the nuclear station would be sited in an isolated locality where the land was not intensively developed. After completion of the station most of the land within the station boundary would be grazed. The probability of a cooling pond option is very low, but, if it were adopted, it is likely that inter-tidal land would be used. On the Clutha, two-thirds of the land to be occupied is farmed, ranging from grazing through irrigated cultivation (18%) to horticulture.

(2) Occupation of Land by Fuel Sources and Fuel Wastes—
(a) Nuclear:
No requirement by the fuel source. Fuel would be imported in manufactured form. Provision required for an annual active waste production of about 100 m^3 of low level waste, 400 m^3 of intermediate level waste, and 30–40 tonnes of spent fuel. These would be stored on site initially, but might ultimately have to be removed for disposal or storage elsewhere (FFGNP report, section 5.4).
(b) Clutha:
While the lakes, strictly, could be regarded as fuel sources, the area occupied has been included earlier.

(3) Associated Housing Land—
(a) Nuclear:
During the construction phase a work force of some 1600 peak will be required. The total construction period will be of the order of 8 years with the peak occurring in the latter half and being of some 2 years duration. A permanent operating staff of 150 will be required.
(b) Clutha:
The construction phase requires a work force of some 1400 peak. The total construction period will be of the order of 20 years, the peak occurring from years four to seven. A permanent operating staff of 60 will be required.

Comment: It is expected that persons living up to 60 km from site will be prepared to travel to it daily. If a population of say 100 000 plus were to live within this radius, then housing would be required for perhaps 25% of the work force. In an isolated area housing could be necessary for up to 75% of the work force. In the case of an isolated site, either nuclear or Clutha, a township approaching 5000 in total population could be needed during the construction phase. It is difficult to predict how much of such a township would remain after completion of the station, but there is a tendency for such towns to become permanent (e.g., Mangakino and Turangi). The operator housing requirements for either nuclear or Clutha are likely to be small compared with other possible re-uses of a town.

A township of 5000 would occupy approximately 150 ha. At the other end of the scale, should housing be associated with existing population centres, little impact would result.

(4) Impacts on Adjacent Land—
(a) Nuclear:
It is normal to site nuclear stations in places remote from large centres of population and, in New Zealand, such sites could be up to 30 km from population centres of less than 1000. Adjacent land will be rural and is likely to be farmed at only a low level of intensity. A major access road would be required to connect the station to the state highway system.

(b) Clutha:

The stations, by virtue of the inundation arising from associated lakes, have substantially greater impact than a nuclear site. In the context of adjacent land some farms may become uneconomic because flat areas are lost. Resettlement of owners or rearrangement of land holdings are solutions. It will become economic to irrigate some twenty-five times the amount of already irrigated land subject to inundation and six to seven times the area of land subject to inundation. Other effects may arise from higher or lower ground water levels.

(5) Reservoir-Induced Seismicity—

(a) Nuclear:

Nil.

(b) Clutha:

There could be changes in the amount of minor seismic activity, following impounding, but significant earthquake activity is unlikely.

(6) Transport Routes for Fuels and Wastes—

(a) Nuclear:

The fresh fuel would be imported in manufactured form and delivered from ship to power station by normal road or possibly rail transport. A 1200 MWe station requires about eight truck loads per year. Disposal of fuel wastes requires about 60 to 70 truck loads per year.

(b) Hydro:

Nil.

(7) Rehabilitation of Land—

(a) Nuclear:

It is expected that a site would be of sufficient area to accommodate both a decommissioned station and an operating station. But unless the structures were removed (which is unlikely in New Zealand) the long-term use of the site for other purposes would be inhibited.

(b) Hydro:

The life of a hydro station is likely to be virtually unlimited in terms of current technological standards, certainly many times that of a nuclear station, but not necessarily of a nuclear site. Decommissioning would not be impossible and probably less difficult than the initial construction. Decommissioning cannot be envisaged as likely in the light of existing technology.

(8) Transmission Lines—

(a) Nuclear:

Will be required.

(b) Clutha:

Will be required and because of the number of smaller stations spread over a likely more scenic area, could have a rather greater impact.

(9) Public Facilities—

(a) Nuclear:

The station will be of interest and public tours and information centres would be provided. If associated site development included park-type amenities, public use could be expected.

(b) Clutha:

A hydro lake has high recreation potential for swimming, boating, and fishing. Access roads, picnic facilities, boat ramps, and active and passive recreation areas will be provided. Such amenities are in great public demand and considerably enhance the holiday, tourist, and retirement population potential of the area. A stable base for the prosperity of Cromwell Borough will result.

(10) Impacts on Natural Systems, Wildlife and Plant Life—

(a) Nuclear:

Negligible impact is envisaged from the station site and normal activity thereon.

(b) Clutha:

Surveys of existing types of vegetation are being carried out and reserves are proposed. Policies for the most advantageous future planting will be developed. The impact of a series of hydro lakes is substantially greater than a single small nuclear site. Proper design of lake edges will provide replacement habitats for wild life. A series of lakes is likely to inhibit the passage of migratory fish along the river system. Alternatives for dealing with the impact are either the provision of fish passes at each dam or the artificial breeding and stocking of individual lakes. The latter can be supplemented by ensuring that natural breeding areas are retained or created by suitable design.

(11) Scenic and Visual Aspects—

(a) Nuclear:

The physical structure of the station will make it a dominant feature in any landscape.

(b) Clutha:

The major effects are as follows:

(i) Objection to change—loss of the familiar scene.
(ii) Loss of gorge river scenery associated with rapids, rock masses, defiles, and broken water, and replacement of these features by linked placid bodies of water.
(iii) Loss of the "meeting of the waters" at Cromwell.
(iv) Loss of river scenery as at Lowburn.
(v) Loss of orchards.
(vi) Loss of trees in the Clutha River bed.
(vii) Risk of unsightly lake shores, shallows, mudflats, and erosion areas.
(viii) Loss of some historic dredge-tailing areas.
(ix) Risk of unsightly transmission structures.

The impact of these items can be mitigated by appropriate design and construction and sensitive landscaping.

Impacts on Water Resources

(1) Adequacy of the Water Supply—

(a) Nuclear:

The station will require cooling water and this will be obtained either by open or closed circuit methods. Significant impacts arise because of the quantity of waste heat to be absorbed and the large works required to accomplish this. The likely solutions are either open cooling to the sea or closed cooling through towers. With appropriate design neither has significant impact on water resources as there is likely to be no competing use.

(b) Clutha:

Other users have major interests in river water with irrigation, fishery, stock water, water supply, and recreation aspects having to be considered.

(2) Impact of the Power Station Facility—

(a) Nuclear:

The open circuit system using sea water can cause damage to aquatic life by entrainment, impingement, and heat. Proper design can minimise impacts. No significant effect is likely on commercial fisheries, and recreational fishing may be improved. Closed circuit systems with cooling towers have insignificant impact in this context.

(b) Clutha:

(i) River flows. River flows will be modified by the operations, and at the station furthest down-stream flows ranging from one-third of mean to two and a half times mean could be expected daily. Residual flows would be left in sections of river from which the main flow had been diverted, for fishery, amenity, and stock boundary purposes.

(ii) Floods. While floods can be passed safely, there is no provision of storage in the new lakes for flood control purposes.

(iii) River stability. Removal of bed load by deposition of the material in lakes might cause channels down-stream to degrade, causing damage to banks and reducing water tables. Fluctuating flows for generation purposes would probably cause some bank damage. Absence of normal flows in sections of river bypassed by canals could allow growth of vegetation which would impair flood capacity in such sections. All these problems are amenable to treatment by suitable river control works which would be carried out.

(iv) Bank stability. Lake perimeter banks, above and below water level, would suffer changed conditions arising from inundation, water level fluctuations, and wave action. Major slips could occur. Proper design and treatment of the lake banks will be carried out to control the lake edges.

(v) Siltation. It is possible that an acceptable stable state of siltation in the lakes might eventuate, with the river's silt burden passed through the stations. If this did not happen, means have been envisaged for passing the silt down-stream via suitable sluices using methods which have been used elsewhere.

(vi) Eutrophication. Lakes are liable to eutrophication, and hydro lakes particularly so. The causes of the problem are understood and solutions are possible. Potential problem areas in the new lake can be identified and physical bed and shore conditions modified to eliminate or minimise problems.

(vii) Control of waste discharge. Existing waste discharges to the river will be subject to review where they discharge into the new lake. Water rights practices will control.

(viii) Weed growths. Control measures will have to be used.

(ix) Water temperatures. River temperatures down-stream of lakes may increase marginally. No adverse effects are envisaged.

(3) Impact of the Fuel Supply—

(a) Nuclear:

Nuclear fuel is unlikely to have a direct effect on the water resource.

(b) Clutha:

Water taken for hydro generation may restrict its availability to other users. This aspect has been referred to earlier.

(4) Impact from Effluents—

(a) Nuclear:

This is a wide-ranging topic in any consideration of nuclear plants and has been dealt with in detail in other submissions.

(b) Clutha:

Not applicable.

Impacts on Air Quality

(a) Nuclear:

If cooling towers were used, the water vapour plume created would be visible but the effect would not be measurable in meteorological terms. No other impacts are likely.

(b) Clutha:

Very minor effects on climate are anticipated such as: small change in incidence of frosts in gorges; small changes in wind patterns; and slight increase in local fog incidence.

Noise Impacts

(a) Nuclear:

During construction there will be noises which could disturb adjacent residents. On the type of site postulated, no persons are likely to be sufficiently close to be affected. No significant noises will occur during operation.

(b) Clutha:

The dam site adjacent to Clyde will be worked on shift and involve a greater period of noisy activity (e.g., earthmoving machinery, concrete batching) than a nuclear site. The noise will be minimised as much as possible but with the contrast to the existing scene, some nuisance will exist over a 5-year period. This is likely to have a major effect on many residents, but will become background to others.

Social Impacts

(a) Nuclear:

In this category come:

(i) disturbance to persons who have to leave established homes—minor displacement only,
(ii) accommodation of construction workers,
(iii) accommodation of operators,
(iv) security matters—dealt with in other submissions.

(b) Clutha:

(i) Disturbance. A very significant effect has resulted with up to 100 persons being displaced, many from long established farms.

(ii) Accommodation. Likely to be similar to that required for the nuclear station except that fewer permanent operators will be required.

(iii) Security. Insignificant.

Safety Aspects—Natural Hazards

(a) Nuclear:

It can be accepted that a nuclear site will have been subjected to intense subsurface investigation, and foundation conditions identified with a high degree of certainty. The siting will be such that the effects of floods and earthquakes can be predicted reliably.

(b) Clutha:

The civil engineering works for the Clutha, embracing five major dams, canals, and lakes will cover a much greater area and consequently a much wider range of foundation conditions and materials, than a relatively small nuclear site. At commitment, foundation performances will be much less certainly known than for a nuclear station, but more detailed investigation would be impractical at that stage. By their nature the Clutha sites will be more vulnerable to floods and, probably to earthquakes, than nuclear sites. Nevertheless the risk of failure is extremely low.

WASTE MANAGEMENT

25. All conventional methods of electricity generation produce wastes which affect the environment. The management of these wastes to minimise adverse effects has usually come late in the development of the technology.

26. The nuclear industry has followed this pattern in both the weapons programme and power generation in that only in the last few years has attention been paid to the more serious aspects of nuclear waste disposal. The Flowers report expressed disquiet at what it saw as insufficient appreciation of long-term waste disposal requirements either by State departments or by other organisations. It considered that there must be "a means to ensure that the issues posed by waste management are fully considered at the outset of a nuclear programme, not dealt with many years after the decisions on development that lead to wastes have been made and when options have been effectively foreclosed."

27. The DSIR in assessing the nuclear waste disposal problem concluded "that New Zealand could well consider adopting the policy of

some overseas countries which advocate not entering into a nuclear power programme until greater assurance of safety of waste management procedures can be given than is available at present" (44).

28. Dangers from radioactivity arise at every stage of the nuclear fuel cycle. New Zealand, should it embark on a nuclear power programme, would not be involved in preparing fuel elements for the reactor. This would be done overseas. However, the wastes from any kind of reactor would have to be handled and disposed of in New Zealand or elsewhere.

29. As has been described in chapter 4, radioactive waste is generally classified as being of "high", "intermediate", or "low" level. High-level waste has relatively small volume but intense radioactivity, and needs long-term shielding and containment, and cooling. The term may be applied to irradiated fuel but is normally used for the highly concentrated waste generated from the reprocessing of spent fuel. Intermediate-level waste is more bulky and less radioactive, and needs containment and shielding, but not cooling. Low-level waste needs least shielding during storage, and some may be discharged into the environment. Information on the constitution of the wastes from an LWR and the rate of decay of the various waste products has been given in full in a DSIR background paper (44), and in the FFGNP report.

30. In any New Zealand nuclear power programme, low-level, intermediate-level, and small amounts of high-level wastes would have to be managed. However, it would be unlikely to need a fuel-reprocessing plant. This stage is associated with the management of 99 percent of all the waste radioactivity from nuclear power generation (44). Probably the only thing needed here would be to store radioactive fuel elements in cooling ponds to allow enough time for heat and radioactivity to decay before shipping them overseas in heavily shielded casks for reprocessing. It has been suggested that the radioactive residue might have to be accepted back from an overseas reprocessing plant after the plutonium and uranium were extracted.

31. Many of those appearing before us were concerned about the management of radioactive waste. The DSIR pointed out that "questions of interim management and long-term storage of long-lived radioactive waste have drawn both reassuring comments and warnings for the safety of future generations" (44). The morality of producing wastes that will be left as a problem for future generations was often mentioned to us and is discussed in chapter 10.

32. The wastes from a nuclear fission power plant differ in two ways from those from a fossil-fuel thermal plant. The amount of nuclear wastes is much less, and the dangers to health arise not from chemical properties but from radiation. We deal with the latter in chapter 11.

33. There is interest in comparing the wastes from a large (1000 MW) coal-burning station with those from a nuclear station of the same size. In the coal-burning station the main waste is the carbon dioxide emitted from the station's stacks at the rate of 270 kg per second. Although carbon dioxide is not in itself a dangerous gas, there is growing concern that its increasing concentration in the atmosphere may have a deleterious effect on the world's climate.

34. It has been estimated that the 266 power plants in the eastern United States were in 1973 putting 17 million tonnes of sulphur dioxide into the air, about two-thirds of that from coal plants, and the rest from oil-fired stations (91). Nitrogen oxides and particulate matter are also discharged. Air pollution from fossil-fuelled plants was said to cause up to

21 000 premature deaths each year in the eastern United States, and it was advocated that any new coal-fired stations built should be made to use coal with the lowest available sulphur content, and to install scrubbers which could remove the greater part of the sulphurous discharges.

35. The Ford Foundation - MITRE group concluded that on balance nuclear electricity generation has significantly less environmental impact than coal (12), a conclusion also advanced by Professor B. G. Wybourne (93). However, our inquiry is concerned primarily with the implications of nuclear technology. It has been estimated that the spent fuel from a 1100 MWe LWR weighs 29–37 tonnes a year for a core-loading of 87–149 tonnes (4). Or considering the volume of wastes produced, a 2 × 600 MWe nuclear station would produce 70 to 140 cubic metres of low- and intermediate-level waste in a year. This would fill between 350 and 700 forty-four-gallon drums. High-level wastes are produced at the rate of 34 cubic metres of liquid waste a year which, when vitrified, is reduced to 17 rods each 3 metres long and 0.3 metres in diameter (40). The amount of wastes from a nuclear plant is insignificant in volume compared with that from a coal-fired plant of equivalent size.

36. The FFGNP described the methods of dealing with radioactive waste. Intermediate-level wastes would be dried and mixed in cement or bitumen in drums. Management policies for low-level wastes may consist either of "concentrate and confine", "delay and decay", or "dilute and disperse". In the event of a nuclear power programme in New Zealand, intermediate- and low-level wastes would be managed locally. They would be disposed of by burial on land or dumping at sea. Sites for burial would have to be carefully chosen, and be in rock of low permeability and porosity, away from people, and in places where groundwater patterns are well understood. The actual burial site should be well above groundwater levels (4). Site investigations would be lengthy and expensive according to the Geological Society of New Zealand (94).

37. Small quantities of radioactive waste, mainly from universities and research institutes, have already been dumped at sea. In 1968 two areas, one south-east of Cook Strait and the other north-east of East Cape were designated as suitable for the disposal of radioactive wastes.

38. New Zealand has signed the international Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter ("London Convention"), and the Convention was given effect by Part II of the Marine Pollution Act 1974. Under the Convention, the permissible level of radioactivity which may be contained in wastes to be dumped at sea is determined by the IAEA. The Marine Pollution Act requires a special permit to be obtained before any waste is dumped in the sea around New Zealand.

39. The two designated sites, which have been adequate for the small amounts and low toxicity of the wastes dumped so far, are not entirely satisfactory long-term, as they may have potential for minerals or petroleum. It is considered that a permanent site should be selected to the east of the Kermadec Trench, well away from the New Zealand continental shelf (95). In July 1976, however, the New Zealand Seamen's Union formally stated that their members would protest at all dumping of nuclear and radioactive waste at sea, and would not be party to the dumping.

40. The Ministry of Transport, which administers the Marine Pollution Act, recommended to us (95) that before any decision is made to establish a nuclear power plant the alternative methods of disposal of the radioac-

tive waste be thoroughly investigated; and that if a nuclear power plant is to be established, and it is intended to dump large amounts of low-level waste at sea, the present International Convention and legislation (together with the procedures laid down in the legislation) would be adequate. Present practices would need some change, mainly to increase supervision.

41. Most of the high-level waste so far produced overseas in commercial power reactors is still incorporated in the spent fuel elements. These are stored in enclosed, water-filled pools which provide radiation shielding and cooling. This well-proven method can be regarded only as an interim solution. It requires continuous surveillance.

42. Though various methods have been proposed for the permanent disposal of high-level wastes, none has yet been used. A New Zealand nuclear programme may have to deal with waste shipped back after reprocessing overseas or waste that has not been reprocessed. The most favoured disposal method proposed has been to solidify the waste and bury it deep underground in geologically stable formations. But New Zealand, situated at the boundary of the Indian and Pacific tectonic plates, and with a consequent history of earthquakes, may be an unsuitable region for the deep underground disposal of high-level radioactive waste. The DSIR and the Geological Society of New Zealand thought it uncertain that suitable geological sites exist here (46, 94).

43. The dumping of high-level liquid wastes on the sea floor is generally prohibited by the London Convention. It has been suggested that wastes incorporated into a glass material to form a solid could be so dumped. The glass is expected to leach away in 3500 years, releasing the radioactive material which would eventually enter the food chain. However, the predicted concentrations are calculated not to exceed natural levels of radioactivity. Though the study has some uncertainties in its results it indicates that the sea floor should not be ruled out as a possible site for the disposing of high-level wastes (96). The Antarctic icecap has also been suggested as a repository. The Antarctic Treaty 1959 prohibits waste disposal in Antarctica. There are good environmental reasons for this.

44. Some of the people Royal Commission members met during their visit to the United States (for example, Dr Chauncey Starr, President, EPRI) expressed a general confidence that means could be found to satisfactorily bury solidified waste if adequate Federal funds were forthcoming. It was claimed that the geologically stable sites had been defined, and were available without foreseeable detriment to the environment. But some British scientists and plant operators were more cautious or less confident about underground disposal of waste, and could not see early action on this matter either in terms of money forthcoming, or of environmental acceptability.

45. When visiting the Harwell Laboratories of the British Atomic Energy Authority, members discussed the progress being made in researching and developing the conversion of high-level fission waste into the form of durable glass. Harwell seems to have done enough development work to justify a plan to store at Windscale until the end of this century glass blocks incorporating the British high-level waste. After that, as discussed in chapter 4, they will be either buried deep underground or placed on or under the bed of the ocean, without prospect of retrieval. The radioactivity of the fission products in the glass will gradually lessen. It was claimed at Harwell that even if this diminished radioactivity was to escape into underground waters or into the sea, the threat to man would

be little worse than that arising from naturally-occurring radioactive materials, or from the dangers arising from metals like mercury, cadmium, and lead.

46. A joint Common Market research programme on the underground disposal of wastes in the three most promising types of rock formation is under way. This has already been briefly mentioned in chapter 4. Under this programme, Britain and France are studying hard rocks such as granite, Belgium and Italy are studying clay, and West Germany and Holland are studying salt. To be suitable as a disposal site, a rock formation must show that it is impermeable to water and is likely to remain so through foreseeable geological and climatic changes. It must be free from fissures and old mine-workings, and preferably from worthwhile mineral resources. It must be able to withstand flooding and erosion, and not be in an area liable to earthquakes. The rock itself must be non-porous, and resist heat and chemical change (97).

47. Sir John Hill, Chairman of the UKAEA, has said that the high-level wastes arising from even a large nuclear programme will be small compared with, say, the world stock of mercury and arsenic (98). He said that burning the actinides in reactors may be more promising as a precursor to disposal than vitrification. Sir John warned of two possible dangers:

> On the one hand we might be driven by short-term expediency, under pressure from various quarters, to adopt prematurely, inadequate measures that are expensive, insufficiently researched, or both. On the other hand the decision-making process could become paralysed so that our nuclear programme was delayed until some magical final solution was found. The truth of the matter is that the engineered storage that we are all planning for the short and medium term will be sufficiently good for there to be no hurry at all in determining the best and most convenient of the many possible methods of ultimate disposal. But this very satisfactory situation is being used to our disadvantage by some of our critics. They contend that since we have not determined how nuclear wastes will be ultimately disposed of, we should stop our nuclear programme until we have determined and proved the disposal method. . . . We must I think, to satisfy our critics, establish one method of disposal whether or not it is the most satisfactory or economic . . . We should also continue . . . to achieve a method of disposal which is not only fully acceptable environmentally but also the best practical and economic solution.

48. The NEA group of experts on waste management made three points about radioactive waste disposal: that discharge into the environment is at present adequately controlled through ICRP recommendations; that the nuclear industry has the technical ability and means to ensure the safe handling and storage of all types of radioactive waste for as long as a century or more; and that safe waste-disposal practices (for example, shallow burial on land, deep burial in geological formations on land, and sea dumping) are already in use for the less radioactive types which do not need long-term containment (99).

49.The ultimate disposal of high-level waste remains unresolved. The NEA group suggested that the only acceptable arrangement is that governments take direct responsibility for the long-term management of waste. This would give the best guarantee that the most appropriate solutions would be adopted and that administrative control and possible surveillance over storage and disposal sites would be maintained. The group also confirmed that technology for dealing with waste management exists, but concluded that a demonstration phase is nevertheless necessary before adopting full-scale application of waste-management techniques.

50. Unless New Zealand could persuade Australia or some other country with geologically stable sites suitable for deep underground burial to take its high-level waste, it is difficult to see an easy solution to high-level waste disposal in this country. And we agree with recommendation No. 27 of the Flowers report that:

> There should be no commitment to a large programme of nuclear fission power until it has been demonstrated beyond reasonable doubt that a method exists to ensure the safe containment of long-lived highly radioactive waste for the indefinite future.

51. The Ford Foundation - MITRE report considered that disposal of such wastes in stable geological formations appeared to give adequate assurance "against the escape of consequential amounts of radioactivity even over long periods of time". It stressed, however, that problems of waste-management are potentially more serious than the purely technical aspects of disposal.

52. Thus we recommend that, before nuclear power is introduced into New Zealand, the feasibility of a suitable local plan for the disposal of high-level radioactive waste should be demonstrated, and details of a waste-management organisation be formulated.

Decommissioning

53. A nuclear power station has a useful life-expectancy of about 30 years. Dealing with it then can be considered a part of waste disposal. During the operational life of the station some structural components become radioactive. These would be left after shut-down and after fissile material and potentially dangerous portable components had been removed. A localised danger would remain and the building might be dangerous to enter without protection. Nuclear stations thus pose more severe disposal problems than most other industrial structures. The difficulties are often compounded because ultimate disposal has not generally been kept in mind when the plant was designed.

54. Regulatory authorities recognise decommissioning to one of three stages described in the FFGNP report as: lock up with surveillance ("mothballing"); conversion and restricted site access ("entombment"); and unrestricted site access ("dismantling"). No large nuclear station has yet been decommissioned. There are reports of nine small reactors having been dealt with (12). Two have been put in protective storage, five have been entombed, and only two have been totally dismantled so that the site became available for alternative uses.

55. The environmental and economic costs of decommissioning are an inevitable part of a nuclear power programme. We agree with the conclusions of the FFGNP that:

> It would seem essential for our future environmental interests that a plan and financial provision for decommissioning be established at the time of the initial planning of the siting, the design and the construction of a nuclear power station so that the ultimate environmental impact of the decommissioned facility is made acceptable (4).

POLLUTION

56. Any method of thermal power generation pollutes the atmosphere in some way with either local or global effects. In normal operation such stations pass waste heat, gas, particulate matter, and radioactive material to the atmosphere. These can not only affect health locally, but it has been suggested, could alter local or global climates. As New Zealand is more

likely to suffer from global pollution than to contribute to it, we shall now discuss some aspects of this problem.

57. The Ford Foundation - MITRE report has said that the man-made contribution in 1975 corresponds to an average global input only of about 0.02 percent of the radiation balance.

> It has probably not affected climate on a large scale. However . . . some local areas do show effects. If energy production should grow at an average annual rate of 4.5%, then in about 50 years the average global artificial heat input will be . . . of the order of 0.2% of the radiation balance; in 80 years, the heat input would be about 0.6% of the radiation balance. An increase of a few tenths of 1% of the global radiation balance could over several decades cause melting of polar sea ice. This man-made heat input may have dramatic effects on the earth's climate over a relatively short time span.

Whether these rates of growth will in fact occur is uncertain.

58. It has been found that the heat emitted from industrial conurbations of north-eastern United States or north-western Europe can alter local climate. The collocation of a number of 1000 MWe nuclear generating plants into a nuclear park has been suggested as a means of reducing the problems of dispersed sites. The waste heat emitted to the atmosphere from a large nuclear park would be equal to a significant fraction of that released in a thunderstorm. The possibility of severe storms near large nuclear parks could not be discounted.

59. The rapid increase in the use of fossil fuels in the twentieth century has raised world-wide concentration of carbon dioxide in the atmosphere. Some of the carbon dioxide is taken up by vegetation, and some by the oceans. Approximately 60 percent is retained in the atmosphere. A doubling of the nineteenth century concentrations is considered possible by as early as 2025.

60. It is generally accepted that the amount of carbon dioxide in the atmosphere has increased from a value of about 290 to 295 parts per million (mid nineteenth century) to about 325 ppm today; that is, an increase of about 12 percent (100). About 13 ppm of the increase has occurred since 1958. The present consumption of fossil fuels implies an annual injection of about 16 256 million tonnes of carbon dioxide into the atmosphere, corresponding to an increase of about 2.1 ppm a year. The observed increase would be only about half this, because the land biota increase their assimilation, and the oceans serve as a sink for carbon dioxide. It has been suggested that at least part of the measured carbon dioxide increase is a consequence of the extensive clearing of some tropical forests, but there is no agreement on what this contributes to the total increase. The significance of carbon dioxide as a pollutant lies in its ability to absorb the long-wave radiation emitted from the surface of the earth (see chapter 3), and, through the so-called greenhouse effect, to increase global air temperature.

61. Manabe and Weatherald calculated that a doubling of carbon dioxide in the atmosphere might imply an average increase in temperature at the earth's surface of about three degrees (within polar regions, more) (101). Although there can be argument about details of such a theoretical calculation, the scientific community takes seriously the possibility of marked global temperature rises. Oak Ridge National Laboratory pointed out that if we are to judge how rapidly we can safely use our fossil fuel reserves a greater knowledge is needed of the way carbon dioxide is exchanged with the oceans and with plants in order to judge how the airborn fraction will change in the future; the climatic effects of increased atmospheric carbon dioxide; and the impact of a change in regional

climate on the environment and on society (102). We were informed that an "Office of Carbon Dioxide" was to be established (1977) within the United States ERDA to assess the effects of carbon dioxide increases in the atmosphere. There appears to be no immediate practical solution to the problems that may arise from carbon dioxide from increasing use of fossil fuels. The Ford Foundation - MITRE report considers them as "the most serious potential impacts on the environment from greatly increased power generation . . . "

62. Thus nuclear power must be seen partly at least in a context of the environmental consequences associated with some of the non-nuclear alternatives. Increasing the number of large coal-burning power stations in the world would appear to be unwise until there is a better scientific understanding of the role of carbon dioxide in climatic change. It has been suggested that the large amount of particulate matter from the combustion could be responsible for altering the amount of solar radiation reaching the earth's surface, and calculations have been made of changes in climate due to this. Again there are uncertainties in the result, and more research is needed.

Chapter 10. MORAL AND SOCIAL CONSIDERATIONS

INTRODUCTION

1. As we have said in chapter 1, a nuclear power programme raises far wider issues than those of generating enough electricity to enable the nation to meet its social and economic goals. It calls into question the assumptions underlying policies—the considerations of continually increasing economic growth and centralising administration. The proponents of nuclear power point out that it presents an electrical energy source which is a natural and necessary successor to the world's diminishing fossil fuels, and is environmentally far less adverse than them in its effects. The admitted dangers associated with nuclear power have, it is said, either been solved or are capable of technical solution, and have up to now been proved to be potential and not actual.

2. But some see a nuclear power programme in New Zealand as bound to alter our way of life for the worse. Nuclear radiation is widely feared as an unseen and unfelt danger to health. News references to leaks of radioactive material in nuclear plants (even when later shown to be insignificant) reinforce the distrust of nuclear power. It is often forgotten that nuclear power is the first large industry to be subjected to such close public scrutiny. Other means of electricity generation, the oil industry, and the chemical industry all have individual and community dangers associated with some aspect of their operation. None has so far had to undergo the same intensive investigation of every facet of its activity as has the nuclear industry. The investigation is, of course, essential, for in a democracy any large-scale nuclear power programme can be implemented only if the majority is convinced that it can live with the consequences. In this chapter we discuss what we see as the more important moral and social considerations that many see as implicit in a nuclear power programme.

3. The National Council of Churches at its 1976 annual general meeting expressed concern at the apparent trend towards New Zealand's adopting nuclear power without sufficiently examining the implicit moral issues. And as well, many submissions to us expressed similar moral and social concern. The Commission for the Future, after discussing the principles of making a decision on nuclear power, added:

> Each of the aspects . . . developed by the Commission for the Future involves an appreciation of the appropriate course of political action, which will be determined by the response of the political machine to the views of the population at large. The latter in turn are influenced by the philosophical and ethical stances of individuals. The debate is, therefore, really about the ethical view which can command a consensus (113).

4. There is no general agreement on the precise meaning of "moral consequences" in respect of a nuclear power programme. Many matters were raised before us under this heading. We shall discuss only the most important which arose mainly in a context of (a) the prodigal and unequal use of the world's resources; (b) the possible links of nuclear power generation with nuclear weapons; and (c) the legacy of radioactive waste to future generations.

THE USE OF THE WORLD'S RESOURCES

5. Chapter 3 discusses in general the rapidly increasing use of energy and the depletion of solid fuel resources. The morality of a relatively few affluent nations being profligate users and the major consumers of the earth's finite energy resources raises much wider considerations than those of nuclear power—the more equitable apportioning of the world's resources, for example. We cannot attempt to discuss here such far-reaching problems. It is sufficient to say that we regard the continual growth of electricity generation in New Zealand, however it is brought about, as a continuation of present social and economic policies. Some advocated changing our life-style to one, which being simpler, would make smaller demands on natural resources and thus conserve them for posterity. Although a return to a less complicated way of life has a certain nostalgic appeal, as we indicate in chapter 3, we have grave doubts whether our largely urban society could be recast in such a mould. However, even in an urban society, there is, as has also been shown in chapters 7 and 8, room for greater efficiency in the generating and consuming of electricity.

6. A proposal that New Zealand should concentrate on exports with a low energy content, although superficially attractive, does not seem to us to be a moral solution to the problems of diminishing resources or polluting the environment. Indeed, some see it as an evading of responsibility by using somebody else's resources and keeping New Zealand unspoiled at the expense of some other country's despoliation. However, as the Department of Trade and Industry pointed out, important contributions to New Zealand's export earnings and industrial growth could be made by non-energy-intensive industries (137). The reasons for promoting such industries would appear to be economic and not moral.

7. Certainly the depletion of fossil fuels, an already rapid process, could be regarded as showing a morally irresponsible attitude towards further generations. However, as was pointed out by Professor J. W. Rowe at the Third New Zealand Energy Conference:

> Confronted with such uncertainty [about the future], it is sensible to leave open as many options as possible for as long as possible. More arguably, the unavoidable uncertainty about the future weighs against currently avoidable sacrifices in the interests of generations to come. We simply do not know whether the twenty-first century will judge them to have been worthwhile or not (138).

There is no consensus in New Zealand on what present sacrifices in the use of resources we should be making for posterity, or indeed whether any sacrifices should be made at all. We consider that:

> The minimisation of illfare is a much safer guiding principle [in these matters] than the maximisation of welfare, even if it is less high sounding because it leads less seductively to imposing one's own values on others (138).

8. Besides the principle of "minimisation of illfare" applied to use of natural resources, there is a moral duty to posterity to hand on as many developed energy producing technologies as possible. Only in this way will posterity have the greatest freedom of choice in the circumstances then prevailing.

POSSIBLE LINKS WITH NUCLEAR WEAPONS

9. As nuclear power generation was an offshoot of a military application of nuclear technology, some people have seen it as essentially evil. Many of those opposed to nuclear power (Women's International League for Peace and Freedom (139), Campaign Against Nuclear Warships (140)) contended that New Zealand, by adopting this technology, would be adding to the possibility of nuclear war. A similar type of argument is to be found in the Fox report which stated that: "The nuclear power industry is unintentionally contributing to an increased risk of nuclear war. This is the most serious hazard associated with the industry" (10). India's explosion of a nuclear bomb demonstrated quite clearly that a country may attain some measure of nuclear weapons capability through a commercial nuclear programme.

10. The problems associated with the proliferation of nuclear weapons are dealt with later in this chapter. We are not, however, convinced that, by rejecting a fission-based nuclear power programme, New Zealand would in any significant way either aid the cause of world peace or set a moral example to the rest of the world as some claimed it would do.

LEGACY OF RADIOACTIVE WASTE

11. The storage of waste fission products was quoted to us many times as involving moral considerations because of the long life and high radiation levels of some isotopes. Thus Professor D. W. Beaven was among those "concerned with the ethical and moral implications of our own particular generation committing hundreds of subsequent generations to the guarding and disposal of radioactive fissile wastes . . . I believe we should come up with the solution to this problem before we commit future generations . . ." (105). Similarly B. E. and G. F. Preddey stated that:

> A consequence of a New Zealand nuclear power programme could be that these questions [on waste disposal] hypothetical for us now, would not be so for future generations. They could have reason to regard their predecessors (us, today) with less than admiration (141).

12. The NEA has stressed the need to consider the effects on posterity of nuclear waste management practices:

> One responsibility of present generations, relying on nuclear fission for their energy needs, is not so much the consequences of deliberate releases of effluents to the environment, which can be adequately controlled even in relation to possible cumulative effects, but the need to manage the remaining waste in such a way that it does not become a burden for future generations. To achieve this objective, present generations should look for technical solutions for the required degree of long-term isolation for the long-lived radioactive waste, in such a way that future generations will not be faced with conditions that we would not accept ourselves (99).

13. We found in our discussions overseas that representatives of the nuclear industry were optimistic about high-level waste disposal. The management of low-level wastes poses no real problems. There are several experts, particularly in Britain, who feel that the public is seeing the problem of high-level waste disposal in the wrong perspective. They imply that, with reprocessing (that is, in particular, the removal of plutonium, and vitrification), storage by burial would be adequate. On the other hand the public may be correct, and in this case there is the real danger

that, even though disposal may prove to be technologically simple, if left too long, it could become unmanageable. NEA experts in Paris claimed to some of us that the lack of action in disposing of military wastes in the United States and Britain is a political and economic rather than a technical problem. The cost is very high so that politicians show little enthusiasm to have it done. Public suspicion and watchfulness will probably prevent a repetition of some earlier slipshod waste disposal. Careless disposal practices or the failure to use the best available technology could rightly be considered as irresponsibility to the future.

14. As in so many moral questions, the issues in the nuclear controversy are by no means clearcut. Professor Wybourne expressed to us the view that the rapid depletion of the world's oil and coal reserves in energy production when they have value as petrochemical raw materials, could be regarded by our descendants as squandering a heritage (93). We could make amends for the materials we are denying posterity by leaving a technology that would enable them to do without those materials. Such a technology must depend on cheap and abundant energy. He concluded that at present the only source we can guarantee is nuclear fission.

15. In essence this argument raises the further question of the morality of depleting our non-renewable resources of oil, gas, and coal while ignoring the enormous quantities of energy in the plutonium contained in high-level wastes from fission reactors. It can be argued that it is far safer to use the plutonium as a fuel in an FBR than to have to provide either temporary or permanent storage for high-level wastes. However, many resolutely oppose the extraction of plutonium from wastes and its use as a fuel in the FBR as possibly leading to greater proliferation of nuclear weapons and nuclear terrorism. From the point of view only of using energy, ignoring plutonium as a fuel is an inefficient use of natural resources. But in a democratic society before plutonium is widely used for energy the public must be convinced that the advantages of its efficiency outweigh the possible dangers.

16. The use of the thorium cycle with breeder reactors has been suggested in an attempt to multiply the energy value of uranium as much as the plutonium cycle would, but without the latter's potential disadvantages. Chapter 4 discusses the conversion of thorium into fissile uranium-233 which can be made unsuitable as bomb material ("denatured") by dilution with non-fissile uranium-238. The United States nuclear industry sees the thorium cycle as a technical solution to a political problem, and does not regard it favourably (142).

THE ILLICIT USE OF NUCLEAR MATERIALS

17. Many submissions stressed the dangers from diverting nuclear fuels to illicit ends, and from the effects on society of the methods that would have to be used to guard fissile materials from theft and nuclear installations from sabotage. With sabotage and terrorism becoming more commonly used by dissident groups and individuals, any increase in nuclear power was seen as adding to the possibility of violence and anarchy. New Zealand's relative geographic isolation was not expected to save it from becoming caught up in these worldwide problems. We fully agree that a solution for such problems of nuclear weapon proliferation, and the possibility of nuclear blackmail, must be found.

18. Nuclear installations could presumably give rise to blackmail and terrorist activities because diversion of fissionable explosive material would result in a real threat to society if the material could be made into a bomb or dispersed in the atmosphere; and sabotage of a nuclear plant could allow radioactivity to escape. We now discuss these possibilities, and the effects on our normal freedoms of the security measures needed to provide safeguards.

Diversion of Nuclear Material

19. Low-enriched uranium or natural uranium used as fuels in the LWR and the CANDU respectively cannot be made to explode or be fashioned into a nuclear weapon. Nuclear weapons are made from either highly-enriched uranium, or from plutonium.

20. However, as we have seen in chapter 4, spent fuel from commercial power reactors contains plutonium which, in a reprocessing plant, can be separated out when making new reactor fuel. Thus a terrorist organisation wishing to make a nuclear weapon would first have to acquire plutonium or highly-enriched uranium from fuel fabrication, from reprocessing plants, or from spent fuel from a commercial reactor. All of these undertakings are dangerous. For instance, spent fuel is extremely radioactive and can be handled only with special shielding and equipment, and the heavy casks (from 30 to 100 tonnes) in which it is shipped further complicate theft. Even if spent fuel is successfully stolen, access to reprocessing facilities are necessary to separate out the weapons material. It appears improbable that bomb fuel could be got from this source unless the operation was a national one. Much greater opportunities of theft occur during the separation of plutonium, and the production of highly-enriched uranium fuels, or when these materials are in transit. Their use in bomb making presents very great difficulties which are, however, not insuperable.

21. It seems to be generally agreed that a determined group of terrorists, with the necessary scientific background and knowledge of the properties of high explosives and the principles of bomb construction, could make a crude bomb which might explode with a force of a few tonnes of TNT. Even though inefficient, such a device would have an enormous psychological effect. There is no general agreement on whether an illicit group could construct a weapon with a yield of 100 tonnes of TNT or more. The Ford Foundation - MITRE report pointed out that details necessary for the manufacture are freely available, but the actual construction needs "substantial knowledge, planning, and extraordinary care in execution. A small group of even highly intelligent people is unlikely to have all the skills needed to carry out such a programme successfully."

22. However the Flowers Royal Commission, because of the dispute about the possibility of making such a bomb, consulted eminent physicists both in Britain and the United States. "Their judgment was that the construction of a bomb that would give such a yield was indeed possible though the actual yield would be very uncertain, for it would be as much a matter of luck as good judgment." The report concluded that "it is entirely credible that plutonium in the requisite amounts could be made into a crude but effective weapon that would be transportable in a small vehicle."

23. Although the use of the thorium cycle has been proposed as a means of combating proliferation, doubts of its effectiveness in this role have been expressed by Karl Cohen, a scientist with General Electric in the United States. He thinks that the cost of enriching the denatured uranium-233 to weapons level may not be beyond the purse of a terrorist organisation. It would need merely a centrifuge system in no more space than that of a 3000 square foot building. He said: "Legend has it that a weapon can be fabricated in a garage if enough fissile material is available. We see that we can undenature U233 in a modest house conveniently adjacent to the garage" (142).

24. A country wishing to build up a large stockpile of nuclear weapons cannot do so on the basis of a civil nuclear programme. It would need dedicated facilities. It is, however, possible to produce one nuclear weapon a year from the plutonium from a heavy water or graphite-moderated natural uranium reactor with a thermal capacity of a few tens of megawatts (155). Details of the technology are in the open literature, and the cost is some tens of millions of dollars. Apparently India followed this route.

Sabotage and Terrorism

25. It has been suggested that terrorists may hold a nation to ransom by threats of sabotaging a nuclear power plant or of dispersing small amounts of plutonium in the atmosphere. It is possible that a raid on a nuclear plant may cause such damage as to bring about an escape of radioactivity. Though it would not be difficult for sabotage to stop generation in an electricity plant, sabotage of a nuclear power station to cause release of radioactive material is much more difficult. The most serious release would come only from producing a core melt sequence. An intimate knowledge of the nuclear plant design would be needed for a successful terrorist raid, and though great damage could be caused to the reactor, it is unlikely that there would be large numbers of casualties (44).

26. Although there have been only a few minor sabotage incidents in nuclear plants, there has been a growing concern that physical protection of installations should be improved. Even if it did not cause loss of life, sabotage could be socially and financially harmful, and the removal of a large block of power from the supply system would have serious consequences. These consequences are, of course, not peculiar to nuclear power stations. The sabotage of any large base-load station could also have serious results. Indeed, a terrorist group, determined on its sabotage producing the maximum effect, could probably gain its ends more easily and effectively *other* than by attacking a nuclear station.

27. Because plutonium in the form of an aerosol is extremely toxic, it has been suggested that even small amounts dispersed in the air could be used for terrorism, leading to many deaths by inhalation. It has been estimated that one gram of plutonium-239 applied in aerosol form to an airconditioning system could cause a lethal dose over an area of about 500 square metres (one floor of an office building) (44). The number of casualties from plutonium dispersed in the open air depends on the weather and the population density at a particular time and place. B. L. Cohen estimated that for average United States conditions, there would be one death from cancer for every 15 grams dispersed in an urban population without warning (91). Such a dispersal would lead to few immediate deaths, most occurring over the ensuing 30–40 years. Clearly

there could be wide divergences from this result because of differences of actual conditions from the averages assumed in the calculations. Because of the uncertainty of the results of malicious dispersal of plutonium, it would appear that terrorism could be more effective by using other methods.

28. In New Zealand, enrichment of uranium and reprocessing of spent fuel would, for economic if for no other reasons, be unlikely in the foreseeable future. There would therefore be no stocks of fissionable explosive material. The possibility of terrorists trying to divert nuclear material would be very small if we were to have a nuclear power programme.

PROLIFERATION OF NUCLEAR WEAPONS

29. Given areas of political instability, any increase in the number of sovereign states with nuclear weapons increases the risk of nuclear war. There is always the possibility that armed conflict between small states in which there is the threat of the use of nuclear weapons will involve the super-powers. The dangers of proliferation are well recognised by the super-powers which have tried to stop it happening by various means while still allowing non-nuclear countries access to the peaceful uses of nuclear technology.

30. The Non-Proliferation Treaty (NPT) described in more detail in chapter 13 is one such attempt. It has been ratified by 105 countries. In return for accepting restrictions on the possession or manufacture of nuclear arms, non-nuclear countries are allowed to buy nuclear power generation plant together with the necessary fuel, and are given access to nuclear technology.

31. Another agreement with much the same aims has just been concluded by the so-called "suppliers group" of countries which export nuclear technology (156). This 15-nation agreement permits the signatories to continue to sell nuclear power generation equipment and technology but lays down an extensive programme of international safeguards to ensure that there is no military use made. Suppliers have tried to meet world power-demands without the risks of proliferation, and at the same time demonstrate to the non-nuclear nations that there is no cartel aiming to raise the price of nuclear fuel and equipment. The agreement bans the sale of reprocessing equipment, but as it applies only to future deals, does not prohibit their current sales by West Germany to Brazil, or by France to Pakistan.

32. In spite of all these safeguards, there can be no absolutely effective restrictions on the proliferation of nuclear weapons. If a sovereign State wishes to become a nuclear weapons power, it can do so as long as it possesses the resources in money and technical expertise. The guiding principle behind the nuclear power policies of the present United States administration is that the development and commercial use of nuclear technology by any non-nuclear state should leave that state no closer to a nuclear weapons capability than if all its nuclear power were derived from low-enriched uranium reactors operating with verified spent fuel storage in secured international facilities. This rules out, at least for the present, the reprocessing of spent fuel, and the plutonium breeder reactor.

33. The nuclear power policy announced by President Carter in his 1977 energy plan (146) defers any United States commitment to advanced nuclear technologies based on the use of plutonium. To set an example to the world in preventing nuclear proliferation, the President announced that the United States would defer indefinitely commercial reprocessing and recycling of plutonium, and the commercial introduction of the plutonium breeder reactor. Also the President proposed to reduce the funding for the existing breeder programme, and use the funds for alternative nuclear technologies with emphasis on non-proliferation and safety measures. Thus there is doubt about the Clinch River FBR project though work on breeder reactors in the United States is by no means finished. A 60 MWe light-water breeder reactor using a thorium/uranium-233 fuel cycle went into commercial service in early November, 1977 (158). The United States nuclear industry disagrees strongly with the President's policy on the commercial FBR, especially as some other nations are pressing ahead with FBR development.

34. The Flowers report, although recognising the increased efficiency of burning plutonium in a breeder reactor, considered that the dangers were such as to negate the advantages of its use and concluded that:

> The dangers of the creation of plutonium in large quantities in conditions of increasing world unrest are genuine and serious. We should not rely for energy supply on a process that produces such a hazardous substance as plutonium unless there is no reasonable alternative.

35. The Flowers report hoped that the large-scale use of the FBR could be avoided by developing fusion power. However, an energy group set up by the council of the Royal Society concluded that the lack of uranium resources in Britain implied that "a credible nuclear policy must be based, in the long run, on fast breeder reactors" (159).

36. The future of commercial spent-fuel reprocessing and the FBR in Britain depends on Government decisions following the Windscale inquiry into building a plant to reprocess spent fuel from Britain and Japan (see chapter 4). The inquiry under Mr Justice Parker finished its public hearings in November 1977.

37. The British Government could face a dilemma in making its decision after the findings of the inquiry are published. The nuclear industry naturally wishes to proceed with the Windscale plant as a first step towards a fast breeder system, for which a second public inquiry is promised. Possibly large foreign earnings are a great incentive to proceed. On the other hand, there is a strong section of the Government which supports President Carter's plan to halt the spread of reprocessing and breeder technology around the world.

38. The communist world is committed to an extensive FBR programme; western countries are divided on the issue, France, for instance, being committed to the commercial breeder reactor. An international reprocessing plant has been suggested to maintain safeguards against proliferation. Clearly the non-communist countries are in the middle of widespread public debate on the so-called plutonium economy, and the only point of general agreement is the strong desire to halt the proliferation of nuclear weapons. In the next few years we can expect both national and international debate to continue on the consistency of such aims with the advantages of the use of plutonium as a fuel.

CIVIL LIBERTIES AND NUCLEAR SAFEGUARDS

39. Some saw the loss of civil liberties as a consequence of the security measures that would accompany nuclear power generation in New Zealand. This contention seemed sometimes to have a more emotional than rational basis. Though affected by a genuine disquiet, many of those who used it could not state precisely what civil liberty of the ordinary citizen would be endangered if nuclear power were to be introduced. The position was more clearly outlined to us in London by representatives of the Friends of the Earth who contended that loss of civil liberties was not brought about by nuclear power *per se*, or by the present nuclear programme. They expected, though, that an advanced nuclear programme involving the extensive use of plutonium would inevitably necessitate a safeguard system which would bring about a hard attitude on the part of the law-enforcement agencies. Methods employed in some countries to combat the drug traffic (such as the use of informers and infiltrators, telephone tapping, opening mail, and forced entry to premises) were expected to be used to a much greater extent to safeguard the plutonium. The need for the quick recovery of stolen nuclear fuel would tend to force the authorities to employ shortcuts in methods of search and interrogation, so that some civil liberties would almost certainly be violated.

40. These dangers may well be real, and we can see that, given certain circumstances, an insidious growth in the use of surveillance methods usually associated with a police state could happen. The growth of anarchy and a widespread disregard for the rule of law, both within nations and in international relations, would bring about conditions conducive to nuclear blackmail. The beleaguered civil authorities and governments would probably have to enforce rigid security measures in nuclear plants where plutonium was used or stored. The scenario postulated by the Friends of the Earth could in these circumstances become a reality. However, in these conditions, nuclear blackmail is but one form of terrorist weaponry, and to combat other more conventional threats, repressive measures could also be used. We consider that although the presence of plutonium might aggravate a lawless situation (which is by no means certain to arise), it would not bring one about.

41. New Zealand, if it introduced nuclear power, would be required under the NPT to ensure the safety of its nuclear materials, by guaranteeing that: unauthorised persons were unable to gain access to and remove nuclear material; there was an effective surveillance system to forestall removal of nuclear material; and quantities and movements of nuclear materials were meticulously recorded. (The records would be subject to inspection by IAEA officers.)

42. There was concern at the possibility of guards being armed thereby creating a state of affairs which, although possibly commonplace elsewhere, is foreign to New Zealand custom. The enacting in June 1977 of the Atomic Energy (Special Constables) Bill in Britain was seen as the pattern New Zealand might follow in the event of starting a nuclear power programme. The Act allows guards on nuclear facilities to carry firearms without obtaining individual firearms certificates as civil police must. The special constables are also now permitted to exercise their powers when guarding nuclear material in transit or pursuing persons suspected of removing or attempting to remove nuclear material unlawfully. In our visits to nuclear installations in Britain we did not see any use of security measures that gave us offence.

43. The contention that guards, armed or unarmed, at electricity generating plants would be the first step on the way to a police state is, we think, exaggerated. But we can see that such conditions might produce a feeling of disquiet in some people in our relatively open society. There are regrettably some other aspects of our society which, following overseas trends, have more reason to cause us concern than the guarding of power stations.

Chapter 11. HEALTH CONSEQUENCES

INTRODUCTION

1. There is much scientific literature about the effects of ionising radiation on living tissue, a survey of which is given in the report of the FFGNP, and summaries in the Flowers, and Ford Foundation - MITRE reports. We do not intend to repeat the material given in these accessible general accounts.

2. Some lay people and organisations appearing before us were apprehensive about the possible effects on man of radiation produced even in the routine working of a nuclear power programme. There were also marked differences of opinion among some scientists and some medical witnesses, especially on the genetic effects of ionising radiation. The differences are an indication of the uncertainties in some areas of radiobiology.

3. Though not competent to resolve these uncertainties, we spent many hours discussing them, and consider that we must at least describe the contentious issues, and show where the differences of opinion lie. This chapter is not intended to be a complete survey of the biological effects of ionising radiation. It aims rather to give the background to the most important matters raised before us, and the essence of the public debate that took place before us.

4. Quantitative analyses of the effects on health of the nuclear power industry must be assessed by comparing them with corresponding effects from alternative energy sources. In such assessments, data should be treated equivalently, that is, for equal energy output, and for the complete cycle of operation.

Units of Absorbed Radiation

5. A short account of the radiation process has been given in chapter 4. We introduce here the physical units used to express the amount of radiation absorbed in irradiated tissue. When radiation penetrates tissue it gives up its energy through a series of collisions with the material of the tissue. The amount of energy deposited in relation to the mass of tissue is used as a measure of the intensity of the radiation. The unit of absorbed radiation dose (the *rad*) is defined as the quantity of radiation which would cause 1 kg of material to absorb 0.01 joules.

6. Different kinds of radiation cause differing amounts of biological damage for the same amount of energy deposited. The relative biological effectiveness of radiation depends also on the nature of the tissue being irradiated. The unit of biological dose is the *rem* which is defined as the product of the radiation dose in rads and the relative biological effectiveness of the radiation. In practice only the effects of different types of radiation are taken into account. The radiation dose in rads is multiplied by a quality factor to give a dose equivalent in rems. The quality factor is taken as 1 for beta, gamma, and X-rays, and as 10 for alpha and fast neutron radiation. Dose equivalent in rems (or millirems) is the appropriate measure when considering the health effects of radiation.

NATURAL AND MAN-MADE RADIATION

7. There is a natural background radiation which affects us all. If nuclear power came to New Zealand, any radiation from the reactor would merely be an addition to this, and would come from the small amounts of liquid and gaseous effluent released during normal operation. Large amounts of radioactive effluent could be emitted only in the unlikely event of a reactor accident breaching the containment. Chapter 12 discusses such dangers.

8. The background radiation is made up of cosmic radiation from space, terrestrial radiation present in the earth and air (and consequently in material used for building), and internal radiation derived from radionuclides present in body constituents. The dose rate from cosmic radiation depends mainly on altitude, and has its least value at sea level at the equator where it is about 28 millirems per annum. It is a little greater at the poles, and much greater with altitude, being about 60 mrems per annum at 1000 metres above sea level. The main source of internal radiation is potassium-40 which contributes an annual dose of about 20 mrems. Terrestrial radiation varies considerably from place to place. Table 11.1 shows variations, largely due to building materials, in various places around Wellington.

Table 11.1

TERRESTRIAL GAMMA-RAY BACKGROUND IN VARIOUS LOCATIONS IN WELLINGTON

(*Source:* FFGNP report)

Place	Annual Dose/mrem
Inside an electric unit (train), Upper Hutt line	44
Inside a wooden house, Waterloo, Lower Hutt	88
Inside a brick-veneer house, Waterloo, Lower Hutt ...	120
Kelburn Park, Wellington	105–130
Reserve Bank, Wellington (9th floor)	114
Wellington Railway Station, platform 3	123
Wellington Railway Station, main foyer	193
Rutherford House (Electricity Department) 2nd floor ...	175
Lambton Quay, Wellington	175–260
Archway at rear of Parliament Buildings	280

9. Besides background radiation, additional doses may be received from medical and dental X-rays, and other man-made sources, including radiation from wrist watches, TV, and global fall out from past bomb tests. Nuclear weapons testing up to 1971 has been estimated to commit New Zealand residents to a dose of about 60 mrems to the year 2000. This is about half the average dose commitment in the northern hemisphere. Professor B. G. Wybourne quoted the following typical doses from man-made sources.

Table 11.2

RADIATION EXPOSURE OF NEW ZEALAND RESIDENTS

(*Source:* FFGNP report)

Source of Radiation	Average Annual Dose/mrem
Natural radiation	120
Medical irradiation	14*
Occupational exposure	0.07*
Other man-made and miscellaneous radiation	3

*Indicates genetically significant dose (GSD)

10. These levels, especially those due to medical sources, would vary greatly. Each chest X-ray over and above the average would add about another 100 mrems. The effects of the extra radiation dose that people would have to accept from a nuclear power programme should be evaluated by comparing them with those of background radiation from which there is no escape.

11. There appears to be no dispute that the radiation exposure of workers in the nuclear power industry is generally kept to doses well within limits recommended by the International Commission on Radiological Protection (ICRP). The World Health Organisation (WHO) has reported that even high average radiation exposures locally and globally from nuclear power are low compared with those from natural sources or medical practices. However, the annual collective radiation dose of inspection, maintenance, and repair workers in nuclear plants is greater than that of the general population. The New Zealand Medical Association accepted that though a normally functioning nuclear power generator produces much radioactive material, the largest part is contained within the reactor (92). It concluded that if the discharged part is kept within specified limits, the added increment of absorbed radiation dose would be clearly within limits of public acceptability.

THE EFFECTS OF IONISING RADIATION ON CELLS

12. Living tissue consists of cells, many of which can divide and so reproduce themselves. The FFGNP report describes how ionising radiation changes the large organic molecules on which the cell functioning depends (4). Very high doses can kill a cell. A single dose of 320 rads to the whole human body has a probability of 1 percent of causing death within a year, while a similar dose of 750 rads has a 99.9 percent probability. The main cause of death is damage to the bone marrow which stops new blood cells from forming. Cells are more likely to be damaged if irradiated while they are growing and dividing. Thus foetuses and young children are much more sensitive to radiation damage than adults.

13. Sub-lethal irradiation may cause cells to divide abnormally or may stop them dividing. A radiation dose received all at once more effectively produces cell damage than if it is given in a series of small doses, or given slowly over a long time. Repair mechanisms may heal some of the damage. Damage to ordinary human body cells may show as a cancer years after irradiation. In reproductive cells radiation may damage the

genes in the chromosomes, and thus affect offspring. The changes, from mild to lethal, may be dominant and appear in the first generation of descendants, or they may be recessive and appear only possibly in future generations.

Genetic Effects

14. The genetic effects of ionising radiation have been studied in simple organisms (for example, in the fruit fly, *Drosophila*-species), and have been produced in laboratory animals (usually mice). There are no quantitative data of genetic damage to man by radiation. Children born to the Hiroshima and Nagasaki survivors who had received doses averaging 100 rads showed no observable genetic effects. However, it is not assumed that man is immune from genetic damage, for 6 percent of all live human births have some sort of hereditary disease. Studies are complicated by the great variety of mutation types, the variation of genetic diseases which may range from the invisible to the conspicuous or from the trivial to the lethal. Some may show up in the first generation, but some may appear later and persist for tens of generations.

15. The genetic effects of a given radiation dose must be indirectly estimated, and such estimates are thus most uncertain. Human response to dose is not known. It is assumed that there is no radiation level below which there are no genetic effects, and also that doubling the radiation dose will double the genetic damage. The WHO working group pointed out that present estimates of radiation-induced genetic effects were based on experimental data from small animals mainly exposed to low dose rates. The data analysed supported the concept of linearity in the dose range, and did not indicate the presence of a threshold dose.

16. An assessment of the genetic damage from a single radiation dose is based on experiments on animal germ cells. The number and type of mutations in genes or chromosomes are analysed, or an estimate may be made of the dose needed to double the naturally occurring genetic effects. The aim is to estimate the number of genetic diseases likely to be caused in the first and subsequent generations from exposing the population to a given radiation dose.

17. The Flowers report in discussing the mutagenic properties of radiation pointed out that the risk of genetic mutations from man-made radiation must be seen in relation to those from natural sources. Genetic mutations which take place all the time are a mechanism whereby a species can adapt and survive in a changing environment. However, for every beneficial mutation there are many that are harmful, but the evolutionary process would usually eliminate harmful mutants from the gene pool of the species. The report concluded that, as the allowable radiation levels from the nuclear power industry were such as to keep the somatic effects at a low level, the genetic effects should be of little concern. It is unlikely that they could be observed.

18. However, we heard argument that the following three points (better medical care preserving human mutations; the genetic effects of carbon-14; the risk of creating a harmful mutant micro-organism) could make the mutagenic effects much more damaging than the Flowers report tended to reveal.

Better Medical Care and Human Mutation

19. Because of the much higher standards of medical care *any* additional human mutations would now tend to be preserved where as formerly they would have died. Dr E. Geiringer and Professor D. W. Beaven submitted that any increase (however small) in ionising radiation is therefore likely to be harmful and should be resisted (104, 105).

20. The Advisory Committee on the Biological Effects of Ionising Radiation (BEIR) estimated that only 3 percent of inherited genetic disease is caused by background ionising radiation. The remaining 97 percent is attributed to other natural causes such as heat, or chemical mutagens (106). Dr H. C. Sutton (*Evidence*, p. 2179) has also estimated that, if by the year 2000 half the world's electricity came from nuclear power, the additional public radiation dose from that source might rise by then to 3 percent of that due to natural causes.

21. We conclude on the evidence given us that nuclear power is unlikely to add to the human mutation rate, a view accepted by the Flowers report. Some submissions, however, rejected it, because of the complicated nature of genetics, and the great uncertainties in the calculations, and statements of the various expert committees—calculations which are only best *present* estimates and which must change in the light of more exact knowledge. The suggestion that any ionising radiation additional to background may cause damage which would not be eliminated from the gene pool of our society seems to us to need investigation. We have no measure of the magnitude of this effect.

22. Unless the estimates produced by BEIR and the Flowers report are wrong by a factor of 10, we would agree with the validity of the basic conclusion of the latter that the genetic effects of a nuclear power programme are of little consequence.

Genetic Effects of Carbon-14

23. Dr E. Geiringer contended that the genetic effects of a nuclear power programme had been further underestimated because of the properties of the radioactive isotope carbon-14, formed in the routine operation of nuclear power stations (*Evidence*, p. 415). It can replace the non-radioactive isotope carbon-12 in atmospheric carbon dioxide and in the cells of the body. Carbon-14 emits beta radiation which has a range of a few cell diameters and decays to nitrogen, emitting energy. Thus, if changes to carbon-14 take place in the molecules of genes and chromosomes, mutation could result from both the beta radiation and the transformation of the carbon to nitrogen. The question is whether the effect of this transformation is greater than that of beta radiation from either inside or outside the cell.

24. Experimental studies to measure the comparable size of these two effects have dealt mainly with carbon-14 decay in chromosomes of bacteria and of plant cells. They have shown (but with great uncertainty) that the effects from chemical transformation are greater by factors of between 2 and 5 than those from beta-ray ionisation (107).

25. The few experimental data from larger organisms give contradictory results. Where the overall size of the tissue exceeds the range of the beta radiation, a beta ray which passes through one cell without causing damage has the chance of bringing about ionisation in one of its neighbours. Thus ionising effects are greatly increased, while those of transformation are unaltered. Although there is no absolute certainty, it is

reasonable to conclude (as the IAEA does) that the effects on human health and genetics from atmospheric carbon-14 are mainly due to beta rays from its decay. We were given no compelling evidence to refute this view.

26. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the National Council for Radiation Protection and Measurement (NCRP) in the United States have estimated the annual human dose from atmospheric carbon-14: 0.7 mrem per annum to the gonads and 1 mrem per annum to the whole body. The background radiation is about 100 mrems per annum (107). These figures which we accept as the best available estimates, show that even a doubling of the carbon-14 in the atmosphere would bring about only a very small increase in the dose to the population.

Mutant Micro-organisms

27. Dr Geiringer spoke of the likelihood of a mutant and damaging form of micro-organism arising from man-made radiation, particularly from the nuclear power industry (*Evidence*, p. 287). He warned that nuclear technology was likely to bring into circulation increasing numbers and concentrations of new radioactive elements, the biological effects of which are as yet uncharted. We asked the DSIR to refer the matter to the British Medical Research Council. Dr R. H. Mole, Director of its Radiobiology Unit at Harwell, writing in a personal capacity, made the following points (108):

(a) Micro-organisms are less mutable than mammals for the same level of radiation dose, and the mutation rate after exposure to background radiation will be relatively low.

(b) There is no evidence of mutation having converted a known non-pathogenic organism into a pathogenic.

(c) Micro-organisms in the cooling gas or cooling water of a reactor are kept to a minimum so that the likelihood of exposure is greater in the natural environment than in a reactor.

(d) One action of ionising radiation is to prevent the micro-organism from dividing. High-level exposures to radiation are self-protecting.

(e) Micro-organisms have existed and multiplied since life began to evolve.

(f) It is probable that a mutagenic agent can only cause to happen something which has previously occurred "spontaneously". Past mutations which have not survived to the present must be biologically inferior. Similar present or future mutations would disappear for the same reason.

28. The Department of Health was asked about the likelihood of a mutant and detrimental form of micro-organism arising from man-made radiation, including that from nuclear power. Its conclusions were essentially similar to those of Dr Mole:

> Any alteration in mutation rates of micro-organisms as a result of the nuclear power industry will be extremely small, and cannot be regarded as a health hazard to man or other species (109).

Dr Geiringer contested the basis of the department's conclusions in his cross-examination (*Evidence*, pp. 2123–2148).

29. Professor D. W. Beaven also doubted whether mankind should in the future carry an increasing rate of harmful mutation.

> . . . as a person generally concerned with the healing services, one must raise the real question as to whether any increased ionising radiation, however small, should be accepted with equanimity in view of the likely increase in radioactivity currently being yearly added to the gene pool as a result of the necessary diagnostic investigations being carried out by the medical profession. . . (105)

30. In spite of uncertainties in radiobiology, and issues raised above, we do not see any adequate reasons for not accepting the conclusions of the Flowers report that: "At the levels of radiation likely to be permitted in relation to possible somatic effects, the genetic effects should be of little concern". We found the interplay of argument on the possible significance of irradiation from nuclear power sources highly interesting. However, some of the contentions seemed to lack objectivity. It is known that several agencies other than ionising radiation induce among micro-organisms and viruses an inherent tendency to mutate. No one chose to describe the general situation, and show irradiation relative to other mutagenic agents likely to be working within man's contemporary environment.

Somatic Effects

31. Besides causing damage to human reproductive cells, ionising radiation may also bring about changes in the non-reproductive or somatic cells. The changes may occur soon after the cells are irradiated ("prompt" changes) or they may be "delayed", not appearing for years or even decades. The delayed changes appear as cancers of various types, and the cancer-inducing effects of high sub-lethal doses of radiation are fairly well established. Information has come from the study of the Japanese atomic-bomb victims, from the after effects of massive medical X-rays, and from experiments on animals. It was found that the incidence of cancer increased with radiation dose and in some cases was approximately proportional to the dose.

32. There are considerable uncertainties in the cancer-inducing properties of small radiation doses. Information on the effects of doses likely to be caused by the normal operation of a nuclear power station is hard, if not impossible, to obtain, for two main reasons: first, delayed radiation-induced cancers are no different from natural cancers; and, second, the number of cancers induced by radiation additional to the background is small, and fewer than the variation in the annual numbers of natural cancers. The existence of extra cancers can thus be established only by statistical means needing very large data samples to get useful results.

33. The possibility that doses below some threshold value may have no carcinogenic effect brings in further uncertainties. There is also some evidence from animal experiments that radiation given continuously or in several discrete doses is less carcinogenic than if a single dose is given within a short period. It is usually assumed that the incidence of cancer from radiation is directly proportional to the size of the dose down to zero, and is independent of the rate at which the dose is received. Although there are many uncertainties in this procedure, it is generally agreed that it leads to overestimation of results.

34. BEIR, UNSCEAR, NRCP, and the ICRP have all interpreted the available data (mainly on high dosage) to establish a relation between dose and death from cancer. The best estimate is that a dose of 1 rem to each of a million people would result in 165 lethal cancers of all forms.

Uncertainties in the calculations give a range of cancer deaths from 88 to 440. Thus in New Zealand one would expect about 50 cancers a year from natural background radiation of 0.1 rem per year. The DSIR estimates a New Zealand incidence (excluding radiation workers) in the year 2000 as 0.15 a year or one in 7 years from a world-wide nuclear power operation of 4300 GW giving a dose of 0.3 mrem a year (44). In 1973, 4700 New Zealanders died of cancer according to the official Yearbook for 1976.

35. The New Zealand Medical Association also thought that the induction of cancer was the only significant effect that needed to be considered at low levels of radiation (92). The association considered that large doses of radiation leading to prompt deaths were unlikely to be met with. It concluded that if a normally functioning reactor were to be operated to the safety standards already achievable, then the added increment of radiation received by the public would be within limits already acceptable by most people.

PERMITTED LIMITS OF RADIATION EXPOSURE

36. Several national and international bodies (among them the ICRP whose standards are advisory only) have recommended maximum permissible radiation doses for the general public as well as for workers with radiation. In New Zealand the Radiological Advisory Council sets standards which are promulgated in the Radiation Protection Regulations 1973 under the Radiation Protection Act 1965. The National Radiation Laboratory administers the regulations, and has established a service to monitor environmental radioactivity.

37. The FFGNP report discusses the permitted limits of radiation exposure and gives the ICRP summary of dose limits for individuals. The ICRP recommends that workers exposed to radiation should limit their dose of radiation to less than 5000 mrem a year over the whole body, and to prescribed higher dose rates for particular organs. This is 10 times the recommended dose rate for any of the general public. If a worker were to receive the maximum permissible dose rate all his life, it is calculated that his risk of death from cancer would increase from its normal incidence of 1 in 670 to approximately 1 in 430. According to the DSIR the health record in the nuclear industry shows in fact no signs of increased incidence of cancer (44).

38. The DSIR also commented on a contention that present radiation standards are too lenient in view of the "hot particle" theory, which states that if finely dispersed particles emitting alpha radiation are lodged in the lung then the effect of the radiation in the immediate neighbourhood of the particle is more likely to cause cancer than if the same dose was spread uniformly throughout the whole lung (44). The theory applies particularly to finely dispersed particles of plutonium. Supporters of the "hot particle" hypothesis assert that the maximum permissible lung burden should be lowered by a factor of 2000, because, by ICRP standards, allowable doses are supposed to spread over the whole mass of an organ (12). Independent investigations have supported the British Medical Research Council which reported that ". . . there is no evidence that irradiation by 'hot particles' in the lung is markedly more hazardous than the same activity uniformly distributed. . ." (4).

SURVEILLANCE AND MONITORING OVERSEAS

39. We now summarise what members of the Commission observed overseas in respect of safety surveillance and monitoring of radiation in typical working nuclear plants. At Pickering, Ontario, the plant is entered through one point in the security control office. The whole plant is divided into four zones rated in terms of potential radioactivity. In passing from a high-rated zone to a lower one, a visitor's hands and feet are machine-checked for radioactivity. At Windscale, Cumberland, one enters the chemical area after passing through a clean room where sterile overshoes and a covering garment are put on, together with radiation badge. Hands are washed on leaving the area, and checked by radiation monitor. The medical department at Windscale keeps records of all staff for 30 years including those who have left. Particular attention is given to plutonium contamination which if it occurs, is removed. The whole body is monitored every 6 months by a counter which is extremely sensitive. It can pick up the body burden of naturally occurring radioactive potassium, and even caesium-137 from bomb fall-out. At estuarine stations like Hinkley Point, Somerset, liquid effluent is closely monitored. It has been shown at Hinkley that radiation on the sea shore is unaffected by the liquid effluent.

40. It is interesting to note in this connection that one of the members of the community Liaison Committee at Hinkley has developed a private enterprise, using the water outflow from the nuclear station to rear fish in tanks for commercial sale. The benefits of using low-grade waste heat from nuclear power stations for fish farming have been demonstrated at three of the CEGB Magnox stations. Dr D. J. Groom, Senior Health Physicist (CEGB), said that it has been demonstrated that more than 70 percent of the radioactivity in fish flesh comes from the fish eating contaminated food. The amount taken up directly from the water is small compared with that from the food chain. Trout are fed with special pellets, while they are being reared, so that even though they live in water with an enhanced radioactivity, little of this is transferred to the flesh of the trout. The farmed trout have radioactivity concentrations in their flesh of about an order of magnitude lower than mature fish which have grown up in a natural lake. It has been calculated that a person eating some 35 kg of trout from the fish farm every year would receive less than 2 percent of the ICRP recommended limit for the general public. In this context it is also worth noting that during the Windscale inquiry Mr Justice Parker called for community volunteers to eat fish caught in the Irish Sea and have continual checks on the whole-body counter to determine changes in body levels of caesium-137. This was intended to assess the possibility of harm arising from the low-level liquid effluents from the Windscale plant which are at present being discharged into the sea.

41. The Ford Foundation - MITRE report concluded that there are uncertainties in assessing the effects on health of nuclear power. It stated:

> Some fuel cycle sources of radiation have not been determined precisely and the many environmental and biological pathways to man are not well understood . . . there is still considerable uncertainty about the relationship between radiation and biological effects, such as the incidence of cancer and genetic disease (12).

Later the report said that health risks, potentially involving deaths, injuries, and illness, arise at all stages of the fuel cycle, from uranium mining to plant decommissioning, and concluded that assessments of health effects from nuclear power are complicated by the fact that there has been relatively little operational experience, and data accumulated thus far have been derived from practices that are changing. Despite the large uncertainties, the general conclusion of the report was that, on average, new coal-fuelled power plants in the United States meeting new source standards will probably exact a considerably higher cost in life and health than new nuclear plants. However, both coal and nuclear power plants built in the rest of this century could have much reduced health risks relative to existing plants. This can be accomplished, said the report, in the case of coal plants by limiting sulphur dioxide and other emissions, and in the case of nuclear power plants, by improving siting and safety controls.

Chapter 12. ACCIDENTS AND COMPENSATION

INTRODUCTION

1. Although commercial nuclear power reactors have had an excellent safety record, most of those opposed to their introduction in New Zealand are concerned with what is seen to be their inherent danger. Dr S. Eklund, Director-General of the IAEA, in discussing reactor safety said:

> In over 1400 reactor-years of commercial power reactor operation no accident leading to a radiation-related disability has occurred—a kind of record that is unparalleled in any other modern large-scale industry. In spite of this record, improved safety features continue to be developed and incorporated in reactors. To help attain a high international standard in the field, member states have supported the IAEA in working out safety codes and guides for thermal power plants (110).

2. This good safety record is not universally accepted as ensuring future safety. Some reckon that the 1400 reactor-years of commercial operation is too short a time for complete confidence. The common association of nuclear power generation with nuclear weapons still continues to influence the public's views on the safety of the nuclear power industry.

3. The industry's high safety standards have led, especially in the open society of the United States, to publicity being given to minor accidents within the plant which in other technologies would not merit public attention. There have also been a few serious accidents within nuclear plants which if they had not been contained could have had serious consequences (111). Proponents of nuclear power see the operating record as indicating that the many safety features designed to cope with accidents are working effectively.

4. The safety record of the commercial nuclear power industry in Britain and the safety organisation and procedures adopted were described to us there by officers of the CEGB. They claimed in October 1977 that since the start of the board's nuclear programme in 1962, no employee or member of the public had been harmed by radiation. We quote a CEGB publication on safety measures:

> The CEGB has a statutory responsibility for the safe operation of its nuclear plant. Additionally, each station is built and operated to the conditions of a nuclear site licence issued by the Health and Safety Executive—the independent Government licensing authority—on the recommendations of its Nuclear Installations Inspectorate (NII).
>
> The Station Manager and his staff have the immediate responsibility for operating the station safely. They have to conform to operating rules and radiological safety rules. The operating rules are drawn up so that the plant is operated in such a way that it will remain safe even under fault conditions. These rules cannot be altered without the sanction of all the experts who have approved them: the NII, senior members of three CEGB Headquarters Departments (Nuclear Health & Safety, Operations, and Research), and the CEGB engineers responsible for power station design and construction. In addition certain maintenance procedures, tests and inspections have to be carried out periodically.

Neither the reactor nor any safety-related equipment can be modified without examination and agreement from CEGB Headquarters Departments and the NII. A committee for each station, which includes senior experienced staff of the CEGB, the UK Atomic Energy Authority and British Nuclear Fuels Ltd. (BNFL), meets regularly to consider proposals for any modifications to operating procedures, and to receive reports of any problems which might affect safety.

Within the CEGB there is [a] Nuclear Health & Safety Department which is independent of all other parts of the Board's organisation. [It] report[s] directly to the Chairman and Board Members, and the Department is responsible for ensuring that there is adequate provision for safety in the CEGB's nuclear plants, right through from design to operation. We have 55 qualified engineers and scientists. They include a team of inspectors who are based at the nuclear stations and carry out checks of the stations' activities. Safety assessments are also regularly carried out by the NII while the stations are being built and when they are in operation.

Another independent body, the Nuclear Safety Advisory Committee, advises the Government on nuclear safety, particularly in respect of siting policy and basic safety principles. The Committee consists of experienced engineers and scientists from industry and the universities who have no direct responsibility within the nuclear power programme (112).

It is claimed that in no other industry are so much time, expertise, and resources given over to the supervision of safety.

5. There is no disagreement that the consequences of a major reactor accident, with the release of a significant proportion of the radioactive material contained in the core, could be very serious. What we have to attempt here is to put the chances of a serious reactor accident into perspective with other dangers, and see what the consequences of such an accident would be in New Zealand. The basic question to be answered is: "Are the risks to New Zealand of a reactor accident so great that safety should be a main consideration in any decision to forego a nuclear power programme?"

6. No technology (including any kind of electric power generation) is absolutely safe. Risk of death or injury is a price of existence. Modern technological society tries to reduce the risk to what it considers to be acceptable. At this level the risks are assumed to be less than the advantages, which implies a subjective evaluation of what is an acceptable level of risk.

Quantification of Risk

7. To compare risks of various sorts one often makes probability statements about the chances of the accident happening to individuals. For example, the death rate in New Zealand each year from motor vehicle accidents is between 200 and 300 a million of the population. One could say that the individual's probability of death from a motor accident each year is between 200/1 000 000 and 300/1 000 000, and express it as 2×10^{-4} to 3×10^{-4} a year. Other sorts of risk to the individual can also be quantified from accident statistics. As the FFGNP has noted, public attitudes towards familiar risks are apparently consistent.

Types of accidents with a death risk of 10^{-3} (1/1000) per person per year to the general public are difficult to find. Evidently this level of risk is unacceptable, and when it occurs, immediate action is taken to reduce it.

At an accidental risk level of 10^{-4} deaths per person per year, people are less inclined to take concerted action but are willing to spend money to reduce the

> hazard. Money is spent for traffic control, fire departments and fences around dangerous areas . . .
> Risks of accidental death at a level of 10^{-5} (1/100 000) per person per year are still recognised in an active sense. Parents warn their children about the hazards of drowning, firearms, poisoning etc., and people accept a certain amount of inconvenience to avoid risks at this level . . .
> Accidents with a probability of death of 10^{-6} (1/1 000 000) or less per person per year are apparently not of great concern to the average person. He is aware of them but feels they will not happen to him . . . Phrases associated with these hazards have an element of resignation: "Act of God" (4).

8. Though this classification may be useful when applied to small events, public reaction is quite different towards accidents involving a large number of people at the one time. New Zealand society appears to be much more tolerant towards 150 drownings a year, than it would be towards an air crash of extremely low probability which killed 150 people.

9. As will be seen later the probability of a major accident involving the public occurring at a nuclear power plant is very small. The consequences may, however, be very serious. Because of this, there are some who consider that the consequences of a major nuclear accident are "unacceptable" no matter how small its predicted probability may be. This attitude was strongly represented to us by the Federation of Labour which said "until such time as the Government through its agencies can prove to us that there is no risk involved then we are not prepared to support nuclear power stations" (*Evidence*, p. 1079).

10. This attitude would seem to imply total opposition to nuclear power generation regardless of the fact that no technology can ever be shown to be absolutely safe. However, the Federation did not consider their stand to be irreversible. It is one which could be reviewed if there were changes in the national economy and employment, or in nuclear technology. At present it seems that the co-operation of the Federation of Labour in a nuclear power programme may be difficult to obtain because of suspect reactor-safety.

11. We noted that organised labour in both the United States and Britain has not seen this issue as a bar to union co-operation in the construction and manning of nuclear power plants. The attitude in the north-eastern United States in particular appears to be that nuclear power is the most promising source of generating electricity in a situation of diminishing alternatives, and that without the necessary electricity, employment prospects would be greatly restricted.

12. The Commission for the Future, in discussing general principles of nuclear safety, concluded that safety standards should be set at a level where the risk, as previously defined, to the general population is no greater than that imposed in everyday life (113).

FREQUENCY OF ACCIDENTS

13. Almost all of the radioactivity in a nuclear power plant is generated by the fission process in the reactor core. Most of this radioactivity will be retained within the fuel unless the fuel melts, which could happen only if the heat generated by the fission process in the fuel is greater than the heat being removed from the fuel by the cooling system. Such an imbalance can occur in only two ways: first, as a result of surges or transients in which the power generation in the core exceeds the capacity of the heat

removal systems to dissipate it; and second, as a result of a rupture in the reactor cooling-system causing a loss of coolant followed by a failure of the emergency system for cooling the core. Melting of the core does not alone create a risk to the public because it occurs within a massive containment structure. But the molten fuel could slump to the bottom of the reactor vessel and melt through the containment. Depending on the type of reactor it is also possible that the containment could be breached by pressure forces generated by thermal or chemical interaction between the fuel and the coolant.

14. If the containment does fail the radioactivity will escape. The concentration of the airborne radioactive material received by people downwind from the accident, and also that deposited on the ground, is determined by the amount of radioactive material that escapes from the reactor and the meteorological conditions at the time (the speed of the wind and the strength of the stirring or turbulent motions in the air).

15. In normal operation there are occasional controlled releases of radioactivity from nuclear plants. These allowable and carefully controlled emissions have now been reduced to the point where few critics of nuclear power consider them to be an issue of concern. The debate on nuclear safety focusses on the possibility of large accidental releases.

16. An accident releasing a substantial amount of radioactive material cannot happen unless a number of the barriers designed to limit the spread of a malfunction are breached. The safeguards in a reactor system are designed to provide a defence in depth. They comprise:

(a) large safety margins built into components, and replication of control systems to guard against defects in materials, unforeseen natural events, and possible human error;

(b) automatic back-up systems to compensate for failure of essential equipment, or for human error;

(c) the reactor enclosed in a structure designed to contain the radioactivity even if the other barriers fail.

17. The probability of the containment structure being breached with release of radioactive material cannot be estimated from operating experience. The event has never happened, and the number of years of reactor operation is still relatively small. But many of the hardware components in a reactor (valves, switches, and pipes of various sorts) have been used extensively in other technologies. Their operating record and their probability of failure are well known. If one particular component fails, and its failure is followed by a succession of failures of other components, one can postulate a chain effect leading to a release of radioactivity. If the probability of failure of each component in the chain is known, the probability of the event of the final accident occurring is found by multiplying each of the individual probabilities together if the failure of each component is independent of the failures of the others.

18. An accident sequence of four steps, with the probability of each step occurring once in 10 working years (1/10), would have a probability of $(1/10)^4$, or a chance of occurring once in 10 000 years. However, if the first failure was *invariably* followed by the other three, the accident sequence would have a probability of 1/10, a type of failure called "common mode failure".

19. In a nuclear power plant it is possible to identify the accident sequences which would follow the failure of various components. A complete analysis of accidents would require the identification of all

possible accident sequences, and the ability to assign probabilities of failure at each step of each sequence. In some cases engineering experience does not give probabilities of failure, so that a best estimate must be judged, leading to uncertainties in the calculated accident probability.

20. The technique of failure analysis described above was developed in Britain. It has been most publicised and applied most ambitiously in the United States. The AEC there initiated a reactor safety study of commercial LWRs in 1972 to assess nuclear risks realistically and to compare them with non-nuclear risks. The study known as the Rasmussen report (114), published in final form in 1975, is described in the FFGNP report along with various criticisms of it. The full report is a large, highly technical document which has been described as "virtually impenetrable to all but the professional reader" (115). As it was often referred to during our inquiry, we give here a brief account of its results, and of some of the criticism it gave rise to.

21. As explained above, there cannot be an accident in which a substantial amount of radioactivity is released without breaching a series of barriers, designed to limit the propagation of a malfunction. To calculate the total probability of a release of radioactivity, the probability of an initiating event for all possible routes to a release is multiplied by the probability that every safety barrier on those routes is breached or bypassed. The product of the probabilities for each accident route are added up for all possible routes to the release.

22. In analysing BWRs and PWRs the Rasmussen report considered a range of accidents increasing from those giving relatively small releases of radioactivity to those releasing a large part of the isotopes in the reactor core. Briefly, it showed that the probability that the core would melt accompanied by a breach of containment in the present generation of LWRs is 5×10^{-5} per reactor year, but that only 10 percent of these meltdowns are estimated to lead to substantial radioactivity releases after a containment breach (12). Thus, the Rasmussen study implies that the probability of a serious accident leading to a release of radioactivity is 1 in 200 000 for each LWR a year.

23. The Rasmussen techniques give in theory a logical basis for systematically analysing and quantifying risk. In practice there are serious problems. The American Physical Society (116), the United States Environmental Protection Agency (118), and the Union of Concerned Scientists (117) have criticised the report. These criticisms were quoted to us by Ecology Action (Otago), Friends of the Earth, and others (2, 3). We were informed while overseas that further studies are at present being made into the validity of the assumptions on which the report is based.

24. The Ford Foundation - MITRE report considered the following were the main technical deficiencies in the methods used:

(a) unknown or unsuspected failure mechanisms cannot be included in the analysis;

(b) the final answers are the result of the assigned probabilities at each of the branch points, and though these can sometimes be based on experience, they must at times be founded on judgment;

(c) the probabilities of breaching each safety barrier are not necessarily independent since common mode failures can increase the likelihood of failure of one barrier once another has been penetrated. Unless the physical mechanism coupling the supposedly independent barriers is understood, the probability of such common mode failure is uncertain; and

(d) the various probabilities may be correlated in different ways for different reactors over which safety predictions are averaged.

The Rasmussen report was also criticised by the American Physical Society for an inadequate treatment of the effects of earthquakes on nuclear plants (116). Although the criticisms appear to be valid, some of them are impossible to quantify so cannot be used to refine the estimates of probability given by Rasmussen.

25. In New Zealand estimating the effects of earthquakes on reactor safety is undoubtedly an important consideration. The Rasmussen report deals with the effects of earthquakes on the probability of LWR accidents occurring in the eastern United States. Its conclusions cannot be applied to New Zealand unless the differences in seismic risk are taken into account. The Rasmussen report assumed a reactor designed for a safe shut-down earthquake (SSE) of 0.2 g. An SSE is an earthquake which produces ground motion for which the structures, systems, and components important to safety are designed to remain functional. The report concluded that accidents induced by earthquake should not contribute significantly to reactor accident risks.

26. The MWD has applied the Rasmussen methods to an LWR situated in the central region of New Zealand and designed for a SSE of 0.67 g. They found that the probability of a core melt as a result of an earthquake was 10^{-6} per reactor year. This is 10 times higher than the United States figure, even though the earthquake is only three times as great (56). The ministry concluded that:

> The level of risk in the New Zealand study may be deemed acceptable. The WASH-1400 (Rasmussen) estimate of probability of core melt from all causes is 5×10^{-5} per reactor per year. So although the estimated contribution of earthquakes in NZ is greater than that derived in WASH-1400 it is still a small contribution to the total; it raises it from 5×10^{-5} to 5.1×10^{-5} per reactor per year.

27. The risks to reactors could be reduced in New Zealand by restricting them to less earthquake-prone areas, or by the careful selection of sites where conditions would tend to reduce the ground response to earthquake excitation. These aspects, and engineering protection serving to reduce the risk, are referred to also in chapter 9.

28. The FFGNP said about the Rasmussen report and its various criticisms:

> Although the Reactor Safety Study [Rasmussen Report] estimates of accident probability are not accepted by all authorities, it seems unlikely that they will prove incorrect by a factor of more than ten and there is fairly general agreement, again within a factor of ten, concerning the likely quantities of radionuclides which might be released in a severe reactor accident with breach of containment.

We fully agree with the FFGNP's summing up:

> It is clear that it is not sensible to accept completely or to reject outright the probability estimates and bounds [for core-melt accidents in Commercial Power Reactors] given in table 4 (iii). They can be used for taking a first step towards reaching a numerical (as distinct from a qualitative or subjective) assessment of the public risk in an overall value judgment of the costs that could offset any benefits from the introduction of nuclear power in New Zealand.

Similar probability techniques for analysing reactor safety have been used in other countries.

29. Britain adopts the pragmatic approach of assigning an upper limit to acceptable public risks, and then by means of quality assurance, engineering standards, reactor licensing, inspection, and control ensures that these risks are not exceeded (103). This is done for individual sites and reactors. The overall policy of the Health and Safety Executive has already been given in chapter 4. A comparison of the results obtained by these methods with those from the Rasmussen analysis appears to show reasonable agreement.

30. Many of those taking part in our inquiry clearly did not like having to base safety to the community on a theory of probability. The PSA, for example, expressed distrust of probability methods and their application to safety analysis (119). This attitude is understandable, especially as specific data on occurrences in nuclear power are still of limited scope and range. We commend the attitude of Friends of the Earth who, though highly critical of many aspects of the Rasmussen study, were able to conclude:

> With these reservations in mind, we nevertheless accept the RSS [Rasmussen report] as a valuable contribution to investigations of reactor safety. We do not believe it proves the safety of LWR's, nor do we believe that this claim is even made in the main report (2).

31. In the attempt to put the risk of a serious nuclear accident into some sort of perspective, comparisons have been made with the risks associated with catastrophes caused by man (air crashes, dam failures) and nature (earthquakes, hurricanes). Sir John Hill, Chairman of the UKAEA, said of nuclear reactor safety:

> Over a period of perhaps 5 years detailed comparisons with other hazards of an industrialised society have shown that tanks of chlorine or ammonia or liquefied petroleum gas, aircraft flying over football matches and large dams pose risks of equal magnitude and much higher probability (120).

ACCIDENT CONSEQUENCES

32. The consequences to the public of a hypothetical serious reactor accident have been the subject of considerable scientific and lay disagreement. The estimates of casualties and damage range from the sensational predictions of R. Nader who said: "[A nuclear accident would result in] up to 100 000 deaths and the destruction of an area the size of Pennsylvania" (121), to the less alarming estimates of the Rasmussen report. There are many uncertainties in assessing consequences. Science does not completely understand the physical and biological problems involved, and the consequences in a particular situation are critically dependent on siting, and on the weather at the time of the accident.

33. A serious accident leading to a breach of the containment vessel would be likely to cause immediate deaths, and some delayed deaths from latent cancers spread over about 30 years. The probability of a cancer developing depends on the magnitude of the radiation dose and to a large extent the age of the person exposed. In a real sense radiation emitters are carcinogens, their effect being little different from similarly classified chemical compounds. The actual consequences of a reactor accident would depend on:

(a) the fraction of isotopes of the fission product released from the core;

(b) the diffusive properties of the atmosphere at the time determining the concentration of the radioactive cloud;

(c) the population density and land use downwind of the reactor; and
(d) the effectiveness of civil defence in evacuating people, warning people to stay indoors, or dispensing iodine tablets as a precaution against thyroid cancer.

34. The Rasmussen report considered a number of accidents giving a spectrum of releases ranging from small to large fractions of the volatile fission product isotopes in the core. The consequences of an extremely serious accident in typical United States population densities and average weather conditions as found by the Rasmussen report are given in table 12.1.

Table 12.1

CONSEQUENCES OF AN EXTREMELY SERIOUS ACCIDENT

(*Source:* Ford Foundation - MITRE report, p. 224)

	Rate per Annum	Assumed Total
Prompt fatalities	–	3 300
Early illness	–	45 000
Thyroid nodules	8 000	240 000 (30 years)
Latent cancer fatalities	1 500	45 000 (30 years)
Genetic defects	200	30 000 (150 years)
Economic loss due to contamination		US$14 billion
Decontamination area		3200 square miles

35. The Ford Foundation - MITRE report said about such consequences:

> The natural decontamination time for caesium-137, the principal source of ground contamination is three to five years. It is difficult to predict how many individuals would leave their homes for extended periods to reduce their chance of eventually dying of cancer. If land contaminated in excess of current standards for permissible concentrations of caesium-137 is withdrawn from use, the economic cost is estimated in WASH-1400 [Rasmussen report] at $14 billion for the accident considered. The figure depends not only on land values but on the use of contaminated land and the effectiveness of decontamination procedures not yet developed.

It must be stressed that the catastrophe described has an extremely small chance of happening, and that the fatalities and damage listed in table 12.1 would occur only in unfavourable weather and with a large exposed population. Rasmussen gave the probability of these conditions as 5×10^{-9} per reactor year.

36. The principles used in deriving this result have been criticised. Many hold it to be an underestimation. The United States Environmental Protection Agency believed that the study understated the risk by something between one hundred and several hundred because health effects as well as probabilities of releases were underestimated (118). The Ford Foundation - MITRE report appears to arrive at much the same conclusion by taking a pessimistic view of possible accident sequences. It also stressed that the estimates apply to "average" conditions, and so cannot be applied to a particular site because consequences could differ considerably from place to place and from time to time. In spite of this the report concluded that the risks associated with nuclear accidents were acceptable in United States conditions since the average rate of loss from nuclear accidents compared favourably with that from the competing fossil-fuel technology. As the result of 20 years' experience with nuclear power, the British Government does not see doubts about reactor safety as hindering the siting of future commercial reactors near cities or towns. As the Flowers report says: "The safety of the public is considered to derive more from high standards in the design, construction and operation of nuclear power stations than from remote siting".

ACCIDENT CONSEQUENCES AND NEW ZEALAND

37. When the Rasmussen analysis is applied to New Zealand, obvious differences from the United States must be taken into account. We have fewer people; a nuclear reactor would almost certainly be built on the coast. Careful siting could greatly reduce the chances of released radioactive material being blown towards a sensitive area. As the Rasmussen report applies to average United States conditions, its results cannot be transferred directly to a specific New Zealand situation. The actual conditions of any particular site would have to be independently surveyed for safety, using probability techniques.

38. A serious reactor accident in New Zealand besides killing people could conceivably contaminate large areas of farmland, with the possible loss for years of a substantial part of our primary produce. The contamination of pasture and hence of milk by the isotope iodine-131 would be the most immediate and widespread agricultural effect. Restrictions on the use of milk from the contaminated area would probably last less than 2 months. One season's grain and vegetable crops might be made valueless over a more limited area mainly by iodine-131 but also by other radioactive products. Caesium-137 (half life 30 years) and caesium-134 (half life 2 years) would produce the greatest risk from long-term contamination of the ground. Their entry into animals and milk is greatest in the first year after release because of the direct contamination of foliage. Once caesium enters the soil, its entry to plants through the roots is much slower, except in soils low in potassium such as those found in Taranaki. Thus the concentrations in dairy products, beef, and mutton in the first few years after an accidental release, would be much higher in Taranaki (and somewhat higher in the Waikato) than they would be in the South Island.

39. The DSIR has analysed the occupational and agricultural restrictions applied after the release of radioactive materials in reactor accidents (44), and the FFGNP report has summarised related material. Casualty figures and agricultural damage produced by a very serious reactor accident cannot be confidently estimated. We fully agree with the FFGNP's qualitative estimate of the consequences:

> It is clear that in the worst possible circumstances in which a major accident as defined occurred when the wind was blowing gently onshore towards a major population centre and highly productive farm land, the personal, social and economic consequences for N.Z. could be disastrous to a degree unparalleled in our history.

One can imagine other catastrophes in New Zealand which would also have consequences unparalleled in our history. A severe earthquake in one of the main centres, volcanic eruptions in the central North Island or in Auckland, dam failures on the Waikato River could all produce disastrous social and economic effects.

40. Deaths from latent cancers for many years after a nuclear accident make comparisons with some other dangers not strictly valid. However, we think it valid to compare the risks of nuclear power with those of other methods of electricity generation. It has been claimed in Britain and in the United States that the risks to employees in a reactor programme are well below those in normal manufacturing industry (122, 123). Mr. I. D. Dick, Secretary of Mines, drew attention to the loss of human life in New Zealand associated with coal mining:

> To supply the coal necessary for one coal-fired power station to replace a nuclear station would require the underground mining of about 3 million tons of coal a year for 30 years. Over this period 20 men would certainly be killed; the probable number of lives lost would be about 50; the maximum credible disaster would be 3–500 lives lost. These figures are not hypothetical; they are regrettably based on hard, operational results (52).

41. The indications are then that under normal operations nuclear power production poses no threat to the general public, and less risk to employees than other kinds of energy production. This was emphasised through our own observations at Peach Bottom (United States), Pickering (Canada), and Oldbury, Hinkley Point, and Heysham (Britain). For any recommendations on a nuclear programme in New Zealand, the emphasis on safety should be based on the likelihood of a serious reactor accident which has a very low chance of happening. The FFGNP was definite on the matter:

> Although the likelihood of such a [major reactor] accident occurring is considered to be very small, we find the magnitude of the possible effects so great as to constitute a major factor to be considered in any decision regarding the acceptability of a nuclear power programme in this country.

42. The evidence we have heard demonstrates that the consequences of the rare serious accident depend on siting and weather. Thus careful selection of a site for a reactor in New Zealand could minimise considerably the consequences of the rare accident. A conclusion of the Flowers report gives an emphasis to safety matters which appears to us to be reasonable:

> The risk of a serious accident in a single reactor is extremely small; the hazards posed by reactor accidents are not unique in scale nor of such a kind as to suggest that nuclear power should be abandoned for this reason alone.

The Ford Foundation - MITRE report, in deciding whether the risks of nuclear accidents were acceptable, also concluded:

1. On a predicted average rate of loss basis nuclear power compares favourably with competing technologies.
2. The health and property consequences of a single extremely serious accident would not be out of line with other peacetime catastrophes that our society has been able to handle.
3. Despite large uncertainties, a reasonable upper limit or ceiling that is not in itself unacceptable, can be placed on the probability of the class of extremely serious accidents.

43. It should be stressed that the confidence of both the Flowers and Ford Foundation - MITRE reports in reactor safety is based on the nuclear industry's very high standards of technical expertise in design, operation, and maintenance. Mr G. G. Page claimed that New Zealand is lacking in some of these skills not only in the nuclear field, which is to be expected, but in quality-assurance techniques in basic engineering (124). Although safety considerations must be given the highest importance in deciding on the introduction of nuclear power in New Zealand, we believe that, if overseas standards of quality control and engineering practice can be guaranteed here, safety should not be a major stumbling block to a nuclear power programme. However, the successful adoption of a nuclear power programme in our society depends on the majority accepting it. This could be ensured only by informing the public on safety matters as fully as possible (see chapter 5).

COMPENSATION AND INSURANCE

44. In the early years of the commercial use of nuclear power, it became clear that the development of the industry would be severely restricted, if not stopped, unless limits were put on the liability of the operator of a nuclear installation for damage suffered by injury to person or losses to property. The technology was new and its safety unproven. There were few installations—too few to give that spread of risk which is the essential base for normal commercial insurance. Though the likelihood of any major accident in a nuclear power plant was regarded as being extremely small, the possibility could not be disregarded. Its likely consequences in terms of the potential liability of the operator were recognised as major in scope but difficult to quantify in its upper limits (125).

45. The main concerns of an operator of a nuclear power plant for insurance relate to: (a) the buildings, machinery, equipment, etc., comprising the plant; and (b) the potential legal liability to those who may suffer death or bodily injury, or property losses, as the result of the escape of radioactivity from the power station. The risk of damage to the buildings and plant could be quantified and insured. It was the potential liability to others that created the need for unique provisions which came to be regarded as an acceptable prerequisite to developing nuclear power in western countries: indeed, a unique law for a unique technological development. There were two further special aspects of nuclear insurance: first, the fact that personal injury caused by radioactive contamination might not become apparent for a long time after the exposure (126), and second, that damage or loss could conceivably spread over national boundaries (125). Especially in Europe the nearness of neighbouring countries was a strong incentive to developing a co-ordinated policy on liability to those suffering loss or injury.

46. Action was both positive and quick. In 1960 the Paris Convention on Third Party Liability in the Field of Nuclear Energy, was signed by Britain, France, the Federal Republic of Germany, Italy, Belgium, and most other west European countries (127). The IAEA later organised a wider international conference which led to the Vienna Convention on Civil Liability for Nuclear Damage which was signed by China, Britain, and other countries, but has not yet been implemented. In scope and concept there is little difference between the two conventions (125). They both contain two important concepts: first, the setting of an upper limit on the amount of compensation that may be claimed by third parties in the event of an accident; and second, the imposition of an absolute and exclusive liability upon the operator of the nuclear installation for third party claims.

47. Underlying the second of these concepts is the recognition of the fact that identifying and proving fault in the case of a major accident could be very difficult, and thus could effectively preclude a claimant from obtaining redress. A claimant does not now have to prove fault, but merely that the damage was caused by the nuclear installation. Making the operator exclusively liable simplifies both the insurance of the risk and the claim procedures. The operator is solely liable even if he is entirely blameless or can prove that the damage was caused by the negligence of someone else.

48. The first concept, the limiting of the amount of compensation, does not so work as to prevent Governments from providing additional compensation directly from their own resources if a catastrophe were to occur. Such provision is to be found in many countries' legislation. The United States and Canada, though neither has signed the Paris Convention nor the Vienna Convention, both incorporate the two basic concepts in their laws. The conventions also define which court will have authority over claims, define time periods within which claims must be made, and oblige operators to maintain insurance or some other financial security to cover their liability. This last provision does not apply to Governments which may, and commonly do, carry their own insurance.

Atomic Risks Pools

49. To provide the large amounts of cover needed by the nuclear industry, insurers in many countries have grouped together to form "atomic risks pools" thus enabling each country's maximum insurance capability to be marshalled at one point (125, 128, 129). Further reciprocity among national insurance pools has been established enabling risk to be spread internationally (128, 129). There are now insurance pools in at least 19 countries giving a large cover on individual installations (130). For example, in the United States, the pools are at risk for sums up to $US300 million on some nuclear power stations.

The Nuclear Exclusion Clause

50. Most if not all insurance policies issued by the insurance market and covering loss or damage to real or personal property exclude "loss or damage caused by contamination by radioactive material". The reason is that the nuclear risk is already covered by the insurance and/or Government indemnity arrangements adopted by countries with active nuclear programmes. It would amount to "double insurance" to include it in private insurance contracts. Insurance policies issued in New Zealand contain the exclusion even though, with no nuclear industry here, the risk

of such contamination is decidedly minimal. The New Zealand market has merely followed international practice.

Nuclear Insurance in Canada

51. The Canadian Nuclear Liability Act 1970 includes the most important provisions of the Paris and Vienna Conventions. The Act makes the operators of nuclear installations absolutely liable for injury or damage resulting from nuclear accidents, limits the liability of such operators to $75 million, and requires all operators other than the Crown to maintain insurance against their liability. The Act also makes provision for compensation by the Government in the event of a major accident where the liability could exceed $75 million.

52. Under the Nuclear Liability Act, the Atomic Energy Board of Canada recommends to the Treasury Board the amount of insurance to be carried by any particular installation. In the event of the insurance carried being insufficient to cover third party claims resulting from an accident, the Act enables the Government to proclaim that special measures for compensation are called for. On such a proclamation, the Act provides for the setting up of a special Nuclear Damage Claims Commission to deal with all claims for compensation. The Commission has exclusive original jurisdiction to hear and determine the claims and to award compensation. The decisions are final and conclusive, subject only to a limited right of review by the Exchequer Court of Canada, and subject also to the right of the Government to control the total amount of compensation to be paid by *pro rata* scaling of awards and other means.

Nuclear Insurance in the United States

53. In the United States the Price-Anderson Act contains the rules for indemnifying the public against damage caused by a nuclear accident. It embodies the same basic concepts as the Paris and Vienna Conventions and includes the following as two of its main provisions (131).

(a) Owners of nuclear power plants must furnish the maximum financial protection available to cover public liability claims. (The indemnity available from the insurance industry in 1957 was limited to $60 million for each installation. It has since risen to $125 million.)

(b) The Act made certain that there would be a total of $560 million for each large installation to indemnify the public. It did so by the Government undertaking to pay indemnity in excess of the market insurance cover up to the maximum. Now that there is private protection of up to $125 million, the Government's coverage has dropped from the original $500 million to $435 million. The Act further gives a means of allocating extra money should the total insurance and indemnity cover of $560 million be exceeded by claims from a nuclear accident.

The utilities in the United States are reported to pay about $100 a megawatt for the Price-Anderson governmental insurance cover (132). The Government has already collected more than $8 million without being called upon to pay out a cent (131).

54. The Price-Anderson Act was due to expire in August 1977, but in 1975 Congress passed an amending Act extending the principal Act for 10 years subject to three main changes: the limit of liability was to be

increased, the Government indemnity was to be phased out, and the indemnity coverage outside the territorial limits of the United States for certain limited activities was to be extended (125). The phase-out of governmental indemnity is to be done by a "deferred premium system" which will eventually transfer to the utilities the entire responsibility for liability protection, both for personal injury and for property damage. Under this plan, each utility will be responsible for between \$2–\$5 million protection for each of its operating nuclear plants to cover any accident that results in damage costing more than can be privately insured for. As new plants are constructed, utilities will eventually assume responsibility for the entire \$560 million specified by the Price-Anderson Act. In the longer term, if the nuclear programme develops on the scale anticipated, the limit of liability itself will extend beyond \$560 million.

Nuclear Insurance in Britain

55. In Britain the Nuclear Installations Acts 1965 and 1969 cover nuclear insurance (133). They follow the Vienna Convention in prescribing a general rule of absolute liability which channels all liability to the operator of the nuclear installation.

56. Article V of the Vienna Convention leaves it to the Government of a country to determine the limit of an operator's liability as long as it is not less than \$5 million for each nuclear incident. British law limits operators to £5 million. If this limit is exceeded, claims are to be made to the Minister instead of to the operator. All claims up to £50 million are paid out; for those beyond, Parliament provides the money and determines the extent of payment.

57. Article VI of the Vienna Convention limits the period of liability to 10 years from the date of the nuclear incident. British law sets a longer time. For the operator the 10 years is retained. But there is also a second limit of 30 years from the date of the nuclear incident within which (but after the expiry of the 10-year limit) claims are made to the Minister and met out of money provided by Parliament.

Nuclear Insurance Overseas—General Observations

58. Over the last 15 years or so, an effective pattern of collaboration and mutual support has grown up among the insurance markets of the world through the atomic risks pools. The large risks insured are thus spread internationally in accordance with sound reinsurance principles, and these arrangements are as essential to the development of the nuclear industry as they have proved to be for other large industries such as aviation.

59. By marshalling world-wide insurance capacity, nuclear insurers have not only covered material damage to the nuclear installations themselves, but have made much progress in covering the legal liability of nuclear operators. The nuclear industry is now at a stage where its record is beginning to give the experience essential to evaluating the risk and determining appropriate premium rates. There seems to be no reason to believe the insurers will not continue to give the financial protection so essential to the continued development of the nuclear industry.

60. In Britain, as in the United States and Canada, the operator's liability is absolute; that is, it is independent of any question of his negligence. Nuclear insurance thus indemnifies absolute legal obligations

imposed by statute, and represents a departure from the more normal, common-law principles deriving from the fault concept. It also imposes upon the operator of a nuclear plant financial responsibility for the consequences of the negligence of others.

61. There are some problems remaining to be solved. First, there are some general exclusions to the insurance cover: for example, genetic injuries, damage due to military operations, civil commotion, etc., deliberately occasioned damage, and damage due to natural catastrophes of an exceptional character (134). Second, it may be difficult to establish whether a delayed cancer, for example, was in fact caused by a nuclear incident, or could be attributed to some non-related cause (135). It is difficult to imagine a simple solution to the last problem.

THE NEW ZEALAND SITUATION

62. If New Zealand proceeds with a nuclear power programme, the Government will need to consider the steps to take to ensure that the public have adequate financial protection from the effects of a nuclear accident. It is assumed that any nuclear power plants here will be owned, controlled, and run by the Government itself through a State department, and that private enterprise will not play the same part in nuclear matters as it does in the United States, where the power utilities are a mixture of public and private ownership.

63. The NZED carries its own insurance, both for material damage to assets owned by the department, and for its legal liability to those who may sustain loss of, or damage to, property through NZED power generating facilities.

The Accident Compensation Act, 1972

64. The Accident Compensation Act 1972 abolished the common law right to sue for damages for personal injury or death by accident, and replaced it with statutory compensation. This means that in New Zealand anybody injured by a nuclear accident would have no right to sue the operator or anyone else for damages but would be limited to the compensation rights of the Act. The Act's purposes and scope set out in section 4 (1) are:

(a) To promote safety with a view to preventing accidents and minimising injury.

(b) To promote the rehabilitation of persons who suffer personal injury by accident in respect of which they have cover under this Act so as to seek to restore all such persons to the fullest physical, mental, social, vocational and economical usefulness of which they are capable.

(c) To make provision for the compensation of:

(i) Persons who suffer personal injury by accident in respect of which they have cover under this Act, and,

(ii) Certain dependants of those persons where death results from injury.

Irradiation and Personal Injury by Accident

65. The expression "personal injury by accident" is defined in a limited way in section 2 (1) of the Act, and specifically excludes "Damage to the body or mind caused exclusively by disease, infection or the ageing process". The Accident Compensation Commission charged with the responsibility of administering the Act commented helpfully on personal injuries suffered by persons from nuclear accidents (136):

[a] To determine whether the claimant has suffered personal injury by accident, the Commission must look at the facts of each particular case. The Commission interprets the expression "personal injury by accident" in its popular and ordinary sense, meaning (in general) an unlooked for mishap or untoward event which is not expected or designed.

[b] The results of exposure to radiation raise a number of questions under the Act. Should there be an escape of radiation from a nuclear power plant, the Commission may expect claims from persons who could show that they received injuries because of their exposure to that radiation. Such claims would be admitted. However, persons who had been exposed to radiation but who could not show that they had yet suffered any injury may have no claim under the Act. Section 150 of the Act provides for the making of a declaration of entitlement, but permits only those who have suffered *personal injury* by accident to apply for such a declaration. The Commission would have to decide in each case whether the exposure to radiation had in fact caused injury. The Commission would probably not regard the mere exposure to radiation (without injury) as giving entitlement under the Act . . .

[c] Section 67 of the Act provides cover for persons who suffer diseases which are due to the nature of their employment, where total or partial incapacity or death arises from that employment within a prescribed period. Section 67 (2) (a) provides that for the purposes of the Section "prescribed period" means: "In the case of any disease due to exposure to X-rays, ionising particles, radium or other radioactive substances or other forms of radiant energy, a period of 20 years or such other period as the Governor-General may (by Order-in-Council) prescribe."

[d] Cover is therefore provided for up to 20 years for workers who may suffer injury as the result of working in an environment which exposed them to the risk of radiation. Other persons, and the public at large, who suffer personal injury by the accidental escape of radiation will be governed by the limitations imposed by section 149 in bringing their claims. Such claims must be brought within 12 months from the date of the accident or the date of death unless the Commission is of the opinion that failure to bring the claim did not prejudice the Commission and was due to a mistake of fact or law or for other reasonable cause.

[e] The Commission's policy [in respect of ante-natal injuries] is to regard each case on its own facts and to apply the normal criteria for determining whether the injured person had suffered personal injury by accident. . . . A foetus may be killed or suffer malformations after doses of radiation as low as 50 rem if received at early stages of development (DSIR paper 7E, Summary A, p. i). Provided the relationship between the radiation and the injurious malformation of a child born alive can be satisfactorily established on medical grounds, the Commission would probably admit a claim from such a person.

[f] However, it is understood that continued exposure to low levels of radiation . . . can have a genetic effect on the reproductive cells of irradiated individuals, leading to defects appearing in later generations. This is not the same as ante-natal injuries and in the Commission's view, children born with genetic defects brought about by chromosome or other cellular damage caused by radiation exposure of a parent, would not have cover under the Act.

66. The Accident Compensation Commission raised with us the question of whether the basis of its funding might need to be specially changed to cope with a major nuclear accident (136). In its view, a catastrophic nuclear accident would probably not be significantly different in its economic effects from any other like disaster. For example, an earthquake

or engineering defect causing hydro dams on the Waikato River to collapse would have immediate economic consequences similar to those from a major incident affecting a nuclear power station in the same area. The Commission does not maintain a disaster or emergency fund to cope with natural, nuclear, or any other type of catastrophe. Its Act does not enable it to do so. Moreover, it is doubtful whether a major disaster could ever be realistically allowed for.

67. The Commission must work on the economic premise that the income for each year must meet all the costs associated with the claims made during the year, including costs incurred in future years for those claims. Thus there is a significant reserve of funds invested ($115 million at 31 March 1977). This is not a free reserve but is the amount of funds set aside to meet the cost of claims already lodged that will be settled in the future. Any major catastrophe would most likely upset this basis and cause the funds to be dissipated more rapidly, because funds held to cover future costs of claims from previous years would be needed to meet the immediate claims being filed. The Accident Compensation Commission believes that its basis of funding would be inadequate to cope with any national disaster—nuclear, earthquake, war, fire, or dam failure. Its existing reserves could prove inadequate even in the relatively short term, and some might themselves be destroyed as the Commission's investments are within the country. A great disaster would most likely call for massive Government aid—organisationally, socially, and financially.

Compensation Payable

68. The benefits payable under the Act to persons who suffer personal injury by accident as a result of a nuclear incident would be identical with those payable to any other accident victim. They include the reasonable cost of hospital and medical treatment, rehabilitation, artificial aids, lump sum payments, and where applicable, earnings-related compensation.

Liability for Third Party Property Damage

69. Although the Accident Compensation Act 1972 effectively eliminated legal liability for acts which result in death or personal injury, common law principles of liability for damage to the property of others still apply. Under common law, an occupier of land which has a nuclear installation can be liable for damage to property, even though the incident causing the damage occurred without his fault, or that of his servants, or that of independent contractors. The operator of the plant (assuming the unlikely event that he is someone other than the occupier of the land) will be liable also if the incident was caused by his own fault, or by the fault of those for whom he is responsible. This is no place to discuss these areas of liability in detail. It is sufficient that it be understood that they exist and can be onerous.

70. We have noted that many countries put an absolute liability for a nuclear accident on the operator of the plant, but limit the maximum liability for any claims. It is generally acknowledged that nuclear power plants have inherent potential to inflict damage upon the property of others. They are not alone in this. Modern technology in all its forms has the same inherent potential. However, in the case of nuclear power plants, the main perceived danger to others would follow a major release of radioactivity. Though the estimated risk of any such major accident is not high, its consequences could be very great. We shall consider here only the risk of possible damage to property.

71. There is still at large the quite mistaken notion that the reactor core of a nuclear power plant can disintegrate with an explosive force like that of the atomic bombs of the Second World War. On the contrary, a nuclear power plant can never explode like a bomb. As we have noted, its real danger is in contaminating people, land, pastures, crops, livestock, buildings, and other property after any substantial release of radioactivity.

72. The question of liability for damage to property would seem therefore to be related primarily to damage caused by radioactive contamination. Any risk of structural damage to, or physical destruction of, buildings and other forms of property is likely to be confined to the site. Radioactive contamination is another matter. It is not inevitable that irradiated property would have to be destroyed; for example, houses and commercial buildings, furnishings and equipment, motor vehicles, clothing, personal effects, and foodstuff. Some things would certainly have to be destroyed at an immediate cost to their owners. Buildings not structurally damaged but contaminated would have to be evacuated until they could eventually be decontaminated. Decontamination would be expensive. The owners would need alternative accommodation, business would be disrupted, other equipment would need to be hired. These are some of the consequential losses that would follow a nuclear accident, and be the likely subject of claims and damages.

73. The owners of farm land could face considerable losses from radioactive contamination. The DSIR pointed out that, in the worst conceivable accident involving rupture of the containment vessel and the release of a significant fraction of its volatile constituents, the consequences could be disastrous if the prevailing wind spread the released activity over pastoral land. Much of the normal beef and mutton exports of the area could be restricted for up to 10 years; the cost (due mainly to loss of the use of the land) could exceed $1000 million. It can be seen therefore that huge claims for property damage could follow the worst conceivable reactor accident (see paragraph 38).

The Earthquake and War Damage Act 1944

74. This Act replaced the original War Damage Act 1942 and extended protection from war damage to damage caused by earthquake shock and earthquake fire. Parliament has seen it as a convenient vehicle for compensating property losses from other natural causes of unusual scope and severity, and has amended it from time to time to cover these additional risks. We discuss the suitability of the Act in respect of nuclear risks.

75. Under this Act, the Earthquake and War Damage Commission insures material property in New Zealand for damage which directly results from war, earthquake, extraordinary disaster, storm, flood, volcanic eruption, and landslip. Two features of the Act are relevant here:

(a) Only property which is insured under a contract of fire insurance made in New Zealand is automatically insured under the Act.

(b) By regulations under the Act automatic insurance provisions exclude any land, any livestock, any growing crops (including fruit trees and vines), any ensilage insured in the open fields, and any hay or other cut crops insured in the open field. Property excluded from the automatic cover may be voluntarily insured with the Commission on such conditions and at such rates as it may determine.

76. The Act as it stands would thus cover a nuclear risk only if an earthquake or any of the other natural convulsions specified *directly* caused the nuclear accident leading to nuclear damage, and then only for certain classes of property if such property were already insured in New Zealand for fire risk. Excluded property (land, livestock, crops, etc.) would not be covered in the event of nuclear damage. The Act as it stands has only limited application to nuclear damage to property.

77. A large reserve fund has been built up—$268 million at 31 March 1977. But this is clearly not big enough to cover a major disaster—say a force 8 earthquake centred on or near Wellington. There is no reinsurance, and the funds are mostly invested internally in New Zealand Government securities. A major disaster would require massive Government subsidy if this was within the power of Government to give. We think that the fund as at present constituted and financed should not be considered a sufficient security to people who may suffer property loss from a major nuclear accident.

RECOMMENDATIONS FOR INSURANCE ACTION

78. If a nuclear power programme was implemented in New Zealand, the Government would need to consider very carefully the desirability of introducing in legislation the main concepts of the Vienna Convention: (a) that absolute and exclusive liability be placed on the operator of the nuclear facility; and (b) that the liability of the operator be financially limited. Under (a) above, as the liability for death and personal injury has already been abolished by the Accident Compensation Act 1972, the only remaining liability is for damage to the property of others, for which the fault concept under common law still applies. We see advantages in modifying these common law rules for nuclear damage to property, as has been done overseas.

79. In regard to (b) above, New Zealand is in a peculiar position. Under the Accident Compensation Act the aggregate payments that can be paid to all the victims of a nuclear accident are not limited, nor should they be limited unless a similar limitation applies to the victims of other major disasters. It follows further, that if a monetary limitation cannot in equity be applied to nuclear victims suffering death and injury, then, maybe, no such limitation should be applied to those who suffer damage to property from a nuclear accident. It may therefore be considered undesirable in New Zealand to follow the overseas practice which limits the operator's financial liability.

80. The Government will need to consider also the adequacy of both the Accident Compensation Fund and the Earthquake and War Damage Fund to cope with the financial obligations likely to arise from any major disaster, nuclear or otherwise. The financial stability of both funds must be open to question should any such event occur. This is a matter for governmental policy decision. Countries overseas have found it desirable to avoid anything approaching a guarantee without limit. We would prefer to see a similar approach in New Zealand but we do not see how this could be done without a major restructuring of the present legislation.

Chapter 13. THE REGULATORY CONTROL OF NUCLEAR INSTALLATIONS

1. Because the world-wide development of commercial nuclear power is not without potential dangers to people and their environment, it has been recognised that both international surveillance and control, and the domestic establishment of licensing and regulatory procedures, are needed in all countries that already have, or plan to introduce, this method of generating electricity.

INTERNATIONAL AGREEMENTS

2. New Zealand's membership of international organisations, and its treaty obligations must be considered in any discussion of the use here of nuclear energy. We thus record them before going on to examine the nature and functions of any licensing and regulatory authority that would need to be set up should it be decided to introduce a nuclear power programme. They were set out for us by the Ministry of Foreign Affairs (78).

3. New Zealand is a member of the IAEA which was founded as a United Nations agency in 1957. It has more than 100 member States who send representatives each year to the headquarters in Vienna. It has among its functions the promotion of the peaceful uses of nuclear power and the establishment and administration of safeguards in respect of nuclear activities, including the transport of nuclear materials and the protection of fissile material. It organises many technical and scientific symposia and publishes their proceedings. It determines basic radiation standards which are based on the recommendations of the ICRP. These are advisory only for member States but binding on States that receive IAEA materials, services, or equipment under an agreement with the agency. Such States are also subject to the detailed safeguards system of the IAEA which provides for inspection by its inspectors.

4. Although New Zealand is a member of the OECD and the IEA (see chapter 3), it is not yet a member of the NEA established by OECD. The NEA has an active secretariat in Paris and promotes a number of scientific conferences whose proceedings are published. It also runs a system of technical committees including the Committee on Radiation Protection and Public Health (CRPPH) which maintains a continuous review of radiation protection standards. Generally, OECD and NEA foster principles which are subsequently incorporated in the administrative and legal systems of member States.

Safeguard Measures

5. New Zealand is a party to the 1968 Treaty on the Non-Proliferation of Nuclear Weapons (NPT) aimed at preventing the diversion and misuse of nuclear materials. According to the treaty, States party to it undertake not to divert "nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices". As a consequence of the treaty, States must conclude agreements with the IAEA for the application of safeguards on all peaceful nuclear activities on their territory or under their control. Such an agreement has been completed between New Zealand and the IAEA.

Other International Treaties

6. New Zealand is also party to: the 1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, or Under-water; the 1972 Convention on Prevention of Marine Pollution by Dumping of Wastes and Other Matter (commonly known as the London Convention); and the 1959 Antarctic Treaty. These treaties and agreements bind New Zealand under international law. They are particularly relevant to the questions of protecting the environment from pollution by nuclear material, and of preventing the diversion of nuclear material for military purposes.

Pollution Aspects

7. The London Convention prohibits the disposal at sea of high-level radioactive wastes, with two exceptions only: first, where dumping is necessary to avert a threat to the life of the crew or passengers of a vessel or aircraft; and second, where there is an emergency involving a threat to human life which has no other possible solution. It is implemented in New Zealand by the Marine Pollution Act 1974, which prohibits the dumping of all waste except that the Ministry of Transport can under Part II of the Act, issue permits to dump waste material, such permits requiring strict regard for New Zealand's obligations under the Convention. Article IV of the Antarctic Treaty binds New Zealand not to dispose of any radioactive waste in Antarctica.

Diversion of Nuclear Material

8. The Test Ban Treaty prohibits the carrying out of any nuclear explosion if it could cause radioactive debris to be present outside the territorial limits of the country in question, and in effect, stops New Zealand from ever carrying out a nuclear explosion. The 1968 NPT amplifies this obligation by obliging New Zealand to refrain from receiving, manufacturing, or otherwise acquiring any nuclear weapon or explosive device.

9. It goes further. Article III puts all fissionable material under IAEA safeguards to verify that nuclear energy is not being diverted from peaceful uses to nuclear explosives. It also obliges New Zealand not to provide other States with any nuclear equipment or material which might be diverted to military uses unless that State also accepts IAEA safeguards.

10. The safeguards agreement concluded between New Zealand and the IAEA has not yet been activated, but in accordance with the Protocol to the Agreement it will be activated when New Zealand actually gets specified quantities of nuclear material. There is an obligation to inform IAEA at least 6 months before acquiring such material. Under Article VII of the Non-Proliferation Treaty, New Zealand must maintain a system of accounting for, and control of, all nuclear material subject to safeguards. The IAEA may send inspectors to make independent measurements and observations. These obligations bind the New Zealand Government under international law. Presumably, the only reason they have not been made law here is that the safeguards agreement has not yet been activated.

11. It is also to be noted that before New Zealand could obtain nuclear material it would need to demonstrate to the supplying country that it had set up an effective safeguards system. Supplying countries in their turn, must not send nuclear materials to any other country unless satisfied that those materials will be subject to safeguards, and cannot be diverted to military uses (78).

REGULATORY CONTROL SYSTEMS—OPTIONS AND CHOICES

12. Every country which has, or is building, nuclear power stations has found it necessary to set up some form of regulatory authority to oversee their design, construction, and operation in the interests of public safety. The forms and functions of these regulatory bodies all have this basic aim, though they may vary among countries. In this section, we give a broad outline of some of the main conceptual and practical differences among the regulatory bodies established in North America, Britain, and Europe. We then consider a possible framework for the New Zealand nuclear regulatory authority that would need to be set up before introducing a nuclear power programme into this country. Much of the material about European practices comes from the submissions of the DSIR (No. 7) and the MWD (No. 16).

13. Variations in regulatory procedures stem largely from differences in the political organisations, the administrative structures of a government, and the nature of the nuclear industry and its degree of development in each country. An historical study of the regulatory systems in OECD countries shows further that these systems have changed as circumstances and technology have changed, and as the need to modify and strengthen the regulatory structure to fulfill basic aims has been perceived. In all OECD countries care has been taken to ensure that the regulatory authority is, and is seen to be, independent of the power utilities (whether publicly-owned or not), and clearly separated from promotion or development. We see this scrupulous observance of independence and integrity to be of paramount importance in working out the criteria for a regulatory authority in New Zealand.

14. The demonstrable separation of the regulatory from the promotional function has been a recent development overseas. For example, the United States Atomic Energy Commission (USAEC) was responsible for setting and enforcing safety standards for power utilities, and also for research, development, and disseminating information to encourage the use of nuclear power. This led to public criticism of the USAEC, and to suggestions that it was allowing its promotional function to influence its attitude to safety. Though the factual basis of such criticism was uncer-

tain, public confidence was weakened, and in 1975, the United States Government abolished the Commission and established two new authorities, the Energy Research and Development Administration (ERDA), and the Nuclear Regulatory Commission (NRC), each with clearly defined and separated functions.

THE UNITED STATES

15. As required by the Energy Reorganisation Act 1974, the NRC was set up on 19 January 1975, and took over the AEC's former work in regulating the commercial uses of atomic energy. We rely very largely on an NRC publication for the material in this section of our report (79). Those planning to build and operate a nuclear power plant must seek approval from the NRC whose licensing process is a two-stage procedure. The first comprises the filing of an application for a construction permit and a review of this by NRC staff. The second comprises the filing of an application for an operating licence, and a similar review of this.

The Application

16. The application for a construction permit must contain a detailed description of the proposed site and proposed design of the plant, and other relevant information required by the NRC regulations. The applicant must also submit an environmental impact report for the proposed plant, and, further, must submit a separate volume of information to allow the Department of Justice to determine whether construction and operation of the proposed facility would be affected by anti-trust laws or policies. A public hearing may be held on anti-trust matters, and these must be resolved before a construction permit can be issued.

Acceptance Review

17. Each application is at first reviewed by the NRC staff to establish the adequacy of its contents. Then also the applicant's quality assurance programme for design and procurement is substantially reviewed and inspected. If the application satisfies the NRC requirements, it is formally accepted for detailed review.

Construction Permit Hearing

18. The NRC is required by the Atomic Energy Act to hold a public hearing before a construction permit can be issued. This is conducted by an independent, three-man Atomic Safety and Licensing Board. The NRC gives notice of the public hearing which will be held on the environmental and safety matters that are identified in the notice. Some months may elapse between the issue of notice and the actual hearing to ensure full public participation in the decision-making.

Environmental Statements

19. Using the applicant's environmental impact report as a base, a "draft environmental statement" is prepared which considers in detail the environmental impacts associated with constructing and operating the proposed facility, and assesses them in terms of the available alternatives and the need for power. The statement is circulated for review and

comment by appropriate Federal, State, and local agencies, and interested members of the public. A "final environmental statement" is normally issued about 7 months after receiving the applicant's environmental report, and is introduced into the record of the public hearing.

20. The public hearing on environmental matters and issues related to the suitability of the site is usually held near the proposed facility. If the Licensing Board's findings are favourable, it may then authorise the NRC to issue a "limited work authorisation" (LWA) to the applicant.

Limited Work Authorisation

21. An LWA allows the applicant, at its own risk, to do the following: prepare the site for construction; install temporary facilities to support construction; excavate power plant structures; and construct service facilities and those not associated with the nuclear parts of the plant. The first LWA can be augmented to allow construction of foundations for the nuclear portions of the plant if such work is needed to maintain continuity of construction. The NRC must evaluate the proposed foundation designs and related safety issues, and these matters must be the subject of a further public hearing.

Advisory Committee on Reactor Safeguards (ACRS)

22. While the environmental review is taking place, the safety aspects of the application have been under review by NRC staff, leading to a detailed "safety evaluation". This is made available to the public, and is reviewed by the independent ACRS. The ACRS gives a written report to the NRC, and this becomes part of the public record. The review procedures normally take about 15 months.

Safety Hearing

23. When these reviews are completed the Atomic Safety and Licensing Board reconvenes the public hearing. If its findings on safety issues are favourable, the board may authorise the NRC to issue a construction permit. The initial decision, and any appeals from it made by any of the parties to the hearing, are reviewable by the Atomic Safety and Licensing Appeal Board.

Operating Licence

24. After about 2 years of construction work, the applicant files a final, technical, safety-analysis report with its application for an operating licence. NRC staff and the ACRS give this the same thorough review as they did for the construction permit. If all requirements are met, the NRC gives notice that it is considering issuing the licence. The notice allows anybody whose interest may be affected by the proposed action the right to petition the NRC to hold a public hearing. If no hearing is requested, the NRC issues an operating licence after the safety and environmental reviews are completed, a quality assurance programme for operation has been implemented and approved, and the facility has been inspected to make sure it has been built properly and is ready for fuel loading. If a request for a further public hearing is granted, the issue of an operating licence will depend on favourable findings by the Atomic Safety and Licensing Board. The Board's decision is open to appeal to the Atomic Safety and Licensing Appeal Board.

25. NRC staff, through its inspection and enforcement programme, watch over the facility during the whole licensing process and throughout its lifetime to ensure compliance with the permit, licence, and NRC regulations.

Possibility of Future Change

26. The regulatory and licensing process in the United States has evolved over a long time. There can be many years between application for a construction permit and its issue because the public are deliberately involved in decision making through the various public hearings and appeal facilities. The issuing of an operating licence can be further delayed, particularly if another public hearing is asked for and granted at that stage. No fault can be found with the comprehensive nature of this machinery set up in the interests of public safety. However, there is some concern that the protracted procedures can adversely affect both the capital cost and the programme timetables of nuclear plants considered necessary to meet electricity demand. It has been reported that President Carter will seek to get a Bill through Congress in 1978 to streamline the regulatory and licensing process and substantially reduce both the long lead-time before construction can start, and, by adopting standardised design and safety features, the construction time itself.

EUROPE EXCLUDING BRITAIN

27. The DSIR in its submission 7 gave two references for summaries of licensing and regulatory control of nuclear installations in Europe (80). Though there is no need to quote detail, it is interesting to note some of the differences between the United States and European practices. In Europe, West Germany has the only written regulations for licensing and regulating nuclear power plants. This does not mean that other European countries do not impose controls, but rather that detailed design criteria are rarely written into laws and regulations. Instead, codes of practice, or rules, are administered by the licensing or regulatory authorities.

28. The DSIR pointed out certain differences between the United States licensing regulations and those of some European countries (81). The United States has far more regulations and guides than West Germany, and generally is more inclined to quantitative requirements. European regulations appear to be more concerned with safety systems, including passive failures, and reflect the siting of plants near load centres in densely populated areas. The United States tries to prevent sabotage mainly by administrative controls and armed guards on perimeters. The more direct European method protects inner areas by making violent entry from the outside world a time-consuming job. As for licensing, countries such as Switzerland, West Germany, and Italy, have typically 60 to 100 licensing steps before an operating permit can be obtained. In Italy, some 50 individual systems-review approvals must be overcome before a plant is completed. In containment design, European regulations (except the French, Spanish, and Italian), unlike the United States, specify double containment and aircraft impact resistance on all units. For combination loadings, West German regulations (unlike the United States general design criteria) do not recognise the possibility that an accident resulting in loss of coolant could be induced by a shut-down earthquake.

29. The early designs of European plants followed NRC standards, since the sellers were mainly based in the United States, and sold systems as "turnkey" projects. European standards were developed more recently—West German regulations were approved only in 1974—and reflect local characteristics, for example, of population density, seismic design, probabilities of aircraft impact, anti-terrorist protection. A greater departure from NRC designs may be expected as domestic industries develop.

BRITAIN

30. In Britain nuclear safety is regulated by the Nuclear Installations Acts 1965 and 1969. The Acts are administered in England and Wales by the Secretary of State for Trade and Industry, and in Scotland by the Secretary of State for Scotland. These Ministers have very wide discretion in the use of their regulatory powers, and no organisation other than the Atomic Energy Authority or a State department may construct or operate a nuclear reactor without the site being licensed by the responsible Minister. The Ministers are also empowered to attach to a nuclear site licence any safety conditions considered necessary, and these conditions can then be legally enforced under statutory penalties. The flexibility of these powers makes it possible to frame conditions to protect the operators and the public from ionising radiation on any of the licensed sites. The Nuclear Installations Inspectorate set up in 1959 when the first four commercial nuclear power stations of the "Magnox" type were in various stages of construction executes the detail of the Act. The safety regulation of power reactors is primarily concerned with the safety assessment of designs, commissioning and operating procedures, and inspection during construction, commissioning, and operation, as well as with evaluating proposed sites. However, for any installation licensed under the Acts, the inspectorate must judge the adequacy of the safeguards provided to prevent an escape of radioactivity or emission of ionising radiations which might cause harm to operators or to the public. This judgment involves assessing the risks of accidents and their consequences, and requires a thorough understanding of the processes and the engineering and control of nuclear plants.

31. The Minister can under the Act require the applicant for a site licence to publicise the proposal and give notice to specified public and local authorities who have 3 months in which to make representations about it. When all interested parties have been given an opportunity to comment or to object to the proposed station, the Minister decides whether their interests are affected to an extent which makes it desirable to hold a public inquiry. If the local planning authority objects, the Minister is obliged to hold an inquiry. Public inquiries have been held on seven of the applications for consent to build a nuclear power station, but only one nuclear power station proposal has been turned down after an inquiry.

32. Compared with the United States procedures, which spell out in great detail the broad area of safety requirements with which the applicant must comply, those of Britain are built upon the philosophy that nuclear power plant operators have a duty under the law to build and run their plants safely. The onus of satisfying the inspectorate in a positive way that the proposed plant will be safe and the site suitable is placed

fairly and squarely on the applicant. The power to impose and enforce conditions to the nuclear site licence gives the inspectorate adequate control over the design, construction, and operation of a nuclear plant. A licence may be varied at the Minister's discretion. This makes it possible to amend, add, or revoke licence conditions at any time. In practice these are kept as free as can be from technical detail, and the licensee is encouraged to prepare his own procedural and technical documents which meet the intent of the various licence conditions, with the advantage that the operators are involved in setting the safety standards and controls with which they have to comply. With the approval of the inspectorate, these can be amended at any time, and implemented by the issue of a simple legal document called a "consent-approval". In this way safety controls can be modified or introduced to meet problems as they arise, with a minimum of delay and interference to the operators on a nuclear site.

33. The licence conditions and the procedural and technical documents drawn up under them are the framework for safety control. This does not relieve the licensee of his responsibility for safety, nor does it ensure safety. The British nuclear industry has an enviable safety record which tends to demonstrate that the operators of nuclear power plants have made safety a prime consideration in all their activities, and that the regulatory procedures are effective (82).

CANADA

34. In Canada, the nuclear industry is regulated by the Atomic Energy Control Act, and regulations made under it. The Atomic Energy Control Board (AECB) was established under the Act in 1946 with its primary role defined as:

> in the national interest to make provision for the control and supervision of the development, application and use of atomic energy, and to enable Canada to participate effectively in measures of international control of atomic energy which may hereafter be agreed upon.

The regulations prescribe among other things that no person shall, unless exempted in writing, operate a nuclear facility except in accordance with a licence issued by the AECB.

35. The licensing of nuclear power stations in Canada includes the issue of a site approval, and two formal licences, for construction, and for operation. The applicant first applies for a site approval and supports the application with a document known as a "site evaluation report" which gives enough information to enable the AECB to determine the suitability of the site proposed. The report includes a summary description of the station, outlining the plant size, reactor type, basic process, and safety systems, together with information about land use, present and future population density and distribution, main sources and movements of water, water usage, meteorological conditions, seismology, and geology. The AECB will issue a site approval if satisfied that the site is suitable for the construction of a reactor of the size and type proposed.

36. Next, the applicant must apply for a construction licence, supporting the application with a "preliminary safety report" which documents the information essential to ensure that the health and safety of the operating staff and the public would be protected should the station be constructed. If satisfied, the AECB will issue a construction licence,

subject to the condition that the preliminary safety report be updated annually as the detailed design and construction of the station proceed.

37. Finally, the applicant may apply for an operating licence when construction is almost completed, submitting a "final safety report" to document the "as-built" design of the station, the updated analyses of postulated accidents, and the capability of safety systems to prevent or limit the consequences of such postulated accidents. Only when the AECB is satisfied that the plant has been designed, constructed, commissioned, and staffed adequately, and that it can be operated safely, will an operating licence be given.

38. This brief outline shows that Canadian procedures tend to be closer to the British than to those of the United States. They differ from the British in that the licences are issued by the AECB rather than by the Ministers responsible; but in the requirement that the applicant must satisfy the authority about essential technical and engineering details bearing on safety, rather than having to comply with details specified by the authority, there is remarkable similarity in the prescribed procedures (83).

A NEW ZEALAND NUCLEAR REGULATORY AUTHORITY

39. In May 1976, the NZAEC set up a subcommittee to be responsible for recommending a framework for a New Zealand regulatory authority. The report was completed in February 1977 and was presented to our Royal Commission (84). Part II of the report contains a useful aggregation of material on regulatory practice in general, its aims, and brief descriptions of the nuclear regulatory processes used in various western countries. The report acknowledges its debt to publications of the IAEA, which, among a wide range of services, offers expert advice on regulatory matters. Part III makes specific recommendations for the framework of a New Zealand regulatory organisation. The substance of these recommendations and our comments on some of them follow.

Recommended Framework—General

40. The subcommittee considered that the best organisation for regulating nuclear activity in New Zealand should have the following shape. There should be set up a statutory authority with independent powers of decision, serviced by a small permanent staff, and directed by a senior technical administrator. The Director and permanent staff should be public servants attached to an appropriate State department for routine administration only, but responsible to the authority and not to the permanent head of the "home" department. The number of the permanent staff will be influenced by the extent to which the authority is able, and finds it technically, administratively, and economically desirable, to call on outside expertise. It is assumed that the authority will be given ready access to expertise in State departments, thus limiting the need to build up technical staff. The NZED suggested that 15-20 trained staff would be needed by the time of the construction of the first nuclear unit.

41. The subcommittee decided against attaching the permanent staff even for routine administration to a constructional or operating department such as the MWD or the NZED, or to an environmental agency with an independent role (the Commission for the Environment), or to any

agencies which could have or could be seen to have a role in promoting nuclear energy (the MER or the DSIR). No recommendation was made on where the authority should be housed.

The Authority

42. The subcommittee recommended that an authority called the "Nuclear Power Regulatory Authority" (NPRA) should be established immediately after any governmental decision to adopt nuclear power generation, and that it should consist of five members: three from outside the State Services to be appointed by the Governor-General by Order-in-Council for a term of 5 years, one of whom should be chairman; the Director-General of Health *ex officio*; and the Director-General of the DSIR *ex officio*. The Director of the authority should attend meetings by right as an observer and adviser. (The subcommittee noted the apparent anomaly between the recommendation that the Director-General of the DSIR be an *ex officio* member of the authority and the inclusion of the DSIR among the organisations likely to be regarded as nuclear promoters. The anomaly is more apparent than real. In any case it will be essential to the authority's proceedings to have as a member a scientific administrator of high calibre as a member).

Legislation

43. The NPRA will need statutory authority to:
(a) adopt design and siting safety criteria and standards that must be followed to assure the safe operation of nuclear power stations;
(b) review the design of nuclear power stations to ascertain that the design meets the design safety criteria and standards;
(c) assess the safety of proposed nuclear power stations to determine if the degree of safety is adequate to assure the protection of the public and the environment;
(d) issue construction permits and operating licences for nuclear power stations;
(e) conduct a programme of compliance inspections and audits;
(f) require the shut-down of any nuclear power station where inspection shows that an unsafe condition exists, or is likely to develop, or that the requirements of the NPRA are not being complied with;
(g) license and inspect all phases of the nuclear fuel cycle, including transport, waste management, and safeguards.

The legislation should bind the Crown.

Staff

44. The subcommittee's recommendation that NPRA permanent staff should be public servants has the advantage of providing a career structure within the State Services. However, the Royal Commission considers that there should be flexibility to allow the board both to employ people from outside the State Services (from overseas or within New Zealand), and to seek assistance from the range of expertise already within the State Services. There would be decided advantages by way of cross-fertilisation.

Political Accountability

45. The subcommittee weighed the alternatives of the NPRA being directly accountable to Parliament (as is the Auditor-General), to the Prime Minister (as is the Head of the Security Service), or in the usual departmental fashion through a Minister to Cabinet. It concluded that:

(a) The NPRA should report formally to Cabinet through an appropriate Minister, but made no recommendation about which Minister, except that he should not have any responsibility for constructing or operating nuclear power plants, for independent environmental auditing, or have any "taint" of promoting nuclear activity.

(b) The NPRA should report annually to Parliament through the Minister, and also to the Minister about each specific licensing decision made.

(c) The NPRA should have independent decision-making powers which could not be overridden either by the head of the department to which it is attached or by the Minister to which it is accountable.

(d) Despite this, because the authority will be an agency created by the Government for the purpose of executing governmental policy (that is protecting people, places, and property from radiation hazards associated with the establishing of nuclear reactors in New Zealand), it is essential for the Government to have some means of assuring that its policy is being followed. The subcommittee considered that the best device (already in use in other contexts in New Zealand) was to require the NPRA by law to "have regard to the views of Government as formally communicated to it by the Minister". By this means the Government would not be able to direct the NPRA to a course of action which the NPRA considered undesirable or against the public interest. But the NPRA likewise would not have unfettered regulatory and licensing powers to adopt standards or enforce decisions which were contrary to governmental policy on public safety.

Structural Relationships

46. The subcommittee saw the present responsibilities of the Department of Health under the Radiation Protection Act 1965 continuing, and being complementary to those of the NPRA. It did not recommend any structural relationship between the NPRA and the present NZAEC. Nor did it see any need for the NPRA to have any structural relationships with local bodies. Although the NPRA must assess the health and safety needs of proposed sites, the applicant would have to obtain such other approvals as are required (e.g., under the Town and Country Planning Act 1953 and the Water and Soil Conservation Act 1967), and to go through the normal reporting procedures on environmental impact. It envisaged that a preliminary site assessment by the NPRA would be regarded as a precondition before consideration by district planning authorities, regional water boards, and the Commission for the Environment.

CONCLUSIONS

47. Though overseas licensing and regulatory matters are by no means uniform in their specifics, they all share the aim of public safety, and protecting property and the environment.

48. In western countries there is a growing involvement of the public in the decision-making process. The advantages of this should not be overlooked in New Zealand. The United States procedures laid down by legislation and NRC regulations are designed for a strongly-developed nuclear power industry comprising a wide variety of utilities, suppliers, and contractors. Because of this, great care has been taken to prescribe in detailed written form a range of design and safety criteria of formidable proportions. In Britain and Canada, where the shape and composition of the industry bears little resemblance to that of the United States, there is a different approach. As in Europe, only broad guidelines and rules are prescribed. We consider that this approach would be most suitable for New Zealand. The point of view was expressed to us in Canada, however, that the Canadian regulatory authority might find it an advantage to reduce more of the details to writing than is presently the case, so that people proposing to construct nuclear plants would know better what criteria they have to meet.

49. We add the observation that the source from which any nuclear plant is to be bought could well have an influence on the form the regulations should take. For example, if light water reactors from the United States were to be imported, it could be necessary to draw heavily from the NRC regulations. The Codes of Practice recently prepared by the IAEA are likely to be of great help. These cover governmental organisation for the regulation of nuclear power plants, safety design, quality assurance on safety, safety in siting, and safety in operation.

50. We do not consider it necessary to outline any legislation that would be needed to establish a regulatory authority. We note the relevant statutes and regulations already in force: The Atomic Energy Act 1945; The Radiation Protection Act 1965; The Radiation Protection Regulations 1973; The Transport of Radioactive Materials Regulations 1973. Some amendment or repeal of these Acts and regulations may be needed after considering the content of any new legislation.

51. The report of the subcommittee of the NZAEC is a valuable structural outline of the necessary legislation if the Government should decide to proceed at an early date with a nuclear power programme. But should a commitment to nuclear power be delayed, it is clear that the subcommittee's proposals would need review in the light of future developments elsewhere including any modification of present IAEA recommendations.

52. We cannot stress too strongly the dominant need for a New Zealand regulatory authority to be, and to be seen to be, an authority of complete independence and integrity, with no promotional or development functions.

53. We consider that the DSIR is the most suitable department to whom the regulatory staff should be routinely attached, and that the authority should report finally to Cabinet through the Minister of Science.

54. The subcommittee's report does not try to prescribe any particular qualifications or experience for the three members proposed to be appointed to the authority from outside the State Services. Though there is no uniform opinion overseas on the matter, we believe that a scientific or engineering background might be desirable, but should not be considered essential because of the fund of technical expertise that would be available to the authority from its staff and its consultants.

Chapter 14. THE COST OF NUCLEAR POWER

INTRODUCTION

1. Economic implications must be taken into account in considering the likely consequences of a nuclear power programme for New Zealand. In this chapter we compare the cost of producing electricity from nuclear sources with that from the more conventional fossil fuels, coal and oil. We believe such to be the most useful economic comparison. Chapters 7 and 15 consider briefly the production costs of hydro and geothermal. Geothermal has a competitive edge over other forms, but its potential for future development has yet to be defined. We do not here consider hydro costs for we do not regard hydro as an alternative for future base-load plant. Chapter 4 quotes certain claimed unit costs for nuclear power in the United States and Britain, but in the present chapter we consider in detail the likely unit cost in New Zealand and how that cost compares with the other fossil-fuel alternatives available. The wider economic implications of a nuclear power programme are considered in chapter 15.

2. Production costs per unit of delivered electricity at the power station gate are to be derived from the various components comprising: (a) the capital investment required to establish the power plant as an operating unit, and the progressive amortisation of such investment over the economic life of the plant, together with interest on it; (b) the annual cost of operating and maintaining the station; and (c) the fuel costs for each unit of energy. None of the components of unit costs should be considered in isolation. Nuclear power stations are characterised by high capital costs and relatively low fuel costs compared with thermal power stations generating steam by burning fossil fuels. In the latter, fuel costs are relatively higher. Nuclear stations are best suited to operating at high output factors, that is, as base-load stations rather than as intermediate or peak stations. It is axiomatic that the output factor of any generating station feeding power to a grid system is a critical aspect of its economics.

3. Various methods can be used for testing the economic advantages of the various types of generating stations one against the other. Whichever method is used, it is necessary to ensure that similar comparisons are made with alternatives that will perform the same function in the power system. Therefore, for the purpose of economic comparison, a nuclear plant must be compared with other base-load alternatives. Similarly, any comparisons should be made between plants of equivalent generating capacity as costs per unit of electrical output should decrease as generating capacity increases. This comes from the savings in labour and materials that can be made in building the larger plants, and from further savings that can follow the sharing of common services by a number of generating installations in the one complex.

HISTORICAL ESCALATION OF CAPITAL COSTS

4. The capital costs of nuclear power plants have risen a great deal in the last decade, and though most of the published information is of American origin and experience, it is likely that the trend applies to other countries which have started a nuclear power programme.

5. The IAEA gives comprehensive and impartial guidance on nuclear power planning to its member States. An important part of this service is advice on estimating capital costs which are a major factor in costing nuclear power generation. Published capital costs of nuclear plant vary widely, and previous IAEA extrapolation of United States cost experience to developing countries has proved to be consistently low. The IAEA therefore convened a meeting of experts in April 1976 to produce an improved method of estimating capital costs in developing countries. The report of this meeting was prepared by G. Woite and will be referred to here as the Woite report (176). Because they are relevant to any country investigating a nuclear power programme, the Woite report estimates were used by the NZED as a starting point for its own calculations of capital costs. We therefore discuss the Woite methodology and findings. It noted that economic studies can be done either in current or in constant value monetary units, but that, because of easy comparability and checking of input data and results, nuclear power planning studies and capital cost estimates sponsored by the IAEA were prepared in constant value units (normally $US). The report further noted that:

> the unit capital costs of LWR plants within the same size range appear to have been multiplied by a factor of about six over a span of eight years. Since neither the cost of the equipment nor the amount of construction labour required showed increases of this magnitude, the situation obviously calls for further analysis. The first step of this is a separation of "accounting" increases due to inflation from "real" cost additions arising from unexpected new requirements or other reasons.

6. The Woite report on real cost increases concluded that: "After bringing cost experience and estimates to a common denominator by expressing them in terms of constant value money, it turns out that real costs of nuclear plants have increased by about 100% over the last five years [April 1971–April 1976]. The combined effect of real and accounting increases has led to consistent underestimation of future nuclear plant costs."

It gave the following reasons:

(a) *Regulatory Impact.* Substantial increases in safety and environmental protection requirements, and higher standards relative to quality assurance and quality control, had a significant effect in increasing capital investment to an extent which could hardly have been foreseen in the earlier years of commercial nuclear power. "Analyses of the combined effect of regulatory requirements lead to the conclusion that they have increased the capital costs of nuclear power plants by a factor of two since the early years of commercial nuclear power."

(b) *Escalation.* "Annual inflation rates in industrialised countries increased considerably since the early years of nuclear power. This leads to a greater relative impact of escalation during construction. Extended design and construction periods reinforce this effect. Whereas in 1969 [in the United States] escalation during construction was estimated to be about 25 percent of direct plant costs, it is now [1976] estimated to be more than 100 percent of direct plant costs. Higher inflation rates lead also to higher nominal interest rates. Together with extended design and construction periods, this means that the relative importance of interest during construction (IDC) has increased as well." IDC in 1976 was estimated to be about 50 percent of direct plant costs including IDC on escalation. This compared with a figure of 20 percent in 1969.

Economic Competitiveness of Nuclear Power

7. The Woite report further concluded that the complexity of today's energy economics made it difficult to frame a clear definition of the economic competitiveness of nuclear power. The situation varied from country to country, depending on energy resources, regulatory requirements, and unit sizes. In industrialised countries, fossil-fuelled units will have to be equipped in future with air quality control systems (AQCS) unless they burn low-sulphur fuel. Since the AQCS will add considerably to the capital (as well as operation and maintenance (O and M)) costs of fossil-fuelled units, nuclear power will remain competitive for base-load electricity generation in industrialised countries, except in regions where very cheap (that is, strip mine) coal is available. The position may well be different in developing countries, and it is necessary to evaluate the competitiveness of nuclear and conventional energy resources specifically for every country considering the introduction of nuclear power.

8. In 1973, when crude oil for oil-fired generating stations was $2 to $3 a barrel, it seemed that nuclear power had a bright future, with the prospect of having possibly a one-third share of the energy market by the end of the century. Within a year the oil price had soared to $8 to $12 a barrel, and, as many countries wished to reduce their reliance on imported fuel, the rapid development of nuclear power appeared even more assured. However, by the end of 1975, it became apparent that, except for a few countries, nuclear power growth was receding to targets even below those considered before the oil crisis. Aspects of this strangely paradoxical situation were considered by R. Krymm in a paper published in an IAEA bulletin (177). He noted that it brought into question the actual cost comparisons between fossil-fuelled and nuclear generating stations. Based on USAEC data, in current dollar terms the cost of LWRs had increased substantially with time, the 1974 estimate being a factor of nearly six over the 1967 estimate. Neither equipment nor labour costs had increased at this rate, and the reasons for the apparent discrepancies were revealed in a USAEC report Wash-1345 as being largely related to inflation and high interest rates. Interest during construction, and escalation during construction (which was negligible in 1967), had combined to almost double the construction cost by 1974. Similar figures were evident for fossil-fuelled units, but these units had an advantage over nuclear stations in lead times. Krymm noted that, for a nuclear system, the time from the contract for the steam supply system to commercial operation was about 90 months, whereas it took only 72 months for an oil-fired system. With high interest rates and inflation such factors have obvious importance.

9. Notwithstanding the factors noted above, Krymm concluded that nuclear power stations appeared to have a decided advantage in generating cost over fossil-fuelled stations, and that the reasons for the declining nuclear power programme were to be sought elsewhere than in economics.

SUBMISSIONS ABOUT NUCLEAR POWER COSTS

10. A number of submissions gave us estimates relevant to likely nuclear power costs in New Zealand. Quite the most helpful of these were those of the NZED (62), Professor R. H. Court on behalf of the Environmental Defence Society Inc. (178), and Ecology Action (Otago) Inc. (3). These were the only ones to treat the topic in depth, and only those of the NZED estimated the unit costs of delivered electricity from the power station. Those of Professor Court and Ecology Action (Otago) were largely confined to estimates of capital costs. References to likely costs of nuclear power plants were made in other submissions, but figures used in these were generally unsupported by any evidence we could regard as authoritative.

11. Professor Court most usefully drew attention to some of the factors likely to affect capital costs of nuclear plants in this country. His evidence received wide publicity, and was directly or indirectly used as a reference source in many other submissions. His professional status had a bearing on this, as had his basic contention that the capital cost of the NZED project if started now and completed around 1984 would amount to a figure in excess of $2 billion, and his further conclusion that if the project was begun in 1982 and completed around 1990 the final overall cost could be decided now only on the basis of a highly speculative imagination.

12. While some of Professor Court's conclusions were challenged, particularly in cross-examination, we acknowledge that he caused the NZED to undertake a major clarification of the costs submitted in its background paper. We propose to deal first with the submissions of the NZED, and then consider briefly the criticism of the department's figures by Professor Court, Ecology Action (Otago), and the Treasury.

The NZED Submissions

13. In its background paper the NZED estimated the cost of a twin 600 MWe (net) nuclear station as NZ$924 million in early 1976 dollars made up as follows (40):

Basic cost taken from the Woite report (176): ...	$840 million
Plus 10 percent seismic allowance (to meet New Zealand conditions):	$84 million
Total:	$924 million

This capital cost estimate includes all direct and indirect costs at site for a complete power station in working condition, but excludes the initial load of fuel and "other costs" associated with the training of personnel by the NZED and other departments, arranging legislation to cover the construction and operation of a nuclear reactor, setting up a licensing organisation, and preliminary site investigation and system studies. The Woite report estimated that for a developing country these costs would be US$10 million to US$15 million or more. Costs outside the scope of supply of the power station (including roading, transmission facilities, and land purchase) could amount to a further $30 million. The NZED noted that information on the likely cost of decommissioning a nuclear station is sketchy at best, but that, even if an allowance of $20 million (in 1976 terms) was made for decommissioning a 2 × 600 MWe station, the contribution to unit generating cost would be less than 0.002 cents per kWh.

14. In a later submission the NZED agreed that a factor representing IDC was omitted from its initial submission under "other costs" (62). The two NZED submissions differed also in their calculations because of (a) a more rigorous representation of the time at which fuel costs must be paid; and (b) a more detailed enumeration of "other costs". Transmission costs (which are normally ignored as being common to all alternatives) had also been considered. In paragraphs 15 to 28 we give details of the NZED capital cost estimate supplied in its submission 118.

15. The NZED began its derivation of the capital cost of the power station from US$700 per kWe (net) at April 1976 costs. This figure is taken from the Woite report and includes all direct and indirect costs for a complete power unit at a non-ideal site and meets early 1976 United States licensing requirements, but it does *not* include: (a) interest during construction, (b) escalation, (c) the main power transformers and switchyard, (d) road and transmission facilities, (e) initial fuel, (f) owner's costs (land purchase, staff training, quality assurance, commissioning, public information facilities, etc), and (g) costs associated with "introducing" the first nuclear power project into the country (legislation, initial training, licensing authority, etc).

16. The basic cost of NZ$840 million (equivalent to $700 per kWe) is for a 1200 MWe station designed and built to withstand a horizontal earthquake force of up to 25 percent of gravitational force (0.25g). In its study of accident probabilities from earthquake in central New Zealand, the MWD used a value of 0.67g for the SSE (56). Thus, if the station is built in such a region, a cost additional to the basic must be added for protection against large earthquakes. From an IAEA study (179) the NZED included an allowance of 10 percent of the basic cost for this purpose, and noted that the seismic allowance could vary considerably and that a site-specific study would be needed in each case. Furthermore, research and development may result in cheaper methods of giving the needed protection. For example, a base isolation system of earthquake protection being investigated and developed in New Zealand may substantially reduce the cost (180).

17. The NZED estimate of total basic cost of NZ$924 million (1976 dollars, after including a seismic allowance of $84 million) is the sum of annual cash payments needed in the period before power production begins (table 14.1). To the money paid when construction is finished, there should be added a return on the money invested over the time from spending the money to completing construction. This is done in line (b) of the table. The currently required rate of return on Government capital investment is 10 percent per annum, and it will be seen from the table that an IDC factor calculated on this basis effectively adds $421 million to the basic cost figure, to give a total capital cost figure of $1,345 million (1976 dollars) excluding initial fuel. By comparing lines (a) and (b) of table 14.1, one can see that the required return on investment has a much greater effect on money spent early in the project than on money spent near commissioning. For this reason, it has a greater effect on the capital cost of nuclear plant, which has a long construction period, than on alternatives which can be completed in a shorter time.

Table 14.1

NUCLEAR POWER STATION CAPITAL COSTS
(2 × 600 MWe PWR)

(Source: NZED submission 118)

	Years from Commissioning									
	–9	–8	–7	–6	–5	–4	–3	–2	–1	–0
	DATE*									
	1982–83	1983–84	1984–85	1985–86	1986–87	1987–88	1988–89	1989–90	1990–91	Total
Capital expenditure spread	1%	3%	7%	13%	20%	20%	21%	11%	4%	100%
(a) Capital expenditure (in April 1976 millions of N.Z. dollars)...	9	28	65	120	185	185	194	101	37	$924m
(b) Capital expenditure plus required return on investment (in April 1976 millions of N.Z. dollars)†	21	57	120	203	284	258	246	117	39	$1345m

*The dates given here are based on an April 1991 commissioning date, obtained by averaging the October 1990 and October 1991 commissioning dates proposed in the 1976 Power Plan. They are not intended to imply expected commissioning dates.

†The required return on investment convers interest during construction, etc.

Line (a) is a simple spread of the $924 million basic cost (e.g., 9 = 1% × 924).

Line (b) equals line (a) plus the required return on investment assuming the expenditure each year is made halfway through the year. A 10 percent per annum rate is used. (e.g., $21 = 9.2 \times 1.1^{8.5}$)

18. The method of calculating costs in 1976 dollars of constant purchasing power as in lines (a) and (b) of table 14.1 is often referred to as the "constant dollars" or "real terms" approach. The NZED uses this method throughout. An alternative is to use inflating dollars, the "current dollars" or "money terms" approach. Under this method the costs shown in line (a) of the table would be inflated up to the years in which they apply. Thus, the money spent in the year 1982–83 would be represented in currency of 1982–83 purchasing power, and so on. The total of the current dollars method would be greater numerically than the total of the constant dollars method by an amount equal to the assumed inflation. Thus, if the total in current dollars was tied to an April 1991 completion date 15 years ahead, and inflation was assumed to be 6 percent per annum, these results would be 2.40 times greater than the result in constant dollars. (The $2.40 = 1.06^{15}$.) The current dollars method, because of the difficulty in forecasting future rates of inflation, presents problems which are avoided in the constant dollars approach. It was mainly for this reason that the NZED used the latter method.

19. The NZED estimates that the required capital investment (including IDC) in oil- and coal-fired stations of equivalent capacity, based upon known New Zealand experience, is significantly less than that for a nuclear plant, thus (in millions of 1976 dollars):

Nuclear	Oil	Coal
\$1,345	\$384	\$492

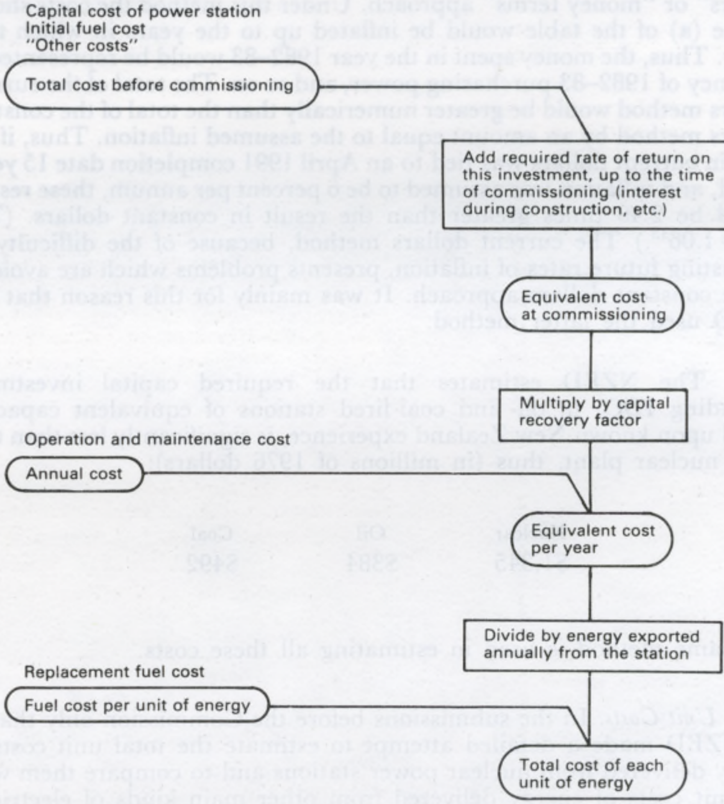
The same method is used in estimating all these costs.

20. *Unit Costs.* In the submissions before the Commission only that of the NZED made a detailed attempt to estimate the total unit costs of energy delivered from nuclear power stations and to compare them with the unit costs of energy delivered from other main kinds of electricity generation. The NZED used the constant dollars method throughout their estimates. To determine the total cost of the electrical energy produced by a power station it is necessary to view the capital cost incurred at date of commissioning (see paragraph 17) as a cost that must be recovered over the life of the station. The amount which must be recovered each year is determined by using a "capital recovery factor", which takes into account the economic life of the station and the assumed rate of return on money. The annual cost of running and maintaining the station must also be added. The total annual cost is divided by the energy exported from the station during the year, taking into account the output factor of the station (the ratio of the energy actually produced to the energy which would have been produced had the station operated continuously at maximum capacity). Fuel costs per unit of energy are added to determine the total cost of each unit of electrical energy at the power station. The cost of the delivered energy can be determined at some point away from the station by taking account of transmission costs and losses, the effect of which is to increase unit costs marginally. Figure 14.1 shows in flow diagram form the methodology used by the NZED to assemble the different cost components.

Figure 14.1

FLOW DIAGRAM FOR CALCULATION OF THE TOTAL COST OF ELECTRICAL ENERGY

(*Source:* NZED submission No. 118)



21. The NZED's comparison of the unit costs of nuclear generation with the unit costs of energy produced by thermal power stations burning coal or oil, using the same method, is shown in table 14.2. Totals A in this table include all costs associated with producing the energy at the power station. Totals B reflect the addition to totals A of the cost of transmission lines and the effect of transmission losses up to high voltage bulk supply points, but do not include subsequent distribution costs or losses between the supply points and individual consumers. The costs for all three options assume one power station containing two 600 MWe generating units.

22. It should be noted that the estimates for the nuclear alternative relate to the PWR type reactor, assumed to be built to meet early 1976 United States licensing requirements. Included in the nuclear cost figures is the total estimated cost of setting up the infrastructure needed to introduce nuclear power (training, legislation, licensing authority, etc). Subsequent stations would not need to bear these costs, although the operating costs of the licensing authority would be a continuing cost of nuclear power generation, having a marginal effect on nuclear unit costs.

Table 14.2

COMPARATIVE COSTS OF ALTERNATIVE FORMS OF BASE-LOAD ELECTRICITY GENERATION

(*Source:* NZED submission 118)

	Nuclear (PWR)	Coal	Oil
Interest and repayments on capital costs of power stations	1.939	0.709	0.554
Fuel cycle costs:			
Initial fuel	0.157	0.017	0.040
Replacement fuel	0.507	1.000	2.300
Operation and maintenance ...	0.125	0.104	0.099
Other costs	0.186	0.082	0.082
A: Total energy cost at power station	2.91c/kWh	1.91c/kWh	3.08c/kWh
B: Total cost of delivered energy ...	3.00c/kWh	1.98c/kWh	3.16c/kWh

(All values expressed in cents per kilowatt hour (c/kWh) in April 1976 New Zealand currency.)

NOTES—

(i) Totals A: As in the background submission (No. 11), all costs associated with producing the energy exported from the power station are included.

Totals B: The cost of transmission lines and the effect of transmission losses, up to high voltage bulk supply points but not distribution to individual consumers, are added.

(ii) The costs for all alternatives assume one power station containing two 600 MWe generating units.

(iii) The total cost of setting up the infrastructure required to introduce nuclear power (training, legislation, licensing organisation, etc.) has been charged against this first station; subsequent stations would not bear this cost.

(iv) The station is assumed to be built to meet early 1976 United States licensing requirements.

(v) The costs shown here are costs to the New Zealand Government. They are not necessarily the direct costs to the consumer.

(vi) The use of PWR costs as the basis for nuclear power costs does not indicate a preference for that type on economic or other grounds; BWR and CANDU costs are less readily available.

(vii) Assumptions:

Average output factor	70%
Station economic lifetime	30 years
Interest rate over life of station (with no allowance for inflation)	10% p.a.
Exchange rate*	NZ$ = US$1
Cost of coal	NZ$25Wte
Cost of oil	NZ$95/te
Cost of yellowcake...	US$35/lb ($77.2/kg)

*The exchange rate at 1 April 1977 was NZ$1 = US$0.9558

23. *Capital costs* of the nuclear power station, estimated to be equivalent to $1,345 million at the time of commissioning, are recovered with interest over the station's life against the electrical energy produced by the station as shown in table 14.3, to give a cost for each unit of energy of 1.939 cents per kWh.

24. *Fuel Costs.* Table 14.4 shows the components of cost for the initial fuel and for replacement fuel as projected by the NZED. According to the figure shown, the total fuel cost per kWh is estimated to be 0.664 cents. If

the spent fuel is not reprocessed, the effect on fuel costs would be relatively small; alternatively the reprocessing cost would eliminate the credit for recovered uranium.

25. *Operation and Maintenance Costs.* The NZED estimates of O and M costs for a nuclear station are based on the IAEA *Nuclear Power Planning Study Manual,* appendix E. Adjusted to convert to 1976 currency, and to a 70 percent output factor (contrasted with the 65 percent output factor used in the *Study Manual*), the O and M costs work out at the 0.125 cents per kWh shown in table 14.5.

26. *Other Costs.* Costs which do not fit into the categories already mentioned are shown in table 14.6. These result in a unit cost of 0.186 cents per kWh.

27. *Total Unit Cost of Nuclear Energy.* By summing all the components of cost, the total estimated unit cost of the energy exported from a 2 × 600 MWe nuclear power station is shown in table 14.7 as 2.914 cents per kWh.

Table 14.3

INTEREST AND REPAYMENT OF THE PWR POWER STATION COST, PER UNIT OF ENERGY

(*Source:* NZED submission 118)

Capital cost, including required return on investment	$1,345 million
Assumed economic life of station	30 years
Required rate of return on investment ...	10 percent p.a.
Capital recovery factor (at 10 percent p.a., 30 years)	0.10608
Annual repayment rate	$1,345 million × 0.10608
=	$142.7 million
Number of hours in a year	8,760
Net power from station	1.2 GW (1200 MW)
Assumed average output factor	70 percent
Annual energy produced (average)	8760 × 1.2 × 70%
=	7358 GWh
=	7358 million kWh
Unit cost to cover capital and interest payments on power station	$\frac{\$142.7 \text{ million} \times 100}{7358 \text{ million}}$
=	1.939c/kWh

(April 1976 New Zealand dollars)

The above does not provide for:
(i) The main power transformers and switchyard;
(ii) Road and transmission facilities;
(iii) Initial fuel;
(iv) Owner's costs (land purchase, staff training, quality assurance, commissioning, public information facilities); and
(v) Costs associated with introducing the first nuclear power project into the country (legislation, initial training, licensing authority, etc.)
which are provided for elsewhere. It therefore does not represent the total money outlaid at the time of commissioning.

Table 14.4

COST OF INITIAL AND REPLACEMENT FUEL FOR A 2 × 600 MWe NUCLEAR STATION (PWR)

(Source: NZED submission 118)

Component	Assumed* Cost	Initial Fuel: Quantity*	Initial Fuel: Cost $m	Replacement Fuel: Quantity per year (at 70 percent output factor)	Replacement Fuel: Cost c/kWh
Yellowcake (U_3O_8)	$77.2 kg U_3O_8 ($35/lb)	479 400 kg U_3O_8	37.0	215 000 kg U_3O_8	0.226
Conversion to UF_6	$5/kgU	406 500 kgU	2.0	182 300 kgU	0.012
Enrichment	$120/kgSWU	250 800 kgSWU	30.1	120 000 kgSWU	0.196
Fabrication	$130/kgU	93 240 kgU	12.1	28 480 kgU	0.050
Reprocessing	$150/kg spent fuel	93 240 kg spent fuel	14.0	28 480 kg spent fuel	0.058
Credit for recovered uranium	Based on Yellowcake (and enrichment) costs	87 000 kgU at 0.74 percent enrichment	−6.7	27 340 kgU at 0.9 percent enrichment	−0.042
Credit for recovered plutonium	†	571 kg (fissile)	–	218 kg (fissile)	–
High level waste management	$17/kg spent fuel	93 240 kg spent fuel	1.6	28 480 kg spent fuel	0.007
Total cost of initial fuel:			$90.1m		
Total cost of fuel per unit of electricity produced:			0.157c/kWh‡	0.507c/kWh	

(Associated transport costs are considered to be included within the above costs).

Notes on table 14.4.

*kg U_3O_8 is the weight in kilograms of the U_3U_8.
kgU is the weight in kilograms of the uranium content of the fuel. One kg of U_3O_8 contains 0.848 kg of uranium.
kg SWU is a measure of enrichment quantity.

†Recovered plutonium has value as a recycled fuel in thermal or breeder reactors, but since it is not being used in this way no plutonium credit is included here. An assigned value of $15 per kg would yield a 0.05c per kWh credit.

‡The initial core of fuel constitutes a fuel inventory which is maintained throughout the station life. It is therefore treated as a capital cost which is paid off over the life of the station, as opposed to replacement fuel which is directly related to the amount of energy produced and can be treated as a running cost. Payment of most of the $90.1 million for the first loading of fuel must be made about 2 years before the station is commissioned. Interest during this time brings the total cost at time of commissioning to $109.0 million (at the 10 percent rate of return). Assuming as with the capital cost of the power station, that this fuel inventory is discounted over 30 years at a rate of 10 percent p.a., and that the station achieves a 70 percent output factor:

the annual repayment rate = 109.0 million × 0.10608 = $11.56 million p.a.

$$\text{unit cost of initial core} = \frac{11.56 \text{ million} \times 100}{7358 \text{ million}} = 0.157\text{c per kWh.}$$

Table 14.5

OPERATION AND MAINTENANCE COSTS FOR NUCLEAR POWER STATIONS

(*Source:* NZED submission 118)

Basic cost in 1975 assuming 65 percent output factor ...	0.122c/kWh
Factor to adjust to 1976 currency	× 1.1
Factor to adjust to 70 percent output factor	$\times \frac{65}{70}$
Operation and maintenance costs	0.125c/kWh

Table 14.6

OTHER COSTS FOR NUCLEAR GENERATION

(All costs in April 1976 New Zealand currency for a 2×600 MWe station.)
(*Source:* NZED submission 118)

	Cost ($m)	Years Before Commissioning	Equivalent Cost at Commissioning ($m)
Costs to prepare for nuclear technology (initial training, licensing, legislation, preliminary studies)	15	9–15	47.7
Regulation during construction ...	4.5	0–9	7.1
Land purchase	2	10	5.2
Prelimiary engineering and studies ...	5	9–14	15.1
Construction or improvement of road, rail, and harbour facilities	10	7	19.5
Barges and trailers	2	6	3.5
Main transformers and switchyard ...	9	0–1	9.4
Power station staff training	5	0–3	5.8
Other owner costs: (quality assurance, commissioning, insurance during construction, general and administative costs, public information centre) ...	9	0–10	15.0
Total Station costs:	46.5		80.6
Decommissioning	16	30 years after commissioning	1
Total of other costs	$77.5 million		$129.3million

Table 14.7

TOTAL COST OF THE ENERGY AT THE POWER STATION: NUCLEAR (PWR)

(All costs in April 1976 New Zealand currency for a 2 × 600 MWe station)

(*Source:* NZED submission 118)

Interest and repayment on the power station capital cost	1.939c/kWh
Fuel cycle costs:	
Initial core	0.157c/kWh
Replacement fuel	0.507c/kWh
Operation and maintenance costs	0.125c/kWh
Other costs	0.186c/kWh
Total:	2.914c/kWh

Table 14.8

COST OF DELIVERED ENERGY FROM A NUCLEAR POWER STATION

(All costs in April 1976 New Zealand currency for a 2×600 MWe station.)

(*Source:* NZED submission 118)

Cost of energy exported from station	2.914c/kWh
Cost of transmission line (two double circuit 220 kV lines, 2 × 400mm² conductor) ...	\$16 million
Cost of line per unit of energy exported from station ...	$\frac{16 \times 0.10\,608 \times 100}{7358}$ $= 0.0231$c/kWh
Transmission loss at full load	28 790 kW
Line loss factor for 70 percent output factor	0.59
Energy lost in transmission	$28\,790 \times 8760 \times 0.59$ $= 149$ million kWh
Total cost of delivered energy	$(2.914 + 0.023) \times \frac{7358}{(7358 - 149)}$ $= 2.998$c/kWh

This assessment of the cost of delivered energy, which includes transmission costs, must be treated as approximate because of the uncertaintities in the assumptions.

28. *Transmission Costs.* The added cost of delivering the energy to consumers is common to almost all alternative methods of energy production (although it can vary in size), and is therefore usually omitted. The cost of delivery depends on the power station site, the location of the consumers, and the existing transmission network, and the power stations. If a total transmission distance of 100 kilometres is assumed, the effect of transmission on the cost of nuclear power would be as shown in table 14.8. The NZED emphasised that this assessment of the cost of delivered energy is only approximate because of the uncertainties in the assumptions. It will be observed that the total cost of *delivered* nuclear energy is estimated by NZED to be 2.998 cents per kWh.

Environmental Defence Society Inc. Submissions

29. In essence, Professor Court's submissions on behalf of the Environmental Defence Society Inc. held that the NZED's capital cost estimates were substantially understated, and that nuclear electricity, if it is ever generated in New Zealand, will be extremely expensive. He claimed that electricity could only be generated in New Zealand by nuclear stations at such a "huge" cost that there was "no way . . . [it] could be used to produce sufficient new wealth to come anywhere near paying for the stations, let alone to provide a net economic gain to the country". Although he refrained from saying so explicitly, his submissions implied that nuclear electricity was likely to prove much more expensive than alternative forms of generation, and should not be countenanced on that ground alone.

30. During cross-examination it became clear that there were differences in the source material and methodology used by the NZED and Professor Court which we were unable to reconcile. It was felt, after cross-examination and detailed consideration, that the NZED submission was a more acceptable statement for the purpose of comparison with alternative forms and contained more complete source material. However, Professor Court's submission caused the NZED to examine closely and amend its earlier estimates, particularly in its third submission 118. Professor Court agreed (*Evidence* p. 1372) that he had made no attempt to consider the comparative economics of other forms of electricity generation.

Capital Cost Estimates of Ecology Action (Otago) Inc.

31. Ecology Action (Otago), in a submission which dealt with many other aspects of the nuclear debate, devoted a section to an estimate of the capital costs likely to be incurred in implementing a nuclear power programme in New Zealand (3). The current dollars method was used. This meant that the extent of future monetary inflation, together with interest during construction, was included in the capital cost. The main problem in this approach is in projecting future rates of inflation.

32. Ecology Action started with the cost figures in 1976 New Zealand dollars used by the NZED and projected them into future dollar values as they estimated them. Initially a factor of 1.59 was applied to the NZED figure of $924 million, which raised it to $1,470 million, assuming a flat rate of 10 percent for inflation during the construction period. (No exception can be taken to an annual 10 percent if it is an acceptable rate for inflation so far ahead. But if it is included, care must be taken to see that it does not recur in another later factor.) However, a further

adjustment is made in the submission by using a factor of 2.18 to raise the $1,470 million to $3,200 million on the basis of its representing "a figure for [future] escalation and interest during construction". This is a factor derived from historical figures over the period 1969–75, and includes many of the elements of extra costs (for example, further safety and environmental requirements, longer construction periods) which the Woite figures covered up to 1976. Obviously IDC must be taken into account. Also the possibility of inflation running at an average above 10 percent should be allowed for. But escalation at past historical rates should not be automatically projected into the future, for it could well be that the very significant upward movements due to more stringent safety requirements and lengthening construction periods evident in the years 1969–75 are not likely to be as significant in the future.

33. Uncertainties such as these have led us to agree with the NZED that the constant dollar method is more helpful for our present purpose which is mainly to compare the unit costs of nuclear power with those of other forms of generation. We must add, however, that the Treasury, though accepting that the constant dollar method is appropriate for construction projects, thought it not altogether suitable for a nuclear project, for "escalation of the total capital cost and escalation of fuel prices somewhat higher than expected would need to be allowed for in some way". We must also make it clear that Ecology Action's submission drew these matters of additional inclusions and the figures to our attention, not so much to establish their accuracy as to demonstrate to us what could happen in an area beset by so many uncertainties.

Treasury Comments on the NZED Economic Comparisons

34. The Treasury indicated to us that it had not developed its own expertise on nuclear power, and therefore would not try to enter any debate about what nuclear power is likely to cost (76). In the course of evidence, the Treasury representatives stated that the methodology of parts of the NZED economic appraisal had been examined while the submission was being prepared, and some suggestions had been made. It was conceded that the mechanics of the approach taken by the NZED appeared legitimate. Despite its stated intention of refraining from entering the nuclear costs debate, the Treasury later criticised the NZED appraisal. It was the Treasury's view, based upon a "brief survey of the literature on the cost of nuclear power stations", that the NZED had underestimated the costs in various areas.

35. The Royal Commission tried to obtain a co-ordinated or jointly agreed report from the Treasury and the NZED, but the Treasury, after acknowledging the limitations of its own research into costs, explained that it could see little merit in pursuing an extended discussion as it had not been possible to reach a consensus of views on the question of the construction and operating costs of nuclear power stations. It felt that this was symptomatic of the scarcity of reliable information. The nuclear power option in its view could be deferred for at least 20 years, and because of this, a detailed cost estimate would be of little value, since nuclear technology, costs, and methods are subject to continual change. It considered that the NZED cost estimates did no more than indicate a general order of magnitude.

36. We received a further communication from the Treasury dated 17 November 1977 after our hearings had concluded. It contained additional

comments about the likely cost of nuclear power generation in New Zealand, but the fact that the department's officers were not subjected to cross-examination thereon should be noted.

37. The Treasury assessed some effects on potentially significant costs as:

(a) A longer construction time because the New Zealand economy is based on limited resources.
(b) Decommissioning costs which might well be greater to meet standards higher than those implied in the NZED estimates.
(c) Although overseas data can be found to show similar escalation rates for coal-fired and nuclear stations, in New Zealand the escalation rate for coal-fired stations should be less than that for nuclear when low-sulphur Huntly coal is used.
(d) Though the Treasury agreed that the constant dollar method used by the NZED was acceptable, it pointed out that, when escalation rates were greater than the general rate of inflation, and differential rates of escalation applied to different components of the economic analysis, some weighting of the constant dollar approach would be necessary. In the case of nuclear power, escalation of total capital cost and escalation of fuel prices should, in its view, be allowed for in some way.
(e) Likewise, as the balance of payments is a main (if not the main) constraint in the real growth of the New Zealand economy, the Treasury felt that there should be some weighting to reflect the real value of foreign exchange expenditure in the total cost, especially for large projects involving a substantial foreign exchange component. The higher total amount of foreign exchange needed for nuclear power in both fuel and capital costs compared with a coal plant using local coal would weigh strongly against nuclear power.

38. For this reason the Treasury did not favour conserving indigenous fossil fuels or refusing to exploit undeveloped hydro and geothermal resources at the expense of imposing additional strains on foreign exchange which has an opportunity cost or real value greater than its nominal value in terms of New Zealand currency. In this connection it is of interest to note the comparative implications for overseas expenditure given in a paper presented in May 1977 to the third New Zealand Energy Conference by S. Wong and M. Hewlett of the NZED. These related to the options of using nuclear energy, imported oil, indigenous coal, and imported coal in station units of like capacity, and were based on the assumption that 50 percent of capital expenditure and all fuel expenditure (with the exception of that for indigenous coal) would be incurred overseas, with all costs present-valued to the first year of commissioning of a station. The analysis revealed that, over the expected lifetime of the plants, oil demands most foreign exchange, followed by imported coal, nuclear power, and indigenous coal, thus:

Type of Plant	Overseas Expenditure (in $ million)
Nuclear—	
Capital	640
Fuel	322
Total	962
Oil—	
Capital	190
Fuel	1546
Total	1736
Indigenous Coal—	
Capital	238
Fuel	...
Total	238
Imported Coal—*	
Capital	238
Fuel	773
Total	1011

*Assume delivery to station at $30 per tonne

LIKELY COSTS OF NUCLEAR POWER

General Comment

39. As New Zealand has no nuclear experience, any assessment of the likely costs here of nuclear power must be largely based upon overseas experience, a point made in the evidence given to us on this issue. Though we were impressed by the fairness and objectivity of the NZED submissions, and found it difficult to fault the methodology used, we had some reservations about the assumptions upon which the calculations were based—assumptions which could lead to both under- and over-estimating. We refer to these below. We have accepted that, in this kind of project evaluation, the constant dollars method is to be preferred to the current dollars alternative as a basis for the economic comparison we wish to make, provided that escalation costs are broadly in line with the general rate of inflation, and that construction times are not increased even further. But some allowance should be made for the possibility that this situation may not always obtain.

Comment on the NZED Calculations

40. *Reactor Type.* The NZED estimates are related to the PWR, but no choice of reactor type has yet been made. *Location and Siting.* No decisions have yet been made, and ancillary capital expenditure, such as roading and transmission, could vary directly according to the choice of location. *Seismic Allowance.* It is perhaps open to question whether the NZED has adequately allowed for seismic requirements in New Zealand.

41. *Extra costs of constructing the power station outside the country which supplies it.* We are unable to express an opinion one way or the other on this point as we have no adequate information. The aspect which should not be overlooked is that, in the absence of any substantial consensus among New Zealanders about the need and desirability of introducing nuclear

power, the construction of a nuclear power station might possibly be accompanied by various forms of active opposition, and a lack of co-operation by organised labour in line with present FOL policy. These are only a few of the things that could adversely influence the financial costs of bringing the first nuclear station "on stream". And as another possibility, the New Zealand licensing authority could impose safety and environmental conditions stricter than those of the 1976 United States licensing standards upon which the NZED estimates are based. Overseas standards of licensing are, however, possibly high enough to be acceptable to New Zealand.

42. *Output Factor.* It may be argued whether the average 70 percent output factor assumed by the NZED is capable of achievement. Overseas experience with PWR stations in operation may not be long enough. If a lower figure eventuates, there would be a corresponding need to reassess unit costs. The evidence from overseas on this point is conflicting and uncertain. Even with the same reactor type there have been marked variations in performance. It should be noted, however, that for the purpose of its comparisons with oil-fired and coal-fired stations, the NZED has predicated a 70 percent output factor for all types, and thus has been consistent in its approach. If the assumed output factor had been 65 percent for all three options, the relative unit costs would not have shown any marked change. Figure 14.2 shows the cost sensitivity, for different output factors, of nuclear (PWR), coal, and oil stations.

Figure 14.2

ENERGY COST v OUTPUT FACTOR
(Costs are in April 1976 currency)
(*Source*: NZED submission 118)

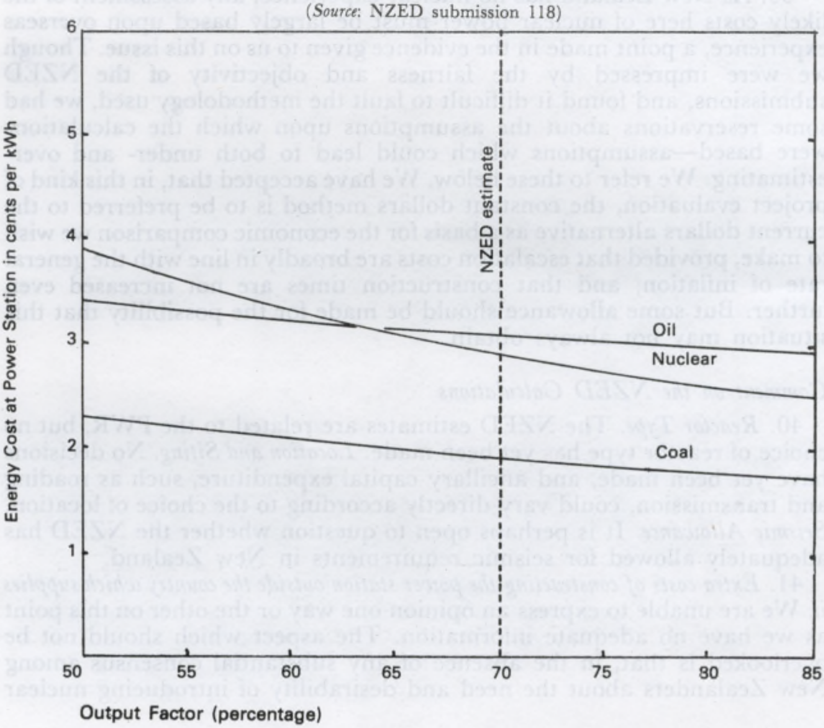
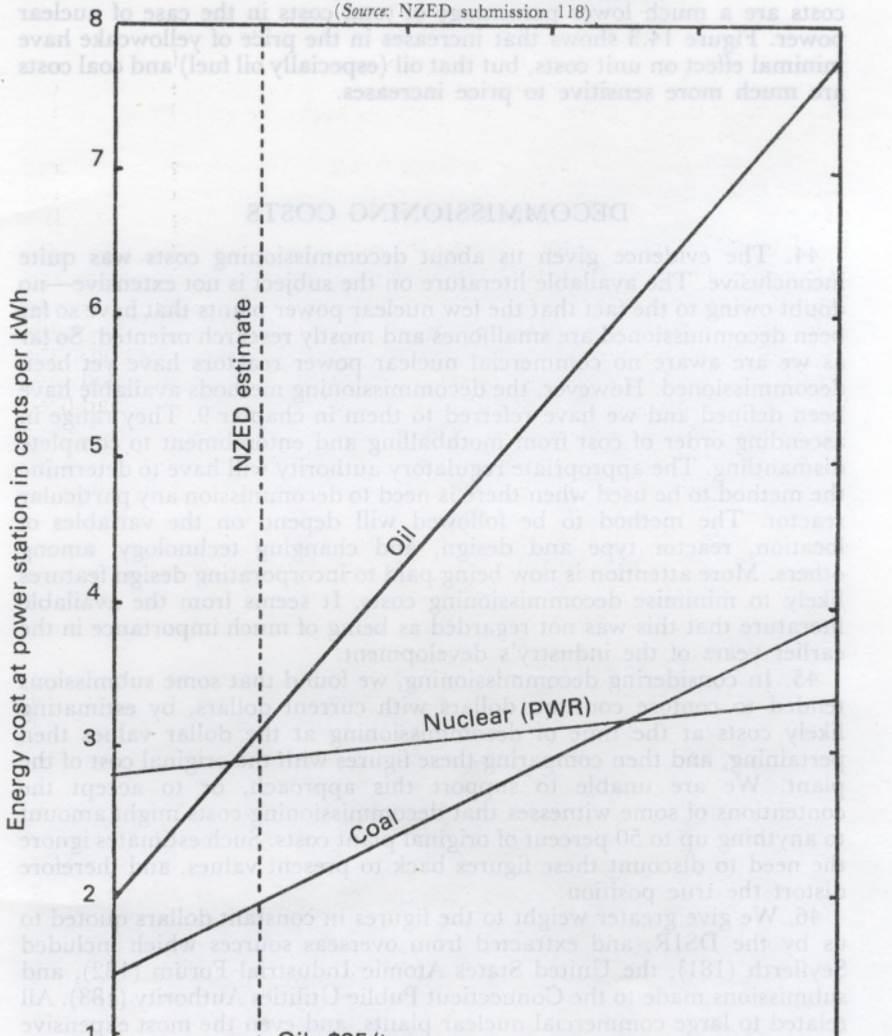


Figure 14.3

ENERGY COST v FUEL COST

(Costs are in April 1976 N.Z. currency)

(*Source*: NZED submission 118)



43. *Fuel Costs.* It is also difficult to predict the effect on the unit costs of increases in the prices of yellowcake, oil, and coal. It is very clear, however, that increases in the price of yellowcake have much less effect on unit costs than comparable increases in the prices of oil and coal, as fuel costs are a much lower percentage of total costs in the case of nuclear power. Figure 14.3 shows that increases in the price of yellowcake have minimal effect on unit costs, but that oil (especially oil fuel) and coal costs are much more sensitive to price increases.

DECOMMISSIONING COSTS

44. The evidence given us about decommissioning costs was quite inconclusive. The available literature on the subject is not extensive—no doubt owing to the fact that the few nuclear power plants that have so far been decommissioned are small ones and mostly research oriented. So far as we are aware no commercial nuclear power reactors have yet been decommissioned. However, the decommissioning methods available have been defined and we have referred to them in chapter 9. They range in ascending order of cost from mothballing and entombment to complete dismantling. The appropriate regulatory authority will have to determine the method to be used when there is need to decommission any particular reactor. The method to be followed will depend on the variables of location, reactor type and design, and changing technology, among others. More attention is now being paid to incorporating design features likely to minimise decommissioning costs. It seems from the available literature that this was not regarded as being of much importance in the earlier years of the industry's development.

45. In considering decommissioning, we found that some submissions tended to confuse constant dollars with current dollars, by estimating likely costs at the time of decommissioning at the dollar values then pertaining, and then comparing these figures with the original cost of the plant. We are unable to support this approach, or to accept the contentions of some witnesses that decommissioning costs might amount to anything up to 50 percent of original plant costs. Such estimates ignore the need to discount these figures back to present values, and therefore distort the true position.

46. We give greater weight to the figures in constant dollars quoted to us by the DSIR, and extracted from overseas sources which included Seyfferth (181), the United States Atomic Industrial Forum (182), and submissions made to the Connecticut Public Utilities Authority (183). All related to large commercial nuclear plants, and even the most expensive option (complete dismantling) did not exceed US$60 million in constant dollar terms.

47. Further, some members had the opportunity of discussing decommissioning costs with the Jersey Central Power and Light Company at Morristown, New Jersey. This company had recently undertaken a comprehensive study with a view to having decommissioning costs reflected in the charges made to consumers as a cost factor to be recovered over the respective lives of the company's operating nuclear plants. The inclusion of this cost in the determination of electricity charges to consumers needed to be approved by the New Jersey Department of Public Utilities. It could be expected that any price-

controlled utility would take great care in an exercise of this kind not to understate the decommissioning cost with which it was likely to be faced. The figures quoted by the company in its official petition related to the Oyster Creek plant (640 MWe) expected to be decommissioned in the year 2003, and the Three Mile Island plant (800 MWe) expected to be decommissioned in 2008. They are set out below, all cost figures being in 1976 United States dollars:

Plant	*Option*	*Cost* (US$ million)
Oyster Creek	(a) Mothballing	11
	(b) In-place entombment ...	35
	(c) Complete dismantling ...	107
Three Mile Island ...	(a) Mothballing	7
	(b) In-place entombment ...	40
	(c) Complete dismantling ...	104

These figures include, as appropriate, the capitalised post-decommissioning surveillance and maintenance costs. The company took the view that in-place entombment was the decommissioning method they could reasonably contemplate, and it was the cost of this method they sought to have included in rate calculations. The company pointed out that the provision proposed would be approximately equal to 0.25 mills (thousandths of a dollar) per kWh, or approximately half of 1 percent of the total cost (including fixed charges) per kWh. On this basis, it is obvious that decommissioning costs would not be a significant factor in increasing electricity charges to the consumer, and even if the more expensive complete dismantling method was used, the consumer would not be greatly disadvantaged.

48. We conclude that the NZED estimates of decommissioning costs are not so unreasonable as some witnesses argued. Though there could well be some understatement, we see no reason for believing that even for the most expensive option, the decommissioning costs would at most exceed 10 percent of original costs. We agree with the NZED which argued that decommissioning costs would in no circumstances have any marked effect on electricity charges.

GENERAL COMMENTS

Capital Costs

49. The importance of establishing (if that is possible) the magnitude of the capital costs of a nuclear power programme in New Zealand has been reflected in the great amount of time we have given to this subject. The diversity of views about capital costs makes it impossible for us to express any confident opinion. This is particularly so for a nuclear power station with a projected commissioning date of 1990–91 or later, because of the long lead time and the possible economic and technological changes which could affect both nuclear and alternative options. Changes in world supply conditions, including availability and pricing of nuclear or alternative energy units for producing electricity could also have significant effects. It is also difficult to estimate capital costs which reasonably provide for escalation due to safety and other standards, and for general worldwide or local inflationary trends. The recent rate of

inflation may not happen again in the medium future, but there can be no assurance of this. Consequently, the capital costs of a nuclear power unit, or for that matter, the construction costs of alternative power stations, cannot be established so far ahead with any degree of certainty.

50. To compare costs, the NZED took present types of nuclear, coal-fired, and oil-fired power stations. For the nuclear it selected a PWR type reactor on which cost data including provision for United States safety and environmental standards are available. As a base it used the Woite study mentioned earlier, modified for New Zealand conditions, including seismic, and arrived at a cost figure in 1976 dollars. It included as capital charges provision for various costs such as those of training, of a regulatory body, etc. It did not include future general monetary inflation, so the total capital cost arrived at will not be the actual cost in 1990–91 dollars.

51. The NZED comparative figures may themselves be compared with those in the Flowers and the Ford Foundation - MITRE reports. These reports arrived at overall costings similar to those the NZED, although there were some differences in the treatment of construction times, of interest during construction, and of capital repayment, and in assumptions about operating costs. In both cases, the cost of electricity generated from nuclear energy was found to be economically competitive with the cost of electricity generated from coal, while in Britain it was also competitive with oil. The NZED estimates showed a total capital cost in 1976 dollars for a basic nuclear power station in New Zealand to be about 33 percent higher than the Ford Foundation - MITRE estimate. This difference would reflect mainly smaller units and the extra costs of constructing the power station outside the country of supply. For a coal-fired power station using low sulphur coal, the NZED total basic capital cost per installed kW was reasonably close to the Ford Foundation - MITRE figure, although the United States coal-fired stations were much larger. No comparable figures were available for oil. The NZED capital costings for oil are based on New Zealand experience. (See further appendix D.)

52. We repeat that the comparisons of total capital costs in 1976 values for nuclear and coal arrived at by the methodology used by the NZED have a satisfactory degree of relevance for comparing the economics of both types of energy. But these figures do *not*, for reasons already given, reflect the total capital costs in 1990–91 dollars.

Unit Costs (or Costs per kWh)

53. *Nuclear Power.* A useful comparison of unit costs can be made using figures derived from the Ford Foundation - MITRE report and those given in the NZED submissions, even though there are differences in output factors and in size of units. The former report assumes an output factor of 60 percent whereas the NZED has used 70 percent. The larger United States nuclear power units could have some economies of scale which would offset the output factor, but these are difficult to evaluate. Subject to these qualifications, the component for total capital costs expressed as a unit cost (per kWh) is 38 percent higher in the NZED submission than the equivalent in the United States. The fuel charges expressed as a unit cost are approximately the same, and, although they are not a significant consideration in total cost, the operation and maintenance costs per unit are lower in the New Zealand case.

54. Overall, the NZED estimates, the methodology of which is broadly the same as that of the Ford Foundation - MITRE report, have resulted in a 22 percent increase on the Ford Foundation - MITRE report figure in terms of 1976 dollars. The various assumptions have resulted in higher fuel costings in the New Zealand case, but are largely offset by the differential in output factor. If a 60 percent output factor had been used by the NZED, then fuel costs would have been about 14 percent higher. These costs, however, can only be considered in a broad sense for reasons already given. (See appendix D.)

55. *Nuclear Compared with Coal.* A useful comparison can also be made between nuclear and coal, using 1976 dollars and the above methodology. The New Zealand figures for a coal-fired electricity station are lower both in capital costs and in (domestic) fuel costs than those of the United States as shown by the Ford Foundation - MITRE report. This comes largely from the use in the eastern States of coal high, or relatively high, in sulphur, necessitating scrubbers and pollutant removers. The capital cost per unit (kWh) in the United States for those plants using scrubbers is nearly 70 percent higher than the unit capital cost in New Zealand. The NZED capital cost figures were based on Huntly estimates, which may not have encountered the same environmental problems and the extra costs for water supplies that the eastern United States cities do. On the other hand the cost of coal at the mines is about the same, but transport costs are significant. The Huntly power station is near a coal field. Taking these factors into consideration, the unit fuel costs, which for a coal-fired power station almost equal or exceed unit capital costs, are about 20 percent higher in the United States for high-sulphur coal mainly owing to the cost of transporting coal.

56. The overall effect of these figures is that, for a coal-fired power station in the eastern United States using scrubbers, the unit cost of power generated (on NZED costings in 1976 dollars) is about 50 percent higher than for one in New Zealand. Whether future New Zealand coal-fired power stations will attract higher capital costs from environmental restrictions and advanced technologies is not known. The general comparison nevertheless is significant, and largely accounts for the margin which nuclear power generation enjoys in the eastern United States. In the middle west, the margin is reduced because low cost, low sulphur coal is available.

57. The above comments explain the apparent paradox that in New Zealand, on NZED cost estimates, the total unit cost of electricity produced from domestic coal near a power station is about two-thirds of the unit cost of that produced from a nuclear station of similar capacity. The unit cost from a coal-fired station may rise from the increased capital costs already referred to; and fuel costs would probably rise if coal had to be imported. Summaries of capital and operating costs for nuclear and coal-fired power in the United States and New Zealand are given in appendix D.

58. *Nuclear Compared with Oil.* We have accepted the oil-fired station costs given by the NZED as they are stated to be based on New Zealand experience. Although the capital costs of an oil-fired station are lower than those for coal or nuclear, the cost of fuel oil, and possible problems of overseas supply and future prices, have largely ruled out a programme of oil-fired stations, unless New Zealand makes a useful discovery of oil.

SUMMARY

59. Though we have been unable to determine with any confidence (because of monetary inflation, and other escalation over time) the future likely capital cost in New Zealand for a nuclear power station for commissioning in 1990–91, some broad magnitudes and unit costings of power generation can reasonably be established so that economic comparisons can be made to help determine future policy.

60. These figures are based on 1976 values and the constant dollar method and must not be regarded as in any way the ultimate costs, as they do not allow for future monetary inflation or other escalation. However, they do, at the level of the unit of power generated, result in figures useful for general economic comparison, subject to some qualifications particularly in respect of assumptions underlying the capital and operating costs. In some cases any change in these assumptions is of marginal effect; in other cases, they are more important.

61. In the matter of capital costs, future inflationary influences are more important the higher the capital outlay. Substantial variations in capital expenditure could obviously have marked effects on the relationship of the unit costs which we have discussed (see table 14.2). Furthermore, the overseas exchange content of a power programme is an important consideration, as the Treasury has pointed out. Allowing for the facts that the nature of the comparisons, and uncertainties about capital and operating costs, permit only broad conclusions, it is nevertheless possible to say that, on present evidence and in general economic terms, electricity from coal is likely to continue to be cheaper to produce than electricity from nuclear power, and oil (if imported) is likely to be the most expensive. Long-term domestic supplies of coal are, however, limited unless further coal reserves are found (see chapters 7 and 15). Imported coal would probably be more expensive than domestic coal.

62. In terms of the significant costs in overseas exchange, the fuel bill for electric power generated from imported oil would be the highest, followed by imported coal, and then by nuclear fuel, subject of course to world prices and available supply. Indigenous coal would involve a comparatively low overseas cost. Overall, the most expensive in terms of overseas exchange would be an oil-fired station (if all fuel was imported), next would be a coal-fired station using wholly imported coal, followed closely by nuclear power, and the lowest would be a power station using indigenous coal.

63. The economic comparisons in this chapter have been between the costs of electricity generation by means of nuclear and fossil fuels. Hydro and geothermal generation are dealt with in chapters 7 and 15. However, for convenience, we give below the unit costs for all generation methods in cents per kWh, derived by the NZED from the capital figures mentioned previously which appeared in the department's submissions.

Nuclear	New Zealand Coal	Oil	New Hydro	New Geothermal
2.9	1.9	3.1	2.5	1.6

These unit costs, when considered along with the capital investment figure given in paragraph 19 (based on NZED calculations), indicate quite clearly how costly a nuclear power programme could be, compared with a programme based on coal-fired stations. However, the supply of indigenous coal for electricity generation is not unlimited.

Chapter 15. OVERALL FUTURE IMPLICATIONS

INTRODUCTION

1. The total impact of nuclear power on New Zealand should be assessed from a long-term development plan not from the introduction of a single reactor. To do this we must speculate on estimated growth beyond the turn of the century, as we were given little or no evidence on this. Though the NZERDC scenarios project well beyond the year 2000, a more simplified approach is needed for this chapter. In addition, the evidence we heard has given us a better understanding of the potential of our geothermal and other indigenous resources.

2. Matters of importance to a possible nuclear programme include commissioning dates, the number of sites that may be needed, the absolute magnitude of the waste problem, centralisation or otherwise of generating units, possible reactor type, capital flows, overseas balance of payment questions, and the security of fuel supplies. Of equal importance is the demand that any such programme may place on the labour force and education system.

3. The source of process heat for industry is another matter of concern beyond the year 2000. In Part III of our report it was tacitly assumed that there was no significant competition for indigenous resources between the electrical supply industry and other industries. For considerations up to about the year 2000 the evidence presented to us made any such assumption axiomatic because the amount of natural resources allocated to the production of electricity was always explicitly stated. However, for even before the year 2000, this assumption could be at fault if, for example, some or all of the natural gas already committed for electricity production was diverted to the direct production of process heat. Of even more importance is that beyond 2000, with increasing restrictions on oil supplies, the total demands on our indigenous resources (especially coal) could seriously limit their supply for electricity production.

4. It is inevitable in this chapter that we should directly or indirectly comment on overall energy policy. However, much of the discussion will of necessity be little more than speculative. The main aim is to reach some kind of measure of the total consequences to New Zealand of introducing nuclear power.

GROWTH BEYOND 2000 AD

5. In chapter 4 we noted that one study group reporting to the World Energy Conference in 1977 estimated that the average annual growth in electricity from 1972 to 2020 would be 4.2 percent for OECD countries, and 5.1 percent for the world as a whole. These figures are reasonably consistent with other estimates based on "present trends" which have been drawn to our attention. For a New Zealand base figure of 15 500 GWh for 1971–72, the OECD growth rate gives a value of 116 000 GWh per annum by the year 2020.

6. During this time the population of New Zealand could grow at a rate above that of most other OECD countries. On the other hand, New Zealand is already a relatively high per capita consumer of electricity, even for an OECD country. We thus assume that the annual New Zealand consumption by the year 2020 will only be slightly above that corresponding to the OECD growth rate—in fact, about 130 000 GWh per annum. For a 55 percent annual load factor, normally adopted for planning purposes, this corresponds to a maximum demand of 27 GW, which, on allowing for a 10 percent margin, gives a total generating capacity of about 30 GW.

7. The choice of 130 000 GWh per annum by 2020 is arbitrary, but reasonably consistent with the discussion in Part III. It implies 60 000 GWh per annum by the year 2000, and 90 000 GWh by the year 2010, these estimates corresponding to average annual growth rates of approximately 4.5 percent from now to the end of the century, 4 percent from 2000 to 2010, and 3.5 percent from 2010 to 2020.

8. Again, applying the type of analysis given in chapter 8, the sector needs for the year 2020 could be: domestic, 35 000 GWh; all industrial plus commercial, 70 000 GWh; and transport 25 000, giving a total of 130 000 GWh. These figures would be consistent with a population of 5 million by the year 2020 which appears possible, but make no allowance for any major technological innovation apart from introducing the electric private car. One type of electric car has recently gone into large-scale production in the United States, so the possibility of much of private transport being electrically powered after 2000 must be taken seriously. About 2020, there could of course be an equal proportion of conventional transport still operating which would use, say, the equivalent of 75 000 GWh of liquid fuels. This is about the amount estimated for all transport for the year 2000 in the NZERDC "continuation" scenario (see appendix C), and is about twice our present oil imports. At this stage we make no comment on the reasonableness of this figure of 75 000 GWh.

9. There are of course many factors that could invalidate our estimate of 130 000 GWh per annum. For example, an upsurge in birth and immigration rates towards the end of the century could lead to a population of say 6 million rather than 5 million by the year 2020. On the other hand, population could decrease, and changes in life-style could drastically modify our present patterns of energy consumption. However, we consider 130 000 GWh to be a reasonable estimate for present purposes.

10. In Part III it was stated and shown that, given the necessary finance and manpower, and assuming no major environmental objections, New Zealand could supply by 2001 at least 70 000 GWh per annum of electricity by using known indigenous resources. It was also implied that beyond 2001 a further 25 000 GWh per annum at least could almost certainly be obtained if needed. This could come from 6000 GWh of

Waikato and 6000 GWh of Southland coals, about 4000 GWh from further major hydro (almost all in the South Island), 5600 GWh from North Island geothermal sources, and about 4000 GWh from small hydro. It seems reasonable to suppose that, if the assured 70 000 GWh per annum which can be fully developed before the turn of the century proves to be both economically and environmentally acceptable, then possibly 20 000 GWh of this extra 25 000 GWh would also be acceptable. Furthermore, from appraisal, the location and type of resource would seem to be adequate to match the load.

11. Taking 60 000 GWh per annum as the actual need by the year 2000 (see chapter 8), we therefore have at least 30 000 GWh per annum which could be generated from known indigenous resources after the year 2001. When this may be produced is open to speculation; but from the preceding discussion and that in Part III, it is reasonable to assume that stations using these known resources will be fully developed before a nuclear or any other type of station dependent on imported fuels, or advanced or improved technology, is commissioned. That this is advisable, at least in the case of nuclear, was strongly emphasised to us by Dr Eklund, the IAEA Director-General.

12. From paragraph 10 it follows that New Zealand can satisfy its electricity demands up to 2010–2011 from known, and presumably acceptable, indigenous resources. For a requirement of 130 000 GWh per annum by 2020, an additional 40 000 GWh per annum from at present unspecified sources must be found. To fully understand the nature of this need, the loads in 2010 and 2020 must be resolved into their peak, intermediate, and base components. Table 15.1 does this. It is assumed (see chapter 7) that peak comprises 3 percent, intermediate 37 percent, and base 60 percent of the load. It is also assumed that the ratio of North to South Island needs is the same as the present ratio of about 2 : 1.

Table 15.1

ELECTRICITY DEMAND 2010 AND 2020

	Peak	Intermediate	Base
North Island—			
2020	2 600	32 100	52 000
2010	1 800	22 200	36 000
Difference ...	800	9 900	16 000
South Island—			
2020	1 300	16 000	26 000
2010	900	11 100	18 000
Difference ...	400	4 900	8 000

13. From 2010 to 2020 the increment in intermediate load could be met by relegating existing base-load plant to intermediate. In the North Island, Auckland thermals No. 1 and 2 with added generating capacity could be used for this, as there would still be enough natural gas from the initial commitment of the Maui field, and associated coal in the case of Auckland No. 2. However, to do this about a further 13 000 GWh per annum of base-load output over and above the 16 000 GWh shown in

table 15.1 would have to be found as replacement. Thus, about 29 000 GWh per annum from new base-load plant would have to be found beyond 2010 to meet North Island needs in 2020.

14. Similarly, in the South Island, the transfer of hydro plant from base to intermediate duty could require a further 7700 GWh from base-load replacement plant. (This assumes a change in output factor from the 55 percent typical of hydro base-load plant operation to 35 percent.) Thus, a total of 16 000 GWh per annum would have to be found from new base-load plant in the South Island. One notes that if thermal stations provided this, only 4000 GWh of base-load requirement (about 15 percent) would come from hydro sources by the year 2020, as Southland coal would already be accounting for 6000 GWh of the total 26 000 GWh per annum of the South Island base load.

15. For plant operating at 70 percent output factors the generating capabilities needed by 2020 could be met by base-load plant, presumably thermal, of about 5 GWe in the North and 2.5 GWe in the South Island, supplied from resources over and above those at present regarded as known and acceptable. The successful introduction of, say, wind-powered turbines for intermediate-load duty could halve the needs, but would probably not retard the date of introducing new base-load plant beyond 2010–2011. On the other hand, if neither the 6000 GWh per annum from Waikato coal nor the 6000 GWh from Southland coal assumed to become available between 2000 and 2010 were used, an additional 1 GWe would have to be added to both the North and South Island requirements, and the date of commissioning of the first of the new base-load plants advanced to about 2005–2007.

16. As we have already implied, the growth of electricity could be showing marked signs of saturation by about 2030. Certain estimates that have been drawn to our attention (for example, see (174)) suggest that by 2020 the annual growth rate could lie in the range 0.3–2.5 percent for OECD countries, and about 1.3–3.0 percent for the world as a whole. Thus, in New Zealand's case it could well be another 5 years beyond 2020 before a further 1 GWe base-load plant was needed. With such a time scale it is conceivable that any additional plant could be of the fusion, as distinct from the fission, reactor type, or some other alternative. Thus, subject to many assumptions, we have possibly estimated an upper limit of what may have to be supplied by fission reactors in New Zealand, namely 5 GWe in the North Island and 2.5 GWe in the South.

GENERAL ECONOMIC CONSIDERATIONS

17. Before outlining a possible nuclear power programme, we briefly discuss the credibility of the estimates we have just made in the light of certain general economic considerations, including the use of indigenous resources for process heat, electricity's share of the energy market, capital requirements, and the depletion of indigenous resources.

Process Heat

18. From the analysis given in chapter 8, and the estimates just made, we estimate industry's needs for process heat to be: 55 000 GWh in the year 2000, 80 000 GWh in 2010, and 110 000 GWh in 2020. These estimates are even more speculative than those for electricity, but are adequate for the points we wish to make. They correspond to an average

annual rate of growth of about 4 percent from now to the end of the century, and about 3.5 percent from then to 2020, and are most likely on the high side.

19. To obtain some measure of the demands that needs for process heat could place on our indigenous resources, we note (as accounted for in chapter 8) that one Maui gas field, with a 30-year life, can provide about 35 000 GWh per annum of useful heat. This assumes an overall industrial utilisation of natural gas of about 60 percent, allowing for losses and efficiency of end use. Similarly, in round figures, for an overall efficiency of 80 percent, 1 million tonnes of coal will produce about 5000 GWh of useful heat. It follows that our assumed process heat requirements could be met by about 11 million tonnes of coal per annum (the figures presented to us by the DSIR agree), or one and a half Maui fields by the year 2000, 16 million tonnes of coal per annum, or about 2 Maui fields in 2010, and 22 million tonnes of coal per annum or 3 Maui fields in 2020.

20. Assuming that the 7.5 GWe of base-load plant needed beyond 2010 is to be nuclear, those stations using natural gas and coal for the electricity growth patterns outlined above are: for the year 2000, about 2 million tonnes of coal per annum and half a Maui field; and for the years 2010 and beyond, 8 million tonnes of coal per annum and three-quarters of a Maui field. As implied in several submissions, it has been assumed that Auckland thermal No. 2 will not be fully commissioned until beyond 2000. This delay might be possible if, as estimated, only 60 000 GWh rather than 70 000 is needed in that year.

21. Assuming that all process heat is to be supplied by coal, the total amount needed, including that for electricity, would be: 13 million tonnes per annum for the year 2000; 24 million tonnes per annum by 2010; and 30 million tonnes per annum by 2020 with probably no great increase beyond that time. This implies that the known economically recoverable reserves of 940 million tonnes would be exhausted by 2040. However, with new mining techniques these reserves could perhaps be nearer to 2000 million tonnes by 2020, rather than about the 1000 million tonnes at present estimated, and hence there would be adequate resources for well into the second half of the next century. As emphasised in chapter 3, the immediate question is therefore one of supply rather than of magnitude of resource. But, again, this depends greatly on the environmental considerations and technological developments discussed in chapter 7.

22. In 1974 the coal industry produced about 2.6 million tonnes with a labour force of about 1600 (44). A necessary ten to twelve-fold increase in production by 2010–2020 would probably not imply a similar increase in the workforce. With new techniques, a force of under 10 000 workers could probably cope. The main problem thus appears to be the demands placed on the coal-mining industry at the turn of the century.

23. For reasons given in chapter 7, it would seem almost impossible to produce 13 million tonnes of coal per annum by the year 2000. However, recent announcements give the magnitude of the Maui field as about 13 percent greater than that assumed in chapter 8. Thus, even with domestic reticulation on the scale discussed in chapter 8, and the use of 10 percent of the Maui output for a petrochemical industry, it is conceivable that natural gas could supply 10 percent of the energy for process heat by 2000. Again, it is possible that the natural gas at present allocated to Auckland thermal No. 2 could be initially diverted for this purpose—a case of "robbing Peter to pay Paul", but the long-term consequences would have

to be carefully investigated before any such action was taken. It might also be possible to import coal and/or natural gas, the former being discussed in chapters 7 and 14 in respect of electricity generation. With, however, the coal for electricity production in 2000 having already been committed many years before then, and as there will be no further major requirements until about 2005–2007, the real problem emerges as one associated with process heat rather than with electricity.

24. Irrespective of how the problem of process heat is solved in and about the year 2000, it appears from the magnitude of the figures previously given that, even in the event of other major natural gas and/or oil discoveries, New Zealand will depend heavily on the coal industry in the first half of the next century. The industry will thus need to be very rapidly built up from 1990 to 2010. It also follows that, because of the potentially large industrial demand, New Zealand cannot rely on indigenous fossil-fuel reserves for electricity production over and above those already assumed to be committed before 2010. However, we stress again that any supply problems about the turn of the century should be assigned to the production of process heat rather than of electricity. To do otherwise could lead to seriously wrong conclusions.

Electricity's Share of the Energy Market

25. From table 3.3 it is apparent that the doubling time for consumer energy in New Zealand from 1924 to 1975 was close to a constant 20 years. This corresponds to an almost constant growth rate of about 3.5 percent a year. The associated energy consumed in 1975 was 74 000 GWh, with electricity's share being close to 23 percent. From the preceding sections we arrive at the following approximate estimate for consumer energy for 2000–2010. The process heat requirements have been increased by 20 percent to allow for losses in end use.

Table 15.2

CONSUMER ENERGY IN GWh PER ANNUM

	Electricity	Process Heat	Transport "Liquid Fuels"	Total
2000	60 000	65 000	75 000	200 000
2010	90 000	95 000	75 000	260 000
2020	130 000	130 000	75 000	335 000

In this table electricity's share of the consumer market goes from 30 percent in 2000 to 35 percent in 2010, and to just under 40 percent in 2020. These figures for electricity's share are probably high since we have ignored the possible domestic and commercial use of natural gas.

26. The figure of 335 000 GWh per annum for 2020 is about 1200 TJ, and lies between the NZERDC "continuation" and "low pollution" scenario values for 2025, as given in table 3.5. Furthermore, the values imply that the 20-year doubling time persists up to 2000 with a decreasing

growth rate beyond that date. Thus, although inferential, the values given in table 15.2 seem reasonable. It is also interesting to note that in 1975, with a population of about 3 million, New Zealand's consumer energy consumption per capita was about 25 000 GWh per annum. For a population of 5 million in 2020, this would have increased to about 65 000 GWh per capita per annum.

27. The Friends of the Earth often asked in cross-examination what electricity's share of the consumer energy market should be. No one could give a suitable answer, and neither can we. We note, however, that provided that the nation's energy supplies as a whole are in no way jeopardised by too great a reliance on one single source, we can foresee no great difficulty in energy supply. We believe that the programme outlined for electricity development in the preceding section is consistent with this concept. Furthermore, with respect to comments made so far in this section, we believe such a programme to be realistic.

Capital Requirements

28. For the proposed programme up to the year 2020, 40 000 GWh per annum of generating capability must be added between now and the end of the century, and 70 000 GWh per annum between then and the year 2020. Provided that the necessary capital can be found between now and the end of the century, and provided the real GNP should double between 2000 and 2020 (a reasonable expectation corresponding to an annual growth rate of 3.5 percent), it can be argued that adequate capital should be available at all times. The Treasury's submission concluded that 60 000 GWh per annum was a reasonable estimate for the end of the century. Thus it would appear that, at least up to that time, the necessary capital can be found, and any associated overseas balance of payment problems dealt with.

29. If Auckland thermal No. 2 station was delayed until beyond 2000, the second half of the programme up to that year would require the complete implementation of the MWD proposal for accelerated geothermal and major hydro resources as discussed in chapter 7. Ignoring interest during construction, the cash requirements for this programme in early 1976 dollars (for typical years) are (56):

		$ million
1980	...	37
1985	...	112
1990	...	220
1995	...	209
2000	...	176

The total cost of the programme would be over $3,000 million, with most of the expenditure over a period of 15 years, corresponding to an average of about $200 million a year. This is to be compared with an increase in the total capital outlay on new stations in 1976–77 of about $185 million (48). The capital outlay on new stations in that year was about 1.5 percent of the 1976–77 GNP of about $12,000 million. By about the mid-point of the MWD programme in 1992 one might anticipate a 60 percent increase in real GNP (at about 3.5 percent per annum) to $20,000 million, and thus, allowing for a 40 percent increase in costs, for interest during construction of individual stations, the MWD programme represents an allocation of funds comparable with the present.

30. The MWD proposal was strongly supported by the Treasury (76), and hence, we may assume, in addition to the arguments in paragraph 29, that the necessary cash flows up to the year 2000 are practicable. It would appear to follow from our previous statement in paragraph 28 that the necessary cash flows would also be available for 2000–2020. However, it can be argued that, with the most economic of our indigenous resources having been developed, the capital cost per unit of electricity generated could rapidly rise in the next century, especially if it became necessary to rely on advanced imported technologies. This would almost certainly be the case if there was no change in either generating unit or station size. Fortunately this need not be so.

31. As figure 15.1 shows, the capital cost per unit of electricity generated decreases dramatically with increasing size of turbine-generator unit, and also with station size. The average station size for geothermal plant will be about 150 MW. Again with the Huntly turbine-generator units for example being only 250 MW, there is clearly scope in New Zealand for a considerable decrease in real costs per unit of electricity produced as the overall generating system grows. Decreases of this nature could compensate for increases associated with importing advanced (for New Zealand) technologies.

32. To take advantage of the economic benefits of increased size it is necessary to centralise the generating system to a large degree. A number of those who presented submissions to us argued that such centralisation was socially undesirable. We reached no definite conclusion on this matter (see chapter 3).

The Depletion of Indigenous Resources

33. The 8 million tonnes of coal per annum needed for electricity production from about 2005 to 2007 onwards, represents a total commitment of about 240 million tonnes, assuming each station has a 30-year life. If these stations were replaced by alternative electricity plant some time between 2030 and 2040, New Zealand would have consumed in producing its electricity about 25 percent of present known economically recoverable coal reserves. This is probably an acceptable figure. But if the extra 7.5 GWe of base-load stations needed beyond 2010 were also to be coal-fired, there would be an extra commitment of over 500 million tonnes, which, considering the process heat requirements, is probably untenable.

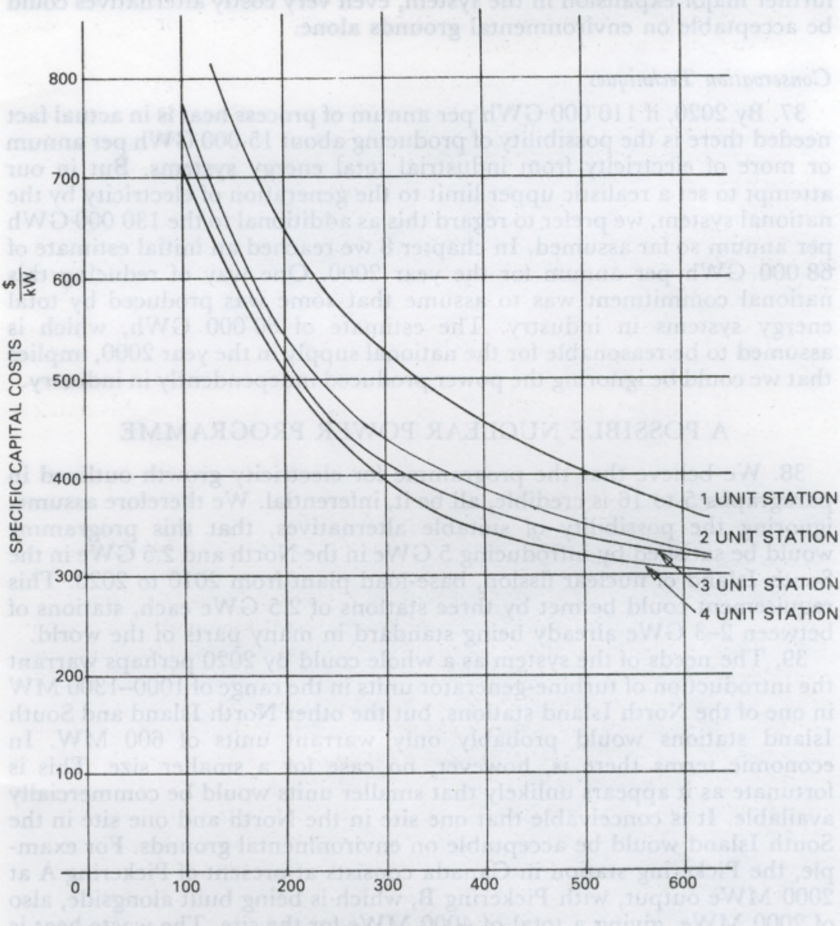
34. From about 2005 onwards, the programme outlined in the preceding section requires about 13 000 GWh per annum from geothermal sources. This corresponds to about 2 GWe which is about two-thirds of the maximum potential that the DSIR estimated to be available (see chapter 7). If the extraction of geothermal heat is regarded as a mining operation for hot water, it has been estimated for the Broadlands field that, for an annual generation of 165 MW at a 90 percent output factor, the life of the field would be 116 years. During this time the temperature would drop from 270°C to about 180°C (57).

35. There is little doubt that the use of geothermal resources will interfere with any associated natural attractions. If, however, the geothermal electrical plants were to be replaced by alternative means of generation after a relatively short period of use (say 30 years), the geothermal fields would almost certainly recover, although the natural displays could be markedly different. That is, by using known geothermal resources now

Figure 15.1

COAL-FIRED PLANT—SPECIFIC CAPITAL COST

(*Source:* Wong and Hewlett (50))



NOTE:

1. Costs as at December 1975.
2. Interest during construction is not included.

we are unlikely to be taking an irreversible step, although the cost of decommissioning a geothermal field would have to be taken into account.

36. Again, there appears to be no reason why a hydro plant could not be decommissioned although, as pointed out in the FFGNP report, this could be a difficult operation. Such a step assumes that there would be an acceptable alternative, and the net cost of replacement could be high. If, however, present trends persist, our analysis implies a high degree of saturation in electricity needs by about 2030. Thus, if there were no further major expansion in the system, even very costly alternatives could be acceptable on environmental grounds alone.

Conservation Techniques

37. By 2020, if 110 000 GWh per annum of process heat is in actual fact needed there is the possibility of producing about 15 000 GWh per annum or more of electricity from industrial total energy systems. But in our attempt to set a realistic upper limit to the generation of electricity by the national system, we prefer to regard this as additional to the 130 000 GWh per annum so far assumed. In chapter 8 we reached an initial estimate of 68 000 GWh per annum for the year 2000. One way of reducing this national commitment was to assume that some was produced by total energy systems in industry. The estimate of 60 000 GWh, which is assumed to be reasonable for the national supply in the year 2000, implies that we could be ignoring the power produced independently in industry.

A POSSIBLE NUCLEAR POWER PROGRAMME

38. We believe that the programme for electricity growth outlined in paragraphs 5 to 16 is credible, all be it, inferential. We therefore assume, ignoring the possibility of suitable alternatives, that this programme would be satisfied by introducing 5 GWe in the North and 2.5 GWe in the South Island of nuclear fission, base-load plant from 2010 to 2020. This requirement could be met by three stations of 2.5 GWe each, stations of between 2–3 GWe already being standard in many parts of the world.

39. The needs of the system as a whole could by 2020 perhaps warrant the introduction of turbine-generator units in the range of 1000–1300 MW in one of the North Island stations, but the other North Island and South Island stations would probably only warrant units of 600 MW. In economic terms there is, however, no case for a smaller size. This is fortunate as it appears unlikely that smaller units would be commercially available. It is conceivable that one site in the North and one site in the South Island would be acceptable on environmental grounds. For example, the Pickering station in Canada consists at present of Pickering A at 2000 MWe output, with Pickering B, which is being built alongside, also of 2000 MWe, giving a total of 4000 MWe for the site. The waste heat is discharged into Lake Ontario. On the other hand, the San Onofre site in Southern California, which discharges its waste heat into the Pacific Ocean, has been limited for environmental reasons to under 3000 MWe. Furthermore, if cooling towers should be used, site capacities nearer 2000 MWe might be thought more suitable.

40. In New Zealand, for security of supply, two sites in the North and one in the South with two 2 × 600 MWe stations at each site might be prudent. (The station size is that given in the NZED proposal discussed in chapter 6.) It may be desirable to increase the capacity of the Cook Strait cables, and, New Zealand may by the required time have installed a

supergrid of 400 kV like that of Britain, making the question of siting depend less on transmission losses than is supposed at present.

41. At this level of development (that is, at 7.5 GWe of nuclear power, about the same as the present British level), there appears to be no basic environmental aspects which cannot be readily dealt with, and which are not already well within the experience of other countries. New Zealand has a seismic problem, but with only three sites needed, suitable areas of reduced seismicity should be available, at least north of Tauranga and in Otago-Southland. Again, by the time the stations are required, ample experience on such matters should be available from the United States and Japan.

42. To assess the total impact on New Zealand, we shall assume explicitly that the development programme is met by commissioning 12 identical 600 MWe reactor-turbine-generator units from 2010 to 2020. These 12 units would be grouped into six stations, at two sites in the North Island and one in the South with two stations at each site. The first unit would be commissioned at one North Island site by 2011, with the other three units at this site being commissioned in alternate years. The first units in the other North and South Island sites would be commissioned in 2012, with subsequent units at each site also being commissioned at 2-yearly intervals. The final units in the total programme should be fully commissioned by 2018–2019.

43. The uniform pattern of development described in paragraph 42 arises from the need to transfer base-load plant then existing to intermediate duty. It is an ambitious construction programme, and would probably be the largest ever undertaken in New Zealand up to the time of its completion. There would no doubt be many advantages gained from the almost complete standardisation (there could be certain problems specific to site) involving design, reliability, costs, licensing, procurement, construction, and operations. A somewhat similar programme for five stations, referred to as SNUPPS (Standard Nuclear Unit Power Plant System), is already being implemented in the United States by the architect engineer corporation, Bechtel. However, there may be some doubt whether such a construction programme could be accomplished in New Zealand.

44. In general the programme would appear to be suitable for implementing on a "turnkey" basis in which the reactor manufacturer contracts with the future plant owner to design, construct, and start up the complete plant or plants. There are advantages in this approach. However, the NZED stated that because the contractor must accept most of the economic risk for delays and failures, a plant built under a turnkey contract would most certainly be a high cost one. Furthermore, the owner, who has ultimate responsibility for safety, is likely to find it hard to establish and ensure that his own necessary standards are met. Again, he is likely to end up with plant with which his staff is unfamiliar (40). Presumably some of the objections to a turnkey approach could be avoided by the secondment of NZED staff to the contractor during design and construction, and by a condition that subcontracts should be placed with New Zealand industries, and with the MWD.

45. The NZED proposal favoured the employment of an architect engineer who would design the plant and, together with the NZED, call separate tenders for each of the many parts and components. Such an approach would almost certainly require, as implicit in the NZED proposal, the commissioning of one station for experience before major

construction started on the others. This could be done in the programme outlined above by interchanging one of the nuclear for one of the coal-fired stations envisaged for 2005–2007.

46. In general the advanced commissioning of one nuclear station could have many advantages, especially for training of operating and maintenance staff. Again, irrespective of the approach adopted, the NZED would no doubt engage a "project consultant", independent of the architect engineer or turnkey contractor, to advise and assist in all phases of the first station at least.

47. Of course we are possibly considering an upper limit to growth and the nuclear programme may not be as large as we have envisaged, although design and construction work on other types of plant may have to proceed in parallel. However, in considering specific aspects such as fuel supplies and reactor type, we assume that the development will be more or less that as outlined in paragraph 42.

Capital Requirements

48. The actual construction of one station takes about 6 years. Hence with the first unit needing to be commissioned by about 2011, work on the first site would have to start about 2003, and governmental approval for construction would have to be given by about 2001. The major construction phase for the complete programme would last about 15 years. For an average of about $1,000 million per station (early 1976 values and ignoring interest and any gains from standardisation), the total programme would cost $6,000 million. This corresponds to an average cash requirement of about $400 million a year with a peak of about $700 million (deduced from the cash flows given in table 14.1) during the 2009–2013 period. This is to be compared with an estimated cost of $200 million (not counting interest) per annum for the accelerated hydro and geothermal programme from 1985 to 2000 (see paragraph 29). The hydro-geothermal cost is half that for the proposed nuclear programme. For an average 3.5 percent per annum increase, the real GNP in 2011 would be double that in 1991, and thus in simple economic terms the two programmes appear to be comparable. However, peak cash needs could be higher for nuclear, and as this programme would perhaps involve more overseas expenditure, the total economic requirements of the nuclear could perhaps be more severe than those for the hydro-geothermal development. Nevertheless, if it is recognised that a nuclear programme of the type being considered may be the only economic alternative open to New Zealand in the early part of the next century, it does not appear impracticable, and should not be dismissed out of hand.

Manpower Requirements

49. The MWD stated that a single station of the type being considered would need a peak construction force of about 1600 (see chapter 9). With construction work proceeding in sequence on two stations on a single site the work force would not have to be doubled, and hence perhaps a workforce of 2500 per site would be adequate, that is a total of 7500 for the three sites. This is to be compared with the approximately 4000 at present employed by the MWD on new construction work for the NZED (48). It is also to be noted that over the greater part of the construction programme, the needs of other projects would be negligible.

50. The NZED at present employs close to 575 on design and construction work and 2400 on operations, in addition to those employed by the MWD. In its proposal it stated that a design team of about 40 engineeers, scientists, and others would be necessary to manage and control the design phase of the first nuclear power station (40). Even in the absence of a turnkey contract, with six stations proceeding in sequence and in parallel, this force would not have to be increased sixfold. The MWD figures in chapter 9 show that once a station was commissioned, there would be about 150 operating staff needed for each station. Standardisation would probably not affect this figure much.

Reactor Type and Fuel Requirements

51. If the "throw-away" option for high-level waste disposal should become universally accepted, it is unlikely that the fuel requirements for the programme outlined above could be met. With the present commercial 1 GWe converter reactors needing about 200 tonnes of natural uranium each year, a programme of 7.5 GWe would need 1500 tonnes per annum, or a commitment of about 45 000 tonnes for a 30-year life. If there is a population of only 5 million by 2020, New Zealand's proportionate share on a population basis of the present known global recoverable reserves of 4 million tonnes is only about 2000 tonnes. If this is taken as a measure, there would have to be a twentyfold increase in known reserves to meet this country's needs.

52. Again, at the other extreme, even though FBRs may become commercially available by the mid-1990s, reprocessing requirements could make them unlikely to be suitable for New Zealand conditions. If, however, this was the only reactor type for which, for example, a "proliferation resistant" fuel cycle was developed, then there may be no choice. More likely candidates are thermal breeders such as the LWBR or perhaps a suitably modified CANDU, or advanced converters such as an HTGR or a corresponding CANDU, all of which would employ a thorium cycle with reprocessing being done overseas.

53. Of course, the present type of converter such as an AGR, LWR, or CANDU could also be considered. In the absence of the "throw-away" option, there may not only be adequate uranium supplies but there could also be international fuel centres breeding plutonium and/or thorium-232 for fabrication as converter fuel. In addition to FBRs, there are other methods, such as the use of accelerators producing "spallation" reactions, or certain types of fusion devices, which could be used for breeding purposes. Furthermore, it may not be necessary to isolate fissile from fertile material in these methods. There is also the possibility of the commercial development of "proliferation resistant" uranium-plutonium FBR fuel cycles, such as the one recently announced by Dr Walter Marshall of the UKAEA, and Dr Chauncey Starr of EPRI.

54. Many factors would obviously have to be taken into account in the choice of a reactor. Fortunately, New Zealand appears to have time to await certain developments before a decision has to be made. However, irrespective of the choice that may be ultimately made, we must emphasise, as IAEA officials brought home to us, that before entering a nuclear power programme, be it big or small, New Zealand must be reasonably assured of its fuel supplies.

Environmental Aspects

55. Explicit environmental aspects and associated health and safety matters have been discussed at length in chapters 9, 11, and 12: Standardisation could simplify these matters, but there could be many problems specific to site which would need close attention. All of these, however, have been dealt with in one way or another elsewhere in our report. There is one aspect of special note. In chapter 9 we said that the annual output of high-level waste from a 1.2 GWe station (once reprocessed and vitrified) could consist of 17 rods 3 metres long and 0.3 metres in diameter. The six stations of the proposed programme, in their 30-year lives, would produce about 3000 rods. Laid side by side they would occupy an area of about 3000 square metres, barely the size of a football field. If alternative energy sources were brought in this could be all the high-level fission waste ever needed to be produced here. However, assuming that this waste, in vitrified form, was eventually returned to New Zealand, we do not at present know if even this relatively small quantity could be adequately disposed of in this country. It is obviously a matter needing further investigation before any final commitment to a nuclear power programme is made.

Training

56. A nuclear power programme in New Zealand would make necessary a greater range of technological skills than at present exist here. Although the training and experience gained from conventional thermal stations is also relevant to the nuclear, extra training in specific matters would be necessary. Highly trained specialists in certain areas would have to be found, and the concept of "quality assurance" would have to be engendered in all. Once a certain reactor had been chosen, staff with operational experience of the particular system would be needed. It may be necessary to recruit temporary or permanent key personnel from other countries. The IAEA could be asked to give substantial help.

57. From the first NZED submission it appears that once a decision was made to plan a nuclear programme, engineers and scientists would be sent to an initial course on nuclear technology such as that at present held by the Australian Atomic Energy Commission at Lucas Heights near Sydney. After the course each trainee would spend at least 2 years on specific aspects of nuclear power in other overseas establishments. Courses for tradesmen (for example, welders and specialist technicians) would be needed later in the programme. Exactly how this would be done if the turnkey contract approach was adopted was not stated, but the Federation of Labour was opposed in principle to introducing overseas tradesmen as it believed that local workers were sufficiently adaptable to be taught the necessary skills. We agree with this. Station operating and maintenance staff would probably be trained both in New Zealand and overseas at a total cost, excluding salaries, of about $4–5 million for each station, assuming no benefit from the parallel and sequential nature of the programme.

58. It was suggested by the MWD and the DSIR, and supported by the New Zealand Institution of Engineers, that a local training research reactor of about 2 MWt could have certain advantages. The MWD proposed that it should be introduced almost immediately after a "decision in principle" for a nuclear power programme had been made. The estimated cost in New Zealand was given as $7.5 million, and operating costs would be about $100,000 a year. It was stated that such a reactor

would give ". . . an incentive and an opportunity for the preliminary steps in a nuclear programme to be taken without the pressures of dead-line dates for electric power supply. These include preparing and passing legislation, establishing and staffing a regulatory authority, and establishing safety philosophies and guide-lines" (56).

59. These goals seem reasonable and have merit. However, we are not convinced that such a reactor would be an adequate training tool. If the differences in scale between it and a 600 MWe power reactor are considered, its relevance becomes somewhat questionable, and this agrees with advice we received during our overseas visits. Until there is a firm commitment to nuclear power, we can see no advantages as far as training is concerned for large-scale power generation in introducing such a reactor into New Zealand.

60. The cost of training of regulatory staff must also be taken into account as well as the cost of training NZED staff. This has been touched on in chapter 14. Though the total dollar cost of all training would be large, we estimate that, allowing for interest during construction, it is likely to be less than 2 percent of the total capital cost of the programme. As such it is no doubt tolerable.

Conclusion

61. We have shown that a significant nuclear power programme during the early part of the next century should be economically possible in New Zealand. The overall economic impact at that time would be little different from that of presently proposed developments up to the end of the century. The actual starting date for any such programme is naturally subject to many uncertainties, but it appears that a firm decision to proceed need not be made until at least about 1992 to 1996. Again, the development of suitable alternatives could not only affect this timing but also markedly affect the magnitude of the programme.

APPENDICES

Appendix A

ORGANISATIONS AND PEOPLE WHO MADE SUBMISSIONS

(Most submissions were presented orally at a public sitting and the people who appeared were subject to questioning. Those submissions that were not presented orally are distinguished by an asterisk. The figures in brackets refer to the number of papers presented.)

Organisations

*Accident Compensation Commission ... ... (1)
Action for Environment ... ... (1)
Agriculture and Fisheries, Ministry of ... ... (1)

BP New Zealand Limited... ... ... (1)

Campaign Against Foreign Control in New Zealand ... ... (1)
Campaign Against Nuclear Warships (CANWAR) ... ... (1)
Campaign for Non-Nuclear Futures ... ... (3)
Church and Society Commission of the National Council of Churches in New Zealand ... ... (1)
Commission for the Environment ... ... (3)
Commission for the Future ... ... (1)
Customs Department ... ... (1)

*Defence, Ministry of ... ... (1)

Ecology Action Auckland and the Auckland University Students Association ... ... (1)
Ecology Action (Otago) Inc. ... ... (1)
Energy Resources, Ministry of ... ... (3)
Environment and Conservation Organisations of New Zealand ... (2)
Environmental Council ... ... (1)
Environmental Defence Society ... ... (3)
Environmental Vanguard Organisation ... ... (1)

Federated Farmers of New Zealand (Inc.) ... ... (1)
Federation of Business and Professional Women's Clubs ... (1)
Foreign Affairs, Ministry of ... ... (1)
Friends of the Earth ... ... (2)
Friends of the Home ... ... (1)

*Gabites, Alington, and Edmondson ... ... (1)
General Practitioner Society ... ... (1)
Geological Society of New Zealand ... ... (1)
Greenpeace New Zealand ... ... (1)

Health, Department of ... ... (2)

Internal Affairs, Department of ... ... (2)

Karuna Falls Ltd. ... ... (1)

*Labour, Department of ... ... (1)
*Lands and Survey, Department of ... ... (1)

*Medical Research Council of New Zealand ... ... (1)
Mines Department ... ... (3)

National Council of Women of New Zealand ... ... (1)
Natural Gas Corporation ... ... (1)
Nature Conservation Council ... ... (1)
New Zealand Atomic Energy Committee ... ... (2)
New Zealand Campaign for Nuclear Disarmament ... ... (1)
New Zealand Ecological Society ... ... (1)
New Zealand Electricity Department ... ... (5)
New Zealand Federation of Labour ... ... (1)
New Zealand Federation of University Women ... ... (1)
New Zealand Forest Service ... ... (1)
New Zealand Government Railways Department ... ... (2)
New Zealand Institute of Chemistry ... ... (1)
New Zealand Institution of Engineers ... ... (1)
*New Zealand Inter Church Council on Public Affairs ... ... (1)
New Zealand Medical Association ... ... (1)
New Zealand University Students Association ... ... (1)
New Zealand Values Party ... ... (1)

*Peace Action Tauranga ... ... (1)
Public Service Association ... ... (1)

Religious Society of Friends in New Zealand (Quakers) ... (1)

Scientific and Industrial Research, Department of ... ... (3)
Soil Association of New Zealand ... ... (1)

Trade and Industry, Department of ... ... (1)
Transport, Ministry of ... ... (2)
Treasury, The ... ... (1)

*United Nations Association, The Wellington Branch ... ... (1)

Victoria University, Chemistry Department ... ... (1)
Voice of Women (Dunedin) ... ... (1)

Women's Electoral Lobby (Auckland) ... ... (1)
Women's International League for Peace and Freedom ... (1)
Works and Development, Ministry of ... ... (3)

Young Nationals, Canterbury-Westland Branch ... ... (1)

People

*Allan, W. J. D. ... ... (1)

Beaven, Professor D. W. ... (1)
Bieleski, I. P. ... ... (1)
Blennerhassett, Mrs V. ... (1)
Browne, R. F. ... ... (1)
Burbidge, Professor P. W. (1)

Cherry, Dr N. J. ... (1)
Chisholm, F. ... ... (1)
*Comer, Mrs V. M. ... (1)
*Conroy, J. ... ... (1)

*Donnelly, T., and family ... (1)
Donoghue, M. F. ... (1)

Ericksen, Dr N. J. ... (1)

Geiringer, Dr E. ... (2)
Glasby, G. P. ... ... (1)
*Gregory, J. G. ... ... (1)
*Griffiths, J. ... ... (1)

Holm, Mrs J. R. ... (1)
*Hopkins, Mrs M. ... (1)

*Kennedy, Mrs J. ... (1)

Lewis, A., and associates ... (1)
*Lord, N. E. ... ... (1)
*Lowry, J. B. ... ... (1)

*MacGregor-Hay, H. ... (1)
Mann, Mrs B. ... ... (1)
McKee, A. ... ... (1)
*McLean, R. J. ... ... (1)
Meder, B. S. ... ... (1)
*Moore, E. M. ... ... (1)
Morris, Mrs D. ... ... (1)
*Mulgrew, Mrs E., and associates ... (1)
*Myers, Mrs J. ... ... (1)

Nevill, R. G., and Coombe, D. M. ... ... (1)

Page, G. G. ... ... (1)
Peet, N. J., and Williamson, A. G. ... ... (1)
Preddy, B. E. and G. F. ... (1)
Richmond, C. J. ... ... (1)

Salmon, Professor J. T. ... (1)
Serrallach, Dr G. F. ... (1)
Sheppard, D. S. ... (1)
Stephenson, J. ... ... (1)

Taylor, W. M. ... ... (1)
Toynbee, P. A. ... ... (1)

*Van Erkel, G. A. ... (1)

Williams, G. ... ... (1)
White, D. U. ... ... (1)
Whitehead, Dr N. E. ... (1)
Wybourne, Professor B. S. (1)

Appendix B

LIST OF PEOPLE, ORGANISATIONS, AND ESTABLISHMENTS VISITED OVERSEAS

UNITED STATES

West Coast

Dr Lawrence Grossman, Professor of Nuclear Engineering, University of California, Berkeley.

Lee Schipper and Alan Lichenberg, Energy and Resources Programme, University of California, Berkeley.

Dr Chauncey Starr, President, Electric Power Research Institute, Palo Alto.

Bechtel Organisation.

California Energy Resources Conservation and Development Commission.

California State Capitol.

General Atomic Company, San Diego.

Lawrence Berkeley Laboratory, Berkeley.

Lawrence Livermore Laboratory.

San Onofre Nuclear Power Plants.

Southern California Edison Electric Company.

Tennessee

Dr Alvin M. Weinberg, Director, Institute for Energy Analysis, Oak Ridge

National Laboratory, Oak Ridge.

Washington.

William Doub (former AEC Commissioner) and associates.

Carl W. Kuhlman, Assistant Director for Waste Management, Division of Nuclear Fuel Cycle and Production, ERDA.

John Leech (Solar Expert, now attached to International Affairs), ERDA.

Whittie McCool, Deputy Director, Division of Safety, Standards and Compliance, ERDA.

Congressmen Mike McCormack and Barry Goldwater.

John O'Leary, Administrator of the Federal Energy Administration.

Herbert Pennington, Director, Nuclear Environmental Protection Agency, ERDA.

Nelson Sievering, Assistant Administrator for International Affairs, ERDA.

Gus Speth, Member for Council on Environment Quality.

Atomic Industrial Forum.

Bechtel's SNUPPS Programme at Gaithersburg, Maryland.

Nader Representatives.

Nuclear Regulatory Commission.

Peach Bottom Nuclear Plant.

Richard J. Barber Associates.

New York and New Jersey

Centre for Environmental Studies, Princeton University (Frank von Hippel, Robert H. Williams, Theodore B. Taylor, Jan Beyea).
Consolidated Edison.
Jersey Central Power and Light Company.

Boston

Dr Chinnery, MIT.
Professor Henry Kendall, Harvard University.
Professor Rose, MIT.
Dr George Wald, Harvard University.

CANADA

Dr Elizabeth Bond, Director of Government Relations for International Nickel Company of Canada.
Dr David Brooks, Friends of the Earth.
G. Joron, Minister of Energy, Quebec.
G. M. McNabb, Deputy Minister of Energy, Mines and Resources.
Dr. A. Porter, Chairman, Ontario Royal Commission.

Atomic Energy Control Board—Regulatory Body.
Atomic Energy of Canada Limited.
Canadian Nuclear Association.
Energy Probe.
Environmental Advisory Council (Blair Seaborn, Deputy Minister).
Hydro Quebec and Gentilly Nuclear Power Station.
National Research Council.
Ontario Hydro and Pickering Nuclear Power Station.

BRITAIN

Dr P. F. Chapman (Energy Research Group), Open University.
Dr John Davoll, Conservation Society.
Sir Brian Flowers and associates.
Gerald Leach.

Atomic Energy Authority.
Berkeley Nuclear Laboratories.
British Nuclear Fuels Ltd.
Central Electricity Generating Board.
Culham Laboratory, Abingdon, Oxford.
Department of Energy (Atomic Energy Division).
Department of Environment.
Dounreay Experimental Reactor Establishment.
Energy Research Group, Cavendish Laboratory, Cambridge.
Foreign and Commonwealth Office.
Friends of the Earth.
Harwell Atomic Energy Research Establishment.
Heysham Nuclear Power Station.
Hinkley Point Nuclear Power Station.
Nuclear Installations Inspectorate.
Oldbury on Severn, Magnox Nuclear Power Station.
Windscale (BNFL).

SWITZERLAND

Swiss Association for Atomic Energy (ASPEA).

SWEDEN

Energy Research and Development Commission.
Secretariat for Future Studies.
Swedish State Power Board (known as Vattenfall).

FRANCE

International Energy Agency—New Zealand Review Team.
International Energy Agency Secretariat—Long Term Co-operation Bureau.
International Energy Agency Secretariat—R and D Division.
National Energy Bureau, French Energy Commission.
Organisation for Economic Co-operation and Development—Environment Directorate.
Organisation for Economic Co-operation and Development—Nuclear Energy Agency.

AUSTRIA

Energy Section, Ministry of Trade.
International Atomic Energy Agency.

SOUTH AFRICA

Atomic Energy Board.
Electricity Supply Commision.

Appendix C

FORECASTS AND SCENARIOS FOR FUTURE ELECTRICITY USE

With minor adjustments to make this appendix consistent with the style and method of cross-referencing adopted in other sections of this report, sections C1, C2, and C3 have been taken verbatim, without prejudice, from the NZED submission 128, pages 27–32 inclusive, and the appendix, page 50. Section C4 contains our own comments.

C1 *Forecasts of Electricity Use in the Year 2000*

The official forecasts are made by the CRPR whose forecasting horizon is 15 years. The uncertainties affecting the forecasts for this timespan will be apparent from other discussion in the report. It is also clear that caution is needed in making extrapolations for timespans longer than this.

In its submission to the FFGNP in November 1976, the NZED suggested two figures indicative of a possible range for electricity generation for the year 2000. The first, 80 400 GWh, was based on an extrapolation of the 1976 CRPR estimates. These estimates assumed a reducing growth rate towards the end of the forecasting period, and further reductions in growth rate were allowed in the extrapolation to the end of the century. The second figure of 68 800 GWh allowed for the effect of additional conservation and substitution measures.

The background work for the 1977 CRPR suggests that the condition of low economic growth which exists at present and is expected to continue in the medium term, together with a reduction in population estimates, will cause a reduction in these end-of-century projections, but will still leave a similar range of uncertainty.

At the present time the NZED believes that for planning purposes it is prudent to allow for the possibility that 60–70 000 GWh of generation could be required in the year 2000 bearing in mind all the uncertainties inherent in the long term.

C2 *Scenarios for Future Electricity Use*

The following descriptions of electricity growth are not forecasts, but have been devised to illustrate the effects of different assumptions on the levels of future electricity use. In each of the two basic scenarios, "STATIC" and "NORMAL GROWTH", certain assumptions have been made about the growth of the following three categories of electricity use: "Domestic", "Commercial and Industrial" (not including forest-based and metal-smelting industries), and "Large Industrial" (forest-based and metal-smelting industries and referred to as "Major Industrial" in chapter 8).

It should be noted that in each case:

(a) The population growth is based on the low fertility and 5000 net immigration per year projection of the Department of Statistics (1).

(b) The growth of "commercial and industrial" consumption has been calculated from a relationship based on the assumed GDP growth (see C3).

(c) There is no certainty that the assumptions for each scenario are economically consistent.

The scenarios shown here are:

(a) "STATIC"—static economic conditions (no change in GDP per head) but growth in population.

(b) "NORMAL GROWTH"—moderate growth in the economy with no large-scale technological innovation.

(c) "ELECTRIFIED TRANSPORT"—the same as "NORMAL GROWTH", but with electrification of a portion of transport energy requirements as an example of a significant technological innovation.

Scenario A, *"STATIC"*

(a) *Description:* In this scenario it is assumed that:

(i) The average "domestic" consumption remains at the present level of 8100 kWh a household a year, and rises only with population changes.

(ii) The GDP per capita remains at the present level so that the growth of total GDP is limited to that of the population. "Commercial and industrial" consumption increases at the rate consistent with the growth rate of total GDP. Details of population and GDP growth are given in table C.1.

(iii) "Large industrial" consumption is a best estimate consistent with the scenario and is shown in table C.2.

(b) *Results:* Generation increases to 30 800 GWh in the year 2000 compared with 20 900 GWh in 1976–77 as shown in figure 6.1. Key assumptions made are given in table C.1., and the components of consumption are given in table C.2.

(c) *Comment:* In practice, if the stagnation conditions of this scenario existed for long, it would seem unlikely that the population assumption would hold, and the net immigration rate could be negative, possibly even to the extent that the population may drop.

Scenario B, "NORMAL GROWTH"

(a) *Description:* In this scenario it is assumed that:

(i) The average domestic consumption rises to 14 000 kWh a household a year by the year 2000 from the present level of 8100 kWh. This would allow a high comfort level from electric heating in half the housing stock, leaving half as now to be heated by some other means.

(ii) The GDP in real terms increases at 3.5 percent per annum. This may be compared with the 1957–76 real rate of 4 percent per annum

(iii) "Large industrial" consumption trebles by the year 2000 which corresponds to an average rate of increase of 4.2 percent per annum.

(b) *Results:* Generation increases to 60 100 GWh in the year 2000 compared with 20 900 GWh in 1976–77 as shown in figure 6.1. Key assumptions made are given in table C.1. and the components of consumption are given in table C.2.

(c) *Comment:* It is of interest to examine the effect of variations in the assumptions on the scenario figures. Higher net immigration of 15 000 instead of 5000 per annum could give an additional consumption of 2000 GWh per annum. The adoption of gas water heating and cooking in 300 000 additional houses would reduce electricity consumption by about 1600 GWh per annum. The substitution of gas space-heating to achieve high comfort levels in the same number of houses would reduce electricity consumption by about 3600 GWh per annum. Alternatively, a reasonably extensive adoption of domestic heat pumps leading to their use for space heating in about 30 percent of homes could reduce consumption by 2000 to 3000 GWh per annum by the year 2000.

Scenario C, "ELECTRIFIED TRANSPORT"

(a) *Description:* In this scenario it is assumed that:

(i) The assumptions of Scenario B apply.

(ii) From the mid 1980s a progressive change to the use of electricity for transport occurs. Initially this would be inter-city and main trunk railway transport which would then be followed by urban and personal transport. An estimate of 72 000 GWh for the energy required for transport in the year 2000 has been suggested (2). It is assumed that one third of this, that is, 24 000 GWh, is met by 8000 GWh of electricity in the year 2000. (This assumes that the efficiency of the electricity to mechanical energy conversion is three times as efficient as that of liquid fuel to mechanical energy conversion).

(b) *Results:* Generation increases by nearly 10 000 GWh above the "NORMAL GROWTH" level in the year 2000 to a total of 69 800 GWh as shown in figure 6.1. Key assumptions made are given in table C.1, and the components of consumption are given in table C.2.

(c) *Comment:* Technological change in response to changing availability of resources, and from innovation generally, will be likely to exert a significant influence on the levels of electricity generation at this time. Electrification of part of the energy need for transport has been chosen as a substantial example of these effects, as it seems likely that electricity will supply a significant proportion of this need in the longer run, the uncertainty being in the timing and extent of the changes.

Table C.1.

SCENARIO ASSUMPTIONS

Year	Population (millions)	No. of Houses (millions)	GDP (index)	GDP per capita (index)
Scenario A: "STATIC"—				
1976	3.07	1.03	1.00	1.00
1981	3.27	1.10	1.07	1.00
1986	3.46	1.17	1.13	1.00
1991	3.64	1.23	1.19	1.00
1996	3.82	1.29	1.25	1.00
2001	4.01	1.35	1.31	1.00

Scenarios B and C: "NORMAL GROWTH" and "ELECTRIFIED TRANSPORT"—				
1976	3.07	1.03	1.00	1.00
1981	3.27	1.17	1.19	1.12
1986	3.46	1.32	1.41	1.25
1991	3.64	1.50	1.68	1.42
1996	3.82	1.57	1.99	1.60
2001	4.01	1.65	2.36	1.81

Table C. 2

SCENARIO CONSUMPTIONS (in thousands of GWh)

Scenario A: "STATIC"

Year	Domestic	Commercial and Industrial	Large Industrial	Transmission Losses	Generation
1976 ...	8.4	5.9	3.4	2.4	20.1
1981 ...	9.0	7.4	5.0	2.6	24.0
1986 ...	9.5	8.9	5.8	3.0	27.2
1991 ...	10.0	9.4	5.9	3.1	28.4
1996 ...	10.5	9.9	5.9	3.3	29.6
2001 ...	11.0	10.4	6.0	3.4	30.8
Percent composition at end of period	36%	34%	19%	11%	100%

Scenario B: "NORMAL GROWTH"

Year	Domestic	Commercial and Industrial	Large Industrial	Transmission Losses	Generation
1976 ...	8.4	5.9	3.4	2.4	20.1
1981 ...	11.1	7.8	5.5	2.2	26.6
1986 ...	14.7	10.2	6.6	3.0	34.5
1991 ...	19.5	13.3	7.2	3.6	43.6
1996 ...	21.3	17.2	9.2	4.7	52.4
2001 ...	23.3	22.3	9.2	5.3	60.1
Percent composition at end of period	39%	37%	15%	9%	100%

ERRATUM

Page 291: The sixth and seventh lines after heading 'C3 *Model for "Commercial and Industrial" Consumption*' should read—

$$E_t = 5.7 + 0.9 \times G_t - 0.35 \times E_{t-1} - 0.16t$$

t test (6.38) (3.65) (2.79) $R = 0.92$

Scenario C: "ELECTRIFIED TRANSPORT"

Year	Domestic	Commercial and Industrial	Large Industrial	Transport	Transmission Losses	Generation
1976	8.4	5.9	3.4	–	2.4	20.1
1981	11.1	7.8	5.5	–	2.2	26.6
1986	14.7	10.2	6.6	1.0	3.0	35.6
1991	19.5	13.3	7.2	2.1	3.9	45.9
1996	21.3	17.2	9.2	4.4	4.8	57.0
2001	23.2	22.3	9.2	9.1	5.9	69.8
Percent composition at end of period	33%	32%	13%	13%	9%	100%

C3 *Model for "Commercial and Industrial" Consumption*
(Non-domestic consumption excluding forest-based and metal-smelting industries)

A mathematical model which relates the growth of electricity consumption in this sector to that of GDP has been developed, using data from 1958 on.

$$E_t = 5.7 + 0.9 \times G_t - 0.35 \times E_{t-1} - 0.16_t$$

t test (6.38) (3.65) (2.79) $R = 0.92$

where E_t = percentage change in "commercial and industrial" electricity consumption in year t.

G_t = percentage change in real GDP for year t.

t = the year of interest. The value of t is based on t = 0 for the financial year 1976–77.

Of different models tried, this one fits the data most closely, and the good fit is indicated by the high value of the R coefficient.

The model describes the growth of electricity consumption in terms of the corresponding growth of GDP with a time trend which reduces the growth component and is not dependent on year-to-year changes in GDP.

The model has been used to estimate the growth rate in the early years of the scenarios up to the year 1986. After this time, the "commercial and industrial" consumption in the "STATIC" scenario is assumed to grow only as fast as GDP (which in turn grows as fast as the population), whereas in the other two scenarios the growth rate given by the model for the year 1986 (5.3 percent) is assumed to continue each year up to 2001.

C4 *Royal Commission Notes*

For G_t the same from one year to the next, the model in the preceding section may be approximated to by a simpler form. In particular, noting that this relationship implies decreasing E with time, put

$$E_{t-1} = E_t + \Delta E_{t-1}$$
$$E_{t+1} = E_t - \Delta E_t$$

Where ΔE_t and ΔE_{t-1} are the changes in E from one year to the next. Assuming that $\Delta E_{t-1} = \Delta E_t$, that is ignoring second order differences, for constant G_t it can be shown directly from the model that

$$\Delta E_{t-1} = 0.12$$

This enables the model to be approximated by

$$E_t = 4.2 + 0.67\ G_t - 0.12\ t$$

and on iterating, the neglect of second order differences can be justified.

In this form it is apparent that for constant G_t, E_t changes by 0.12 from one year to the next.

In the model t = 0 corresponds to the year ending 31 March 1977. To refer time to another year Y, replace t by t − T where T = 1977 − Y. This gives

$$E_t = 4.2 + 0.12T + 0.67G_t - 0.12t$$

where t = 0 for the year Y. If U is the energy consumed in any year then

$$\Delta U = \frac{E_t}{100} U \Delta t$$

where ΔU is the change in U in the time Δt. On integrating this relationship

$$U_t = U_Y \exp\ (\ (0.042 + 0.0012T + 0.0067G_t)\ t - 0.0006t^2)$$

Taking T = 1 this is the relationship that was used to obtain the values given in table 8.5.

In terms of logarithms, this expression is

$$\ln U_t = \ln U_Y + (0.042 + 0.0012T + 0.0067G_t)\ t - 0.0006t^2$$

where U_t can be in any convenient units, that is GWh, kWh, etc.

Taking G_t = 3.8, which was the average from 1958 to 1976 (3), and referring time to 1967 (that is taking T = 10), this relationship becomes

$$\ln U_t = \ln U_{1967} + 0.079t - 0.0006t^2$$

We compare this with the best quadratic fits obtained by the Applied Mathematics Division of the DSIR which were prepared for and presented to us by the Campaign for Non-Nuclear Futures (4).

For total energy consumption over the period 1958–1976, the best quadratic fit for the logarithm is

$$\ln U\ (GWh) = 9.296 + 0.0721t - 0.00055t^2$$

where t = 0 for 1967. Note that U is the total energy consumption and not just non-domestic energy consumption (ignoring the large industries), as in the NZED case.

This expression for total consumption can obviously be rewritten in the form

$$\ln U_t = \ln U_{1967} + 0.0721t - 0.00055t^2,$$

where $\ln U_{1967}$(GWh) = 9.296 giving U_{1967} = 10 900 GWh. This value is slightly less than the actual 1967 value, but exact agreement is not to be expected since the relationship gives a smooth curve fit over the period 1958–1976, and fluctuations, presumably associated with G_t, are to be expected.

The similarity between the NZED model and the Applied Mathematics Division's fit is startling, there being, though, numerical differences. Such differences are to be expected since one is relevant to non-domestic consumption and the other to total consumption. These differences are further emphasised if Comalco is neglected from the total consumption, the fit then being given by

$$\ln U_t = \ln U_{1967} + 0.06528t - 0.00143t^2$$

with $\ln U_{1967}$ (GWh) = 9.294 giving U_{1967} = 10 900 GWh no different from before, which is to be expected because Comalco started operations only in that year. The significance of these differences is naturally that the growth patterns are different in different sectors as one would expect. Nevertheless, the importance of such relationships is that they imply saturation in the long term in all sectors.

Of course, as implied by Mr D. C. Cook of the NZED *(Evidence* p. 2233), the pattern of past consumption can always be fitted by a time series, a quadratic expression for the logarithm being just a second order approximation. That is putting

$$\Delta U = \alpha U \Delta t$$

where α can be a general function of time, on integrating

$$\ln U = \ln U_Y + \int_o^t \alpha \, dt$$

For α expanded as a time series this gives lnU as a time series, which may be fitted to past patterns of consumption. However, compared with the NZED model, there is little subtlety in this.

In its most general form, as given in C 3, the NZED model not only relates the rate of growth of electricity to the rate of growth of real GDP, but it also relates past to present or present to future patterns of consumption. Furthermore, this relationship is such that the feedback is negative rather than positive, implying a controlled situation. Although this mechanism is not explicitly apparent in the approximation that we obtained and used for constant G_t, it is nevertheless still implicit.

A final point is that the simple exponential function in which the exponent is a purely linear rather than a quadratic function of time is obviously an approximation to a more general case. However, it must also be appreciated that the coefficients in the quadratic expression may not necessarily be constants, being themselves functions of time. That is, in particular, for a significant period of time in the past, the coefficient of t^2 could have been much smaller than what it is now, and could thus be neglected.

Clearly the problem is a complex one and warrants further study.

References

1. "New Zealand Sub-National Population Projections", 1976–1991, p. 44, Department of Statistics, January 1976.
2. NZERDC, Report 19 (Continuation Scenario).
3. *New Zealand Official Year Book, 1976,* p. 703.
4. Campaign for Non-Nuclear Futures, submission 132, addendum.

Appendix D

D. 1. ESTIMATED NUCLEAR CAPITAL AND OPERATING COSTS—UNITED STATES AND NEW ZEALAND COMPARED

(Based on Constant Value 1976 dollars—US$1 = NZ$1)

UNITED STATES

(*Source:* Ford Foundation—MITRE Report)

Station size: dual 1150 MWe units
Commissioning date: 1985
Capital Costs—
Basic "best estimate": $667/kW[a]

At completion: $1,000/kW (*1985*)

Escalation factors: 8% p.a. to mid-1985
Discount factor: 13% p.a. (rate of return)
Capacity (Output) Factor: 60% assumed
Fuel Costs—

Yellowcake (U_3O_8) ...	$30/lb
Conversion ...	$3.33/kgU
Enrichment ...	$80 kg/SWU
Fabrication ...	$90 kg

No reprocessing of spent fuel.
Waste management (see below)

NEW ZEALAND

(*Source:* NZED submission No. 118)

Station size: dual 600 MWe units
Commissioning date: 1991
Capital Costs—
Basic estimate: $770/kW (including seismic allowance)[b]
$837/kW (including initial fuel)[c]
At completion: $1,120/kW (*1991*)[d]
$1,210/kW[e]
Escalation factor: Nil (except 10% IDC)
Discount factor: 10% p.a. (rate of return)
Capacity (Output) Factor: 70% assumed
Fuel Costs—

Yellowcake ...	$35/lb
Conversion ...	$5/kgU
Enrichment ...	$120/kg SWU
Fabrication ...	$130/kgU
Reprocessing ...	$150/kg
Waste management ...	$17/kg (spent fuel)

Generation Costs—	*U.S. Cents per kWh*
Capital charges	1.65
Total capital costs	1.65
Fuel charges *(60% output factor)—*	
Yellowcake	0.25
Conversion	0.01
Enrichment	0.20
Fabrication	0.04
Reprocessing	
Spent fuel disposal	0.04
Total fuel	0.54
Operation and maintenance	0.20
Total energy cost (at power station)	2.39*

*Plus 0.05 or minus 0.04 depending on uncertainties in future costs.

Generation Costs—	*N.Z. Cents per kWh*
Capital charges (basic station)	1.94[f]
Other Capital Costs	0.34[g]
Total capital costs	2.28
Fuel charges *(70% output factor)—*	
Yellowcake	0.23
Conversion	0.01
Enrichment	0.20
Fabrication	0.05
Reprocessing (net)	0.01
Waste management	0.01
Total fuel	0.51
Operation and maintenance	0.13
Total energy cost (at power station)	2.92

Notes on Assumptions and Calculations Used In D.1

(a) US$667 per kW initial capital cost (includes cooling towers $75 kW extra).
(b) NZED total cost $924 million for 2 × 600 MWe units = $770 per kW.
(c) NZED total cost (including initial fuel) is $1,004 million for 2 × 600 MWe = $837 per kW.
(d) NZED total (including 10 percent p.a. interest during construction for 9 years) is $1,345 million for 2 × 600 MWe = $1,120 per kW at completion.
(e) NZED total on same basis as (d) plus fuel is $1,454 million for 2 × 600 MWe = $1,210 per kW at completion.
(f) Based on total capital cost $1,345 million (1991) excluding initial fuel $109 million (1991), using a 70 percent output factor.
(g) Based on total other capitalised costs (including initial fuel/inventory, training, consultant's fees, land, roading, etc.) amounting to $238 million (1991).

D.2 ESTIMATED COAL-FIRED CAPITAL AND OPERATING COSTS—UNITED STATES AND NEW ZEALAND COMPARED

(Based on Constant Value 1976 dollars—US$1 = NZ$1)

UNITED STATES
(*Source:* Ford Foundation—MITRE Report)

	With Scrubbers	Without Scrubbers
Station size: dual 1150 MWe units		
Commissioning date	1985	1985
Capital Costs—		
Basic (1976)	Not stated	
At completion (1985)[a]	$555/kW	$465/kW
Escalation factor: 8% p.a. to mid 1985		
Discount factor: 13% p.a. (rate of return)		
Capacity (Output) Factor	60%	67%
Fuel Costs—		
(i) High sulphur coal—10^6 BTU	$1.08	..
(ii) Low sulphur coal—10^6 BTU	..	$0.43
(i) Transportation (300 miles)		
(ii) Transportation (1400 miles)		

NEW ZEALAND
(*Source:* NZED submission No. 118)

Station size: dual 600 MWe units	
Commissioning date	1991
Capital Costs—	
Basic (1976)	$320/kW
At completion (1991)[b]	$410/kW
Plus extras (land, roads, etc.)[c]	$467/kW
Escalation factor: Nil (except 10% IDC)	
Discount factor: 10% p.a. (rate of return)	
Capacity (Output) Factor	70%
Fuel Costs—	
Low sulphur ($25/te) equivalent—$10^6$ BTU	$0.95[d]

Generation Costs—	U.S. Cents per kWh	
Capital Charges—		
With scrubbers	1.37	..
Without scrubbers	..	1.03
	1.37	1.03
Fuel Charges—Output Factor	(60%)	(67%)
Coal at mines	1.00	0.40
Transportation	0.20	1.13
	1.20	1.53
Operation and Maintenance	0.28	0.16
Total Energy Cost (at power station)	2.85*	2.72†
*Cost variation	∓0.04	
†Cost variation		∓0.03

Generation Costs—	N.Z. Cents per kWh
Capital Charges—	
Basic station	0.71
Plus extra capital costs (land, etc.)	0.10
	0.81
Fuel Charges—Output Factor	(70%)
Based on $25/te (near coalfield)‡	1.00
	1.00
Operation and Maintenance	0.10
Total Energy Cost (at power station)	1.91

‡$1.06+ for Australian coal (imported)

Notes on Assumption and Calculations Used in D.2

(a) Based on Ford Foundation—MITRE Report (page 123).
(b) Based on NZED adjusted capital cost for station (2 × 600 MWe) $492 million (in 1991).
(c) Based on NZED adjusted total $561 million (in 1991) including land, roads, and general.
(d) Factors used: 1 kJ = 1.055 MBTU.
1 tonne gives 25^3kJ = 26.375^3 MBTU.
$25 tonne—equivalent $0.95 per 10^6 BTU.

GLOSSARY

1. Technical Terms—

Actinides—Elements following actinium in the periodic table. They include uranium and plutonium. Many of them are long-lived alpha-particle emitters.

Advanced converter—A reactor in which the reactor plus fuel assembly has a conversion ratio slightly less than unity.

Alpha particle—A positively charged particle composed of two protons and two neutrons, the nucleus of a helium atom.

Annual load factor—The ratio of the average half hourly electric power demand for the year to the maximum half hourly demand in that year expressed as a percentage.

Annual output factor—The ratio (expressed as a percentage) of electrical energy actually produced in a year to that which would have been produced in the same period if the unit had operated continuously at rated capacity.

Atoms—The building blocks of all matter, composed of a nucleus containing protons and neutrons, surrounded by electrons.

Background radiation—The natural ionising radiation of man's environment including cosmic rays, natural radioactivity in the ground and immediate surroundings, and in a person's body.

Base load plant—An electricity generating plant designed to operate at near constant output with little hourly or daily fluctuation and an annual output factor of more than 55 percent.

Base isolation—An engineering device which absorbs most of the energy from shaking ground in the base of a building or structure, thus affording a measure of protection from earthquakes.

Beta particle—An electron emitted from the nucleus of an atom; a light, negatively-charged particle.

Biota—Flora and fauna of a given region.

Biomass—Cultivated or natural vegetable matter used as a source of primary energy.

Breed—To form fissile nuclei, usually as a result of neutron capture possibly followed by radioactive decay.

Breeder reactor—A nuclear reactor that produces more fissile material than it consumes.

Burner—See *converter.*

Calandria—A cylindrical vessel within a reactor containing the heavy water moderator through which run the pressure tubes (CANDU reactor).

Capacity factor—See *output factor.*

Cogeneration—The generation of electricity with direct use of the waste heat for industrial process heat or for space heating.

Combined cycle—A gas turbine which in addition to driving its own electrical generator provides exhaust heat which is used either to raise steam for use in a steam turbine or as preheated combustion air for the normal firing of coal or oil in a boiler.

Common mode—Of failures, in which failure in one part of the system also affects the ability of another, supposedly independent, part to respond.

Constant dollars—Dollar estimates from which the effects of inflation or deflation have been removed, reported in terms of a base-year value and assumed to have constant purchasing power.

Conversion—The process which changes a fertile atom into a fissile atom using neutrons released in a fission process.

Conversion factor—Ratio of the number of fissile nuclei formed by conversion to the number of fissile nuclei consumed.

Converter—A reactor in which conversion takes place. Explicitly refers to a reactor for which the conversion ratio is significantly less than unity.

Coolant—A liquid or gas circulated through the reactor core to extract heat for the steam generators.

Core—The region of a reactor containing nuclear fuel where the nuclear chain reaction takes place and heat is thereby generated.

Core power density—Thermal power per unit volume generated in the reactor core and expressed in kW per litre.

Cosmic rays—Radiation emanating from high energy sources outside the earth's atmosphere.

Critical—Of an assembly of nuclear materials, being just capable of supporting a nuclear chain reaction.

Criticality—The condition, when a sufficient mass of fissile material is reached, where a self-sustaining chain reaction can occur.

Curie—A measure of the rate at which a radioactive material disintegrates. One curie corresponds to 37 000 million disintegrations per second (the amount of activity displayed by one gram of radium-226).

Current dollars—Dollar values that allow for inflation or deflation.

Daughter product—The nucleus which remains when a radioactive parent disintegrates. The daughter may itself be radioactive.

Decay—Disintegration of a nucleus through the emission of radioactivity.

Decay heat—Heat generated by radioactive decay of the fission products, which continues even after the chain reaction in a reactor has been stopped.

Delayed deaths—Deaths from cancer resulting from the effects of ionising radiation and occurring long after the irradiation process. The delay may be years or even decades.

Deuterium—A heavy, stable isotope of hydrogen having one proton and one neutron in its nucleus and present to the extent of 150 ppm in ordinary hydrogen; sometimes referred to as heavy hydrogen.

District heating—Space heating of buildings in a district by piping waste heat, in the form of hot water or steam, from a power station.

Dose—A measure of the quantity of ionising radiation to which a sample has been exposed (see *rad* and *rem*).

Dose commitment—Future radiation doses inevitably to be received because a particular radionuclide has been incorporated in body tissues, or has been dispersed in the environment.

Emergency core cooling system—A safety system in a nuclear reactor, the function of which is to prevent the fuel in the reactor from melting should a sudden loss of normal coolant occur.

Enrichment—The process by which the percentage of the fissionable isotope uranium-235 is increased above that occurring in natural uranium (0.7 percent).

Exponential growth—The type of growth in which the rate of change of a quantity is proportional to its magnitude. (The larger the quantity becomes, the faster it grows).

Fast breeder reactor—A fast reactor in which the degree of enrichment is such that breeding occurs.

Fast neutrons—Neutrons resulting from fission and not slowed down by a moderator.

Fast reactor—A reactor in which fast neutrons sustain the chain reaction, and the moderator may be dispensed with.
Fertile—Of a nucleus, that it can become fissile by capture of one or more neutrons, possibly followed by radioactive decay; uranium-238 is an example.
Fissile—Capable of fission by neutrons emitted in the fission process.
Fission—The splitting of a heavy nucleus into two or more lighter parts with the release of energy.
Fission product—A nucleus of intermediate size formed from the breakdown or fission of a heavy nucleus such as that of uranium. Such a nucleus will be radioactive, and usually emits beta particles.
Fluidised bed combustion—A process in which finely ground solid fuel is freely supported in a furnace by an upwards fluid-like flow of particles which separates fuel particles and increases combustion efficiency.
Fusion—The merging of two light nuclei to make a heavier one, usually with a release of energy.
Gamma radiation—High energy X-rays (highly penetrating radiation) emitted from the nucleus of many radioactive atoms during radioactive decay.
Generating capability—The energy output from an electrical generating station or unit. It could be given in joules, but is usually expressed in gigawatts hours (GWh) or megawatt hours (MWh).
Generating capacity—The power output from an electrical generating station or unit; usually expressed in megawatts (MW) or gigawatts (GW).
Genetic effects—Effects produced by ionising radiation in the reproductive cells of an organism and becoming manifest (usually as malformations) in the offspring or descendants.
Gross domestic product—The total annual value of all goods and services produced in a country.
Gross national product—The annual national income plus an allowance for depreciation at market prices.
Half-life—The time in which the number of nuclei of a particular type is reduced by radioactive decay to one half.
Heavy water—Water in which the hydrogen atoms all consist of deuterium.
High-level waste—The waste containing more than 99.9 percent of the fission products which is left after the uranium and plutonium have been extracted from irradiated fuel.
Hot particle—An insoluble particle of breathable size containing alpha emitting radioactive material.
Insolation—The radiation received at the earth's surface from the sun.
Intermediate-load plant—Electricity generating plant designed to meet that part of the load which drops to zero overnight but is relatively constant during the day. Output factor between 50 and 55 percent.
Ion—An atom that has gained or lost one or more electrons and thus become electrically charged.
Ionising radiation—Radiation which can deliver energy in a form capable of knocking electrons off atoms and turning them into ions.
Irradiated—Of reactor fuel, having been involved in a chain reaction and having thereby accumulated fission products; in general usage, exposed to radiation.

Isotope—One of perhaps several different species of a given chemical element, distinguished by variations in the number of neutrons in the atomic nucleus but indistinguishable by chemical means.

Light water—Ordinary water.

Load factor—See *annual load factor* (Used in many submissions synonymously with *output factor*).

Loss of coolant accident—A reactor accident in which the primary coolant is lost from the reactor core.

Magnetohydrodynamic (MHD) electricity generation—Production of electricity by the motion of an electrically conducting fluid in a magnetic field.

Meltdown—Of reactor core, result of inadequate cooling which causes part of or all of the solid fuel in a reactor to reach the temperature at which cladding and possibly fuel and support structure liquefy and collapse.

Moderator—Substance used to slow down neutrons emitted by nuclear fission.

Mutation—Any change in the inheritable material of a living cell.

Mutagen—Substance producing mutations.

Nuclide—Any particular type of nucleus, not necessarily radioactive.

Output factor—See *annual output factor*.

Particulates—Fine solid particles that remain individually dispersed in emissions from fossil-fuelled plants.

Peak load—The maximum power demand on a power supply system.

Peak-load plant—Electricity generating plant designed to operate during periods of maximum demand. The output factor is usually less than 15 percent.

Prompt deaths—In distinction to delayed deaths: deaths from the effects of ionising radiation occurring soon after irradiation.

Quality factor—A factor that attempts to account for the differing biological effectiveness of the various types of radiation. It is taken as 1 for beta- and gamma- radiation, and 10 for alpha-radiation and fast neutrons.

Rad—The unit of absorbed radiation corresponding to 0.01 joules of energy per kg of material (*R*adiation *A*bsorbed *D*ose).

Radiation—The emission and propagation of energy such as solar radiation, gamma rays, or fast particles such as alpha particles or electrons.

Radioactivity—Process in which nuclei are spontaneously undergoing transformation and emitting radiation; radioactivity *produces* radiation.

Radionuclide—A nucleus that is radioactive.

Recycling—The re-use of fissionable material (e.g., plutonium in irradiated nuclear fuel).

Reflector—Material surrounding a reactor to reduce neutron loss and thereby improve the operation.

Rem—A unit quantifying the biological effect of ionising radiation; the product of the dose in rads and a quality factor.

Reprocessing—The chemical and mechanical processes by which spent reactor fuel is separated into uranium, plutonium, and radioactive waste (mainly fission products).

Scrubber—A device for removing certain pollutants, such as sulphur dioxide, from stack gas emissions.

Slow neutrons—Neutrons that have been slowed by a moderator to increase their probability of capture by fissile nuclei.

Somatic effects—Effects produced in the non-reproductive cells of an irradiated organism, usually cancers.
Spallation—Any nuclear reaction when several particles result from a collision.
Spent fuel—Fuel depleted of fissile material after burn-up in a reactor. It contains radioactive waste and unburned fissile material.
Thermal neutrons—Neutrons travelling with a speed comparable with that of gas molecules at ordinary temperatures (about 2 km/s).
Thermal reactor—A reactor in which the chain reaction is sustained by slow (thermal) neutrons. The fuel enrichment is not enough to produce sufficient fissions to support a chain reaction with a moderator.
Thermal station—Electricity generating station in which energy is provided by burning a fuel.
Total energy system—An electricity generating system in which the heat in the fluid which has passed through the turbines is used instead of going to waste.
Tritium—A radioactive isotope of hydrogen in which the nucleus contains one proton and two neutrons.
Unit—In common usage, and in that of the electrical supply authorities, a kilowatt hour of delivered electricity.
Vitrification—The incorporation of high-level wastes into glass.
Waste (radioactive)—Radioactive materials (mostly fission products) from the nuclear fuel cycle.
Weapons grade—Of uranium or plutonium, capable of being made into a nuclear assembly that would be critical on fast prompt neutrons alone.
Yellowcake—The concentrate of uranium oxides and impurities extracted at a mill from uranium ore (typically 95 percent U_3O_8).

2. Acronyms and Abbreviations—

ACRS—Advisory Committee on Reactor Safeguards (USA).
AECB—Atomic Energy Control Board (Canada).
AGR—Advanced Gas-Cooled Reactor.
AIF—Atomic Industrial Forum (USA).
AQCS—Air Quality Control System.
BEIR—Advisory Committee on the Biological Effects of Ionising Radiation.
BNFL—British Nuclear Fuels Ltd.
BWR—Boiling-Water Reactor.
CANDU—*Can*adian *D*euterium-moderated natural-*U*ranium fuelled reactor.
CEGB—Central Electricity Generating Board (UK).
CERCDC—California Energy Resources Conservation and Development Commission.
CFR—Commercial Fast Reactor.
Ci—Curie.
COP—Coefficient of Performance.
CRPPH—Committee on Radiation Protection and Public Health (EURATOM).
CRPR—Committee to Review Power Requirements.
DSIR—Department of Scientific and Industrial Research.
ECO—Environment and Conservation Organisations of New Zealand.
EPRI—Electric Power Research Institute (USA).
ERDA—Energy Research and Development Administration (USA).

ERG—Energy Research Group (NZERDC).
FBR—Fast Breeder Reactor.
FFGNP—Fact Finding Group on Nuclear Power.
Flowers Report—Sixth report of UK Royal Commission on Environmental Pollution.
Ford-Foundation - MITRE Report—Report of US Nuclear Energy Policy Study group—*Nuclear Power Issues and Choices.*
Fox Report—First report of Australian Ranger Uranium Environmental Inquiry.
GDP—Gross Domestic Product.
GEC—General Electric Company Ltd.
GJ—Gigajoule(10^9 joules).
GNP—Gross National Product.
GW—Gigawatt (10^9 watts or one million kilowatts).
HTGR—High Temperature Gas-Cooled Reactor.
HWR—Heavy Water Reactor.
IAEA—International Atomic Energy Agency (Vienna).
ICRP—International Commission on Radiological Protection (UK).
IDC—Interest During Construction.
IEA—International Energy Agency (Paris).
kWh—Kilowatt-hour.
LMFBR—Liquid Metal Fast Breeder Reactor.
LWA—Limited Work Authorisation.
LWBR—Light Water Breeder Reactor.
LWR—Light Water Reactor.
MER—Ministry of Energy Resources.
MHD—Magnetohydrodynamic.
MSR—Molten Salt Reactor.
MW—Megawatt (10^6 watts or 1000 kilowatts).
MWD—Ministry of Works and Development.
NCRP—National Council on Radiation Protection and Measurements (USA).
NCW—National Council of Women.
NEA—Nuclear Energy Agency (Paris).
NII—Nuclear Installations Inspectorate (UK).
NNC—National Nuclear Corporation (UK).
NPC—Nuclear Power Company Ltd. (UK).
NPRA—Nuclear Power Regulatory Authority.
NPT—Treaty on Non-Proliferation of Nuclear Weapons.
NRC—Nuclear Regulatory Commission (USA).
NZAEC—New Zealand Atomic Energy Committee.
NZED—New Zealand Electricity Department.
NZERDC—New Zealand Energy Research and Development Committee.
OBE—Operating Base Earthquake.
OECD—Organisation for Economic Co-operation and Development (Paris).
O and M—Operation and Maintenance.
PCEPD—Planning Committee on Electric Power Development.
PFR—Prototype Fast Reactor.
PFUC—Policy and Finance Utilisation Committee.
PHW—Pressurised Heavy Water.
PJ—Petajoule (10^{12} joules).
PSA—Public Service Association.

PWR—Pressurised Water Reactor.
Q—Unit of energy = 10^{18} British Thermal Units.
Rasmussen Report—AEC, Wash–1400, 1974.
SGHWR—Steam Generating Heavy Water Reactor.
SSE—Safe Shut-down Earthquake.
SSEB—South of Scotland Electricity Board.
TES—Total Energy System.
TJ—Terajoule (10^{15} joules).
UKAEA—United Kingdom Atomic Energy Authority.
UNSCEAR—United Nations Scientific Committee on the Effects of Atomic Radiation.
USAEC—United States Atomic Energy Commission.
USNRC—United States Nuclear Regulatory Commission.
WAES—Workshop on Alternative Energy Strategies (USA).
WHO—World Health Organisation.

3. Prefixes, Units, and Conversion Factors—

(a) Prefixes indicating multiples and submultiples of units:

peta (P) × 10^{15}
tera (T) × 10^{12}
giga (G) × 10^{9}
mega (M) × 10^{6}
kilo (k) × 10^{3}
femto (f) × 10^{-15}
pico (p) × 10^{-12}
nano (n) × 10^{-9}
micro (μ) × 10^{-6}
milli (m) × 10^{-3}

(b) Units of energy and power:

The joule (J) is the unit of energy.
The watt (W) is the unit of power.
1 joule per second = 1 watt.
1kWh (kilowatt hour) = 3.6 MJ.
1MWh = 3.6 GJ.

(c) Energy content of fuels:

1 kg of organic fossil fuel (typical)	35 MJ
42 gallon (US) barrel of oil	6.1GJ
1 cubic metre of natural gas	36 MJ
fission of 1 kg of uranium-235 (approximately) ...	100 TJ
fusion of 1kg of deuterium	400 TJ
complete conversion of 1 kg of matter	90 PJ

REFERENCES

1. G. F. Serrallach, submission 65.
2. Friends of the Earth, submission 91.
3. Ecology Action (Otago) Inc., submission 34.
4. Report of the Fact Finding Group on Nuclear Power, Wellington, March 1977.
5. Ministry of Energy Resources, submission 13.
6. G. S. Harris *et al., Energy Scenarios for New Zealand.* NZERDC Report No. 19.
7. *A Blueprint for Survival, The Ecologist.* (Penguin Books) 1972.
8. BP Statistical Review of the World Oil Industry 1975, quoted in the sixth report of the Royal Commission on Environmental Pollution, London, 1976.
9. *Energy: Global Prospects 1985–2000.* Report of Workshop on Alternative Energy Strategies (McGraw Hill) 1977.
10. Ranger Uranium Environmental Inquiry. First report, Canberra 1976, (Fox report).
11. BP (N.Z.) Ltd., submission 51.
12. *Nuclear Power Issues and Choices.* Report of the Nuclear Energy Policy Study Group, 1977 (Ford Foundation - MITRE report).
13. M. M. Pennell, "The Changing Pattern of Energy Resources". Keynote address to the Pacific Basin Economic Council, May 1977.
14. T. Price, "The Balance of Uranium Supply and Demand". Submission to Windscale Inquiry, 1977.
15. Report on Nuclear Resources 1985–2020, Executive Summary. World Energy Conference, 1977.
16. *Nuclear Power Issues and Choices,* p. 81. (Total *3310* for "reasonably assured" should be *2420*).
17. Communication on the World Energy Conference from the New Zealand Institution of Engineers.
18. Report of the Ministry of Energy Resources for year ended 31 March 1977.
19. Report of the International Energy Agency, 1977.
20. Report of the DSIR for year ended 31 March 1975.
21. J. Stephenson, submission 75.
22. Harris, Ellis, Scott & Wood, paper to third New Zealand Energy Conference, 1977.
23. Commission for the Environment, submission 14.
24. New Zealand Values Party, submission 76.
25. Dr E. Geiringer, submission 93.
26. Friends of the Home, submission 70.
27. Campaign for Non-Nuclear Futures, submission 57.
28. Environmental Defence Society, submission 100.
29. P. Bieleski, submission 33.
30. Professor J. T. Salmon, submission 56.
31. Environment and Conservation Organisations, submission 102.
32. Mines Department, submission 110.
33. Ministry of Energy Resources, submission 129.
34. G. Williams, submission 31.
35. Church and Society Commission, National Council of Churches, submission 82.
36. Environment and Conservation Organisations of New Zealand (Dr F. Knelman), submission 120.
37. Nature Conservation Council, submission 47.
38. Report of the PCEPD, 1976.
39. Report of the CRPR, 1976 appendix 1.
40. NZED, submission 11.
41. Report of the CRPR, 1977.
42. Report of the PCEPD, 1977.
43. Report of the CRPR, 1975.
44. DSIR, submission 7.
45. Ministry of Energy Resources, submission 136.
46. DSIR, submission 112.
47. N. J. Peet and A. G. Williamson, submission 113.
48. Report of the NZED for the year ended 31 March 1977.
49. Deduced from the 1976 report of the NZED, and the *New Zealand Official Year Book, 1976.*
50. S. Wong and M. Hewlett "Comparative Economics of the Principal Forms of Electricity Generation", third New Zealand Energy Conference, 1977.
51. *New Zealand Official Year Book, 1976.*
52. Mines Department, submission 17.
53. NZED, submission 128.

54. "Maui Field—Gas Reserves and Deliverability", Maui Development Ltd., 1975.
55. Natural Gas Corporation, submission 21.
56. MWD, submission 104.
57. "Broadlands Geothermal Power Scheme—Report of Disposal of Waste Fluids", Power Division, MWD, September 1977.
58. Dr N. J. Cherry, "Wind Energy Resource Survey of New Zealand", NZERDC report No. 8.
59. Dr N. J. Cherry, submission 117.
60. Sir John Hill, UKAEA; Royal Commission visit to London.
61. J. H. Troughton and I. D. Cave, "Potential for Energy Farming", DSIR Information Series No. 117, 1975.
62. NZED, submission 118.
63. NZED, submission 138.
64. Friends of the Earth, submission 137.
65. Appendix C.
66. Campaign for Non-Nuclear Futures, submission 132.
67. P. J. Graham, "Overview of Energy Demand and Opportunities for Conservation", third New Zealand Energy Conference, 1977.
T. R. O'Malley, New Zealand Institute of Economic Research (NZERDC contract 3013).
68. R. A. Shaw and J. Stephenson, "The Feasibility of Heat Pumps for Residential Space Heating in New Zealand", NZERDC report 18.
69. World Energy Outlook, OECD, Paris 1977.
70. New Zealand Federation of Labour, submission 88.
71. Biennial Report of State Energy Commission, Vol. 3, California 1977.
72. Notes prepared for Royal Commission by Commission for the Environment.
73. *Electric Light and Power (U.S.A.)* Vol. 55, No. 8, 1977.
74. "A Critique of the Electricity Industry", ERG, Open University. ERGO 13, 1976; also Royal Commission interview with Dr P. F. Chapman (Open University), London.
75. Ministry of Energy Resources, submission 136 (p. 3 amended).
76. The Treasury, submission 125.
77. Royal Commission visit to Hydro-Quebec, Canada, 1977.
78. Ministry of Foreign Affairs, submission 18.
79. "Licensing of Nuclear Power Reactors". US Nuclear Regulatory Commission.
80. (1) "Licensing and Regulatory Control of Nuclear Installations" IAEA publication. STI/PUB/421, 1975.
(2) "Authorisation Procedure for the Construction and Operation of Nuclear Installations within the EEC Member States". European Atomic Energy Community (5284e) 1974.
81. DSIR Submission 7c quoting J. A. Richardson, *Nuclear Engineering International.*
82. W. S. Gronow and R. Gausden, "Licensing and Regulatory Control of Thermal Reactors in the United Kingdom". Nuclear Installations Inspectorate, London.
83. "Government Regulation of the Canadian Nuclear Industry". Atomic Energy Control Board (AECB-1093).
84. New Zealand Atomic Energy Committee, submission 108.
85. Department of Lands and Survey, submission 10.
86. Wild Life Division, Department of Internal Affairs, submission 20.
87. New Zealand Atomic Energy Committee, submission 133.
88. "Reactor Site Criteria". United States Nuclear Regulatory Commission (10-CFR-100).
89. F. R. Charlesworth and W. S. Gronow, "Containment and Siting of Nuclear Power Plants". IAEA, Vienna (STI/PUB/154).
90. CEGB Newsletter No. 104, June 1977.
91. B. L. Cohen, *Scientific American,* Vol. 236, 1977.
92. New Zealand Medical Association, submission 97.
93. Professor B. G. Wybourne, submission 85.
94. New Zealand Geological Society (Inc.), submission 96.
95. Ministry of Transport, submission 12.
96. P. Grimwood and G. Webb, *New Scientist,* March 1977.
97. J. B. Morris, *Information Papers on Nuclear Waste Management,* Harwell Laboratory, 1977.
98. Sir John Hill, "Radioactive Waste Management in the U.K." *Atom,* No. 240, 1976.
99. "Objectives, concepts and strategies for management of radioactive waste arising from nuclear power programmes", report of OECD Nuclear Energy Agency, 1977.
100. B. Bolin, *Energy and Climate* (Secretariat for Future Studies), Sweden, 1975.
101. S. Manabe and R. Weatherald, "The effects of doubling the CO_2 concentration on the climate of a general circulation model", (GFDL/NOAA) Princeton N. J., 1974.
102. C.F. Baes *et al., The Global CO_2 Problem,* Oak Ridge National Laboratory, 1976.

103. Royal Commission on Environmental Pollution. Sixth report, Nuclear Power and the Environment. H.M.S.O., 1976 (Flowers report).
104. Dr E. Geiringer, *Evidence,* p. 1258 and submission 141.
105. Professor D. W. Beaven, submission 116.
106. Report of the Advisory Committee on Biological Effects of Ionising Radiations, National Academy of Sciences, and National Research Council, Washington 1972 (BEIR).
107. H. C. Sutton; "Biological Hazards of Carbon-14", Institute of Nuclear Sciences (11/21), 1977.
108. Professor R. H. Mole, private letter to Dr I. K. Walker of the DSIR.
109. Department of Health, submission 109.
110. Dr S. Eklund, IAEA International Conference on Nuclear Power and its Fuel Cycle, Salzburg, May 1977.
111. Walter C. Patterson, *Nuclear Power* (Pelican Books).
112. R. R. Matthews, "Nuclear Power and Safety", CEGB publication, 1976.
113. Commission for the Future, submission 130.
114. N. C. Rasmussen,* "Reactor Safety Study. An Assessment of Accident Risks in Commercial Nuclear Power Plants", US Nuclear Regulatory Commission (Wash-1400), 1975.
115. F. Von Hippel, *Bulletin of the Atomic Scientists,* 1975.
116. American Physical Society, *Review of Modern Physics,* Vol. 47, 1975.
117. Union of Concerned Scientists (Cambridge, Mass.), News release April 27, 1977.
118. U.S. Environmental Protection Agency, *Reactor Safety Study. A Review of the Final Report,* 1976.
119. New Zealand Public Service Association (Inc.), submission 69.
120. Sir John Hill, *Atom,* April 1977.
121. R. Nader, address to the Massachusetts Legislature, 1974.
122. Sir John Hill, *Atom,* September 1976.
123. P. Beckman, *The Health Hazards of Not Going Nuclear* (Golem Press), 1976.
124. G. G. Page, submission 111 and *Evidence,* p. 1713.
125. DSIR submission 7m quoting D. Kovan, "Nuclear Insurance and Indemnity", *Nuclear Engineering International,* 1976.
126. DSIR submission 7m quoting C. A. Miles, "Some considerations affecting nuclear insurance in respect of land-based installations", *Insurance for Nuclear Installations,* IAEA, Vienna, 1970.
127. DSIR submission 7m quoting *Maritime Carriage of Nuclear Materials.* Proceedings of a symposium, Stockholm 18–22 June, 1972. IAEA, Vienna, 1973.
128. DSIR submission 7m quoting J. Marrone, "Nuclear Liability Insurance—a Resumé of Recent Years", *Nuclear Safety,* 1975.
129. DSIR submission 7m quoting J. Marrone, "Nuclear Liability Insurance—a Brief History Reflecting the Success of Nuclear Safety", *Nuclear Safety,* 1971.
130. DSIR submission 7m quoting *Insurance for Nuclear Installations,* IAEA, Vienna, 1970.
131. DSIR submission 7m quoting Atomic Industrial Forum Inc., "Questions and Answers on Price-Anderson", 1975.
132. DSIR submission 7m quoting Public Service Electric and Gas Company, "Questions and Answers about Nuclear Power", 1974.
133. DSIR submission 7m quoting J. P. H. Trevor, "Third Party Liability—the International Legal Framework and Its Transposition into National Legislation", *Insurance for Nuclear Installations,* IAEA, Vienna, 1970.
134. DSIR submission 7m quoting G. Hertel "Basic Principles of Insurance for Nuclear Risks" in *Insurance for Nuclear Installations,* IAEA, Vienna, 1970.
135. DSIR submission 7m quoting W. R. Bentzien, *The Liability for Genetic Radiation Damage* (Goettingen University, Instut. fur Voelkerrecht), 1971. (In German, but an English abstract is available. Refer *INIS,* Vol. 7, No. 7, 234183).
136. Accident Compensation Commission, submission 29.
137. Department of Trade and Industry, submission 15.
138. J. W. Rowe, third New Zealand Energy Conference, 1977.
139. Women's International League for Peace and Freedom, submission 44.
140. Campaign Against Nuclear Warships, submission 66.
141. B. E. and G. F. Preddy, submission 43.
142. *Electric Light and Power,* "US leans towards denatured thorium cycle", Vol. 55, No. 8, 1977.
143. California Energy Resources Conservation and Development Commission, 1977 biennial report, volumes 1–7.
144. *Electric Light and Power,* Vol. 56, No. 1, 1978.
145. Cambridge Reports Inc.—Westinghouse Survey.

146. *The National Energy Plan,* Executive Office of the President, Energy Policy and Planning (U.S. Government Printing Office), 1977.
147. B. Greer-Wootten and L. Mitson, "Nuclear Power and the Canadian Public", Institute of Behavioural Research, York University, 1976.
148. New Society Research Survey, report printed in *Atom,* June 1977.
149. Dr P. Phillips, "Household Attitudes to Energy Use and Conservation", NZERDC Report No. 10, May 1976.
150. Dr N. J. Ericksen, submission 114.
151. National Council of Women of New Zealand, submission 87.
152. New Zealand Federation of University Women, submission 30.
153. New Zealand Federation of Business and Professional Women's Clubs, submission 41.
154. Canterbury-Westland Young Nationals, submission 40.
155. C. Walske, "Nuclear Electric Power and the Proliferation of Nuclear Weapon States", International Security (Harvard University), Winter 1977.
156. *Financial Review,* 13 January 1978.
157. "Canadian Policy-Makers' Views on Nuclear Energy", Institute of Behavioural Research, York University, 1976.
158. *Electric Light and Power,* Vol. 55, No. 12, 1977.
159. "Energy Research and Development in the United Kingdom," the Royal Society, 1977.
160. G. E. Coote "Nuclear power and the Environment 14—Breeder Reactors" (INS 867) DSIR, 1977.
161. CEGB Corporate Plan—A discussion document, 1977.
162. *Power Reactors in Member States,* IAEA, Vienna, 1977.
163. Atomic Industrial Forum (AIF) personal communication.
164. AIF 1977 report (*Electric Light and Power,* Vol. 55, No. 8, 1977).
165. Atomic Energy of Canada Ltd., annual report, 1977.
166. World Energy Conference 1977, *World Energy Demand to 2020,* executive summary.
167. *Atom News,* September 1977.
168. CEGB annual report 1977.
169. CEGB Statistical Year Book 1976–77.
170. "Windscale Planning Application", British Nuclear Fuels Limited.
171. H. J. Dunster and R. Gausden "Some Aspects of Safety of Nuclear Installations in Great Britain", United Kingdom Health and Safety Executive publication, January 1977.
172. United Kingdom Health and Safety Executive news release, 29 July 1977.
173. V. Joksemavic, W. J. Houghton, and D. E. Emon "HTGR Risk Assessment Study" (GA-A 14336), General Atomic, USA, 1977.
174. "Nuclear Fuel Cycle Requirements", report of OECD Nuclear Energy Agency, Paris, 1978.
175. *New Zealand Official Year Book,* 1977.
176. G. Woite "Draft Report on Advisory Group Meeting on the Extrapolation of Capital Costs Experience to Developing Countries" IAEA, Vienna, 1976.
177. R. Krymm, "A New Look at Nuclear Power Costs", IAEA Bulletin 18, No. 2, 1976.
178. Environmental Defence Society, submission 23.
179. "IAEA Nuclear Power Planning Study Manual", Division of Nuclear Power and Reactors, IAEA, Vienna, 1975.
180. R. F. Skinner, G. N. Bycroft, and G. H. McVerry, "A Practical System for Isolating Nuclear Power Plants from Earthquake Attack", *Nuclear Engineering and Design 36,* 1975.
181. L. Seyfferth, "Planning for Decommissioning" IAEA. Quoted in DSIR submission 7n.
182. Atomic Industrial Forum, *Nucleonic Week,* December 1976. Quoted in DSIR submission 7n.
183. Connecticut Public Utilities Authority, *Nucleonic Week,* January, 1977. Quoted in DSIR submission 7n.
184. Report of the Combined Committee on the New Zealand Electric Power Supply, 1957, quoted in NZED submission 11.

INDEX

References are to chapter and paragraph, with important topics in capitals and main references in bold type. The following abbreviations are used: f "and also in the next paragraph"; ff "and in the following paragraphs"; n. "nuclear"; n.p. "nuclear power".

Appendices, tables, and figures are listed in the table of contents, but are not indexed.

E. C. K

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