New Zealand After Nuclear War

THE BACKGROUND PAPERS

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460

CONTENTS

BACKGROUND PAPER 9

RADIATION EFFECTS ON THE ENVIRONMENT AND PEOPLE OF NEW ZEALAND

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This is one of a set of background papers prepared in consultation with the Nuclear Impacts Study Team for a study of the impacts on New Zealand of a major nuclear war. Along with other sources the papers comprised the basis of the book ***New Zealand After Nuclear War*** *by Wren Green, Tony Cairns and Judith Wright, published by the New Zealand Planning Council, 1987. The asumptions that the study was based on are explained in Background Paper 1, note particularly the assumption that New Zealand is not a target, and the variable assumption involving an electromagnetic pulse (EMP - for an explanation, see Background Paper 5).*

OVERVIEW

August 6th 1945 brought new dimensions to the inhumanity of war. Radiation and fallout were experienced on a large scale. Images of burnt bodies, violently-ill people, deformed babies and a legacy of cancer entered our consciousness. Today, bigger bombs are available in 'overkill' numbers. The prospects are terrifying, and have led to a general notion that after a large-scale war the initial survivors would be wiped out within weeks by a deadly cloud of radioactivity, or succumb eventually to cancers or birth defects.

This notion is incorrect. Radiation levels over large areas of the earth's surface would be lethal for a period after a war. However, over even larger areas the dominant threat to human survival would not be radioactivity. This would be because the released radioactivity quite rapidly:

*disperses and dilutes
*deposits on the surface
*decays

This behaviour means that even for the most powerful bombs, people in regions remote from any explosion (approximately more than 1000 km away) cannot receive doses that are lethal in the short-term. In this situation, the long-term health effects are surprisingly small.

This is not to concede that the long-term effects are unimportant or that no prior planning would be needed. It does explain why policy-makers may give less attention to the radiation-related consequences of nuclear war than most people believe warranted. There are likely to be more urgent and demanding problems. This issue paper examines why.

EXPLANATORY NOTES

Radiation is energy which can be transferred across empty space. It includes heat, radiowaves, radar, micro-waves, ultraviolet and visible light, and X-rays. In this paper radiation is taken to mean *ionizing radiation*. As this form of radiation passes through matter, it disrupts the structure of atoms and molecules, splitting chemical bonds and leaving electrically-charged fragments called *ions*. From these initial ionizations arise the eventual biological effects we discuss.

Nuclear weapons produce blast, heat radiation and ionizing radiation by either rapid *fission* or *fusion* processes. *Fission* (atomic bombs) involves the splitting of the nucleus of an atom into 2 or more nuclei. *Fusion* (hydrogen bombs) involves the amalgamation of small nuclei. Both processes release energy which in weapons would be measured in *megatonnes* (Mt). One Mt would be the explosive equivalent of one million tonnes of TNT.

Neutrons and *gamma-rays* are important types of radiation which are released in the explosion. Neutrons are one of the two principal particles of nuclei (protons are the other). Neutrons have no electric charge and penetrate long distances in air or deeply into tissues. Gamma-rays are electro-magnetic waves, like light, lacking mass and charge. They also penetrate air and tissues.

Over 300 different types of atoms are produced during fission. Many of these *fission products* emit radiation, which can be of three types. One type would be a gamma-ray discussed above. Since gamma-rays pass right through the body, a gamma-ray emitter is a hazard from both outside and inside the body. It exposes the whole body to radiation. A *beta-ray* is a fast moving electron which can penetrate only a few millimetres into tissue (skin-deep). Beta-emitters threaten only those tissues with which they are in contact (e.g. the skin or an organ in which they localize). The heavier *alpha-ray* is an ionized helium atom which can penetrate only 0.05 mm into tissue. An alpha-ray is absorbed within the outer layers of skin, and are only a hazard when alpha-emitters are taken into and retained in the body.

Fission products which spontaneously emit radiation are said to be *radioactive* and are often called *radioactive isotopes*. Since radioactive fission products dominate the long-term effects of weapons, it is important to know the *fission fraction* of a weapon, the fraction of the total energy (Mt) produced by fission. In an H-bomb the remaining energy is provided by fusion.

Each radioactive fission product emits radiation with a characteristic energy and rate. This rate is expressed as a *half-life*, the time taken for half the original radioactivity to disappear or decay. For example, if the half-life is 200 days then that radioactive isotope will have lost (by decay) half its radioactivity in 200 days, half of the remainder (a quarter of the original) in a further 200 days and so on. The half-lives of fission products vary from less than a second to thousands of years. As a rule of thumb, for this issue paper, multiplying the half-life of a radioactive isotope by 10 will show how long it takes for the radioactivity to diminish to an insignificant level. Chemically, radioactive isotopes behave identically to the corresponding stable element. Thus radioactive iodine behaves like normal, or stable, iodine. Thus their uptake, retention and removal from tissue and the movement in eco-systems parallels the uptake or movement rates of the stable element.

Some important radioactive isotopes in the environment are iodine-131, cesium-137, strontium-90 and plutonium-239.

Iodine-131 emits both beta and gamma-rays. It has an 8-day half-life and so is of importance for only 2-3 months (8 days x 10). It concentrates in the thyroid after inhalation or ingestion. *Strontium-90* is a beta-emitter. It remains a hazard for many years (half-life is 28 years). It resembles calcium chemically, and after ingestion locates in bone, from which it is be displaced very slowly. *Cesium-137* has a 30-year half-life but is a gamma-emitter. It delivers dose to the whole body when present externally or internally. When taken into the body it distributes throughout most tissues, especially muscle, but is excreted from the human body in 1-2 years. *Plutonium-239* has a half-life of 24,000 years. It is an alpha-emitter (non-penetrating) and is hazardous only when ingested and then retained within the body. The lung, liver and bone are the main tissues in which it is found, and in which it is retained for many years.

Radiation causes biological damage when its energy is absorbed in tissue. The absorbed energy is measured in *RAD* (0.01 Joule/kg). Different radiations deposit this absorbed energy with differing degrees of concentration at the microscopic, cellular level. The practical unit for biological effects must account for this. The measurement unit used is the *REM*. For simplicity we can take 1 rad = 1 rem for the beta and gamma-rays mentioned here. However alpha-rays and neutrons have a ten to twenty-fold greater effect per rad. For these radiations 1 rad = 10-20 rem.

New units of radiation dose are now in use. The *gray* (1 Joule/kg) is 100 rad, and the *sievert* (Sv) is 100 rem. As people are more familiar with the older units, rem is used here. 1 mrem will be one-thousandth of a rem. The rem is more properly called a unit of *dose equivalent*, but we shall simply call it a unit of dose.

Finally, radioactivity and radiation are not solely products of technology. Everyone is exposed to cosmic radiation and naturally radioactive elements in the soil, rocks, food and our bodies. This *natural background* provides an unavoidable annual dose of about 0.2 rem.

SECTION ONE

BACKGROUND INFORMATION

1. SOURCES OF RADIATION EXPOSURE

A nuclear detonation exposes our eco-system to increased radiation levels from the instant of the explosion until thousands of years afterwards. For convenience, the radiation is classed as either *initial* or *residual* radiation. Initial radiation is experienced within 1 minute of the explosion; residual radiation exposure occurs at longer times, and is mainly due to radioactive fallout.

1.1 Initial radiation

The fission/fusion process causes the emission of a mixture of radiations. Gamma-rays and neutrons are important to initial radiation levels since they can travel long distances in air. Lethal doses can occur over distances of a few kilometres from the explosion centre.

Only about 5% of the explosion energy results in initial radiation. Twice as much energy goes into the residual radiation. Most of the energy goes into blast (50%) and heat (35%). As a result, the area covered by lethal initial radiation levels lies within larger areas in which blast and heat are lethal (Table 1*). A minor exception to this occurs with very small weapons of about 1kt (kilotonne) (1Mt = 1000 kt).

1.2 Residual radiation (fallout)

All nuclear explosions result in fallout or particles produced by the explosion which eventually settle to earth. Fallout contains radioactive isotopes which emit radiation. Typical bombs produce a total of about 300 radioactive isotopes of some 36 different elements (Table 2). The radiations emitted are alpha, beta and gamma rays.

The radioactivity associated with fallout, and when and where it is deposited depends upon the energy and height above the ground of the explosion. Whether the fireball touches the ground or not is critical. If it does (called a 'surface burst'), large quantities of ground debris are sucked into the fireball. Some elements in this debris are made radioactive, increasing the total radioactivity. More importantly, the fission products, which are initially gases, cool as the fireball rises and condense onto particles of debris. Many of these particles are relatively large (a few hundredths of a millimetre) and gravity brings them to earth within 24 to 48 hours. This constitutes *early* or *local* fallout.

If the fireball does not touch the ground (called a 'high air-burst'), the radioactive fission products condense into far smaller particles. These can remain suspended in the atmosphere for several years. This is *delayed* or *global* fallout.

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*Tables and figures follow at the end of this paper.

The time at which the fallout returns to the earth's surface is also critical. As the radioactive isotopes emit radiation (decay) the total radioactivity and, hence, the consequences decrease. The decay rates of radioactive isotopes vary tremendously. However, the decrease in radioactivity can be estimated satisfactorily by a simple rule. For each sevenfold increase in time, total radioactivity decreases tenfold (Table 3).

1.3 Early fallout

A near-surface explosion usually deposits about 50% of the fallout as early fallout. In theory, it spreads out over 48 hours in a cigar-shaped pattern. In practice, particle size, wind speed, local terrain and rainfall dictate the pattern. Early fallout can cover a wide, but not unlimited, area. As an illustration, the fallout within 24 hours from a surface burst involving 1 Mt of fission may require evacuation from an area roughly 300 x 60 km (18,000 km^2). Lethal doses can be received over about 100 x 40 km (4,000 km^2).

As a result of radioactive decay and dispersion, 90% of the dose that can be accumulated at any point would be received within 3 days if no countermeasures are taken.

1.4 Delayed fallout

Fallout remaining in the atmosphere beyond 48 hours returns to earth after spending time either solely in the lower atmosphere or troposphere (tropospheric fallout) or in the upper atmosphere or stratosphere followed by the troposphere (stratospheric fallout), as depicted in Figure 1. The troposphere extends for 10 to 17 km above the earth's surface. It contains the phenomena we associate with "weather" - clouds, rainfall and wind patterns. Tropospheric fallout returns to earth via gravity or with rain within a few weeks. It is deposited within the hemisphere of origin, mostly within a 30° latitude band.

The stratosphere extends above the troposphere. In the lower region, exchange of material between the hemispheres takes many years. Within 1-2 years, lower stratospheric fallout re-enters the troposphere and comes down with rain over a large proportion of the hemisphere of origin. Fallout in the higher stratosphere can be exchanged between the hemispheres and experiences a longer delay before reaching the troposphere. This is truly global fallout and would be the main source of fallout in New Zealand after a northern nuclear war. High stratospheric fallout is most likely with large weapons exploding high above the target. Roughly 75% of stratospheric fallout would fall in the hemisphere of origin, the remainder in the other hemisphere.

1.5 Nuclear reactors as targets

Civil and military nuclear reactors could be strategic targets in a war. Most are sited in likely combatant countries and they contain large quantities of radioactive material. A nuclear industry also requires associated facilities to store radioactive spent fuel and a few reprocessing plants. These involve less massive shielding than the reactors themselves.

A comparison of the possible contribution to fallout from weapons and demolished reactors is difficult. Reactors and their associated facilities world-wide contain cesium-137 equivalent to about 10,000 and 60,000 Mt of fission weapons respectively. The total is far greater than current nuclear arsenals. However, whereas cesium-137 from weapons dominates the consequences of delayed, global fallout, targeted nuclear facilities would contribute largely to early, local fallout. It would be also extremely unlikely that all nuclear facilities would be hit or that the radioactivity in any single facility would be completely dispersed into the air.

Targeting nuclear facilities would have its most obvious impact in a war that was otherwise limited in scale. Then the number of lethal effects from early fallout would be dominated by the fallout originating in these facilities and not by weapons fallout. In a large-scale war an increase in the long-term health consequences of some two-sixfold has been predicted for mid-Northern Hemisphere latitudes as a result of releases from nuclear facilities. The effect on Southern latitudes is very speculative. It would be much less than the two-sixfold quoted above, but may not be negligible.

2. RADIATION EFFECTS

2.1 Human health effects

There are four ways in which fallout exposes people to radiation.

a) Externally as the 'cloud' of fallout material envelops people in its path. Alpha-emitting isotopes are unimportant as the alpha particles do not penetrate. Skin 'burns' can be produced by beta-rays, which can penetrate only a few millimetres. More damage would be produced by gamma-emitters, since gamma-rays are penetrating and expose the whole body.

b) Internally by inhalation of radioactive isotopes in the cloud. The whole body would be irradiated by inhaled gamma-emitters; alpha- and beta-emitters expose mainly the lungs and organs to which they migrate.

c) Externally via gamma-emitters deposited on the ground (external dose).

d) Internally from ingestion via the food chain, or via inhalation of material re-suspended from upper soil layers.

Doses received from the cloud (a and b) predominate in areas receiving early fallout. At later times, external dose from the ground (c) assumes greater importance. Areas receiving only delayed fallout are spared the effects of short-lived radioactive isotopes. This reduces the importance of external exposure, which becomes comparable to that from the contaminated food chain.

It is the total dose accumulated, and the time over which it accumulates that determines the health effects observed.

2.1.1 High doses and dose rates

If doses above 100 rem occur within a few hours, effects can include eye cataracts and immune suppression. Death, at least within a few years, would be an unlikely result below 200 rem to the whole body, but its likelihood increases rapidly as the dose increases. At 600 rem early death would be almost certain.

Individuals vary considerably in their susceptibility to radiation. The dose level that would be on average, lethal to 50% of a large population (LD50) is a useful yardstick. It would be about 350-450 rems normally, but in conditions of high stress and with other injuries (as in combatant countries) lower values in the region of 250 rems may be lethal. Death would be protracted at doses near the LD50. A period of nausea, vomiting and diarrhoea (2 days) would be followed by apparent normality for perhaps several weeks. However, the radiation has sterilized the bone marrow, and this eventually results in critically low levels of white blood cells and platelets. Death occurs in 4-8 weeks via widespread infection. Doses well above the LD50 result in a different pattern of health problems, with death inevitable and more rapid.

LD50 levels are higher when the dose accumulates over longer times which gives the bone marrow the opportunity to recover. The relationship between LD50 and protracted doses would be uncertain.

2.1.2 Low Doses and Dose Rates

When the accumulated dose is insufficient to cause death via bone marrow failure, health appears normal, or is restored to normal over a few months. There are suggestions of greater susceptibility to disease, and to a general ageing effect, but these are tenuously based. The long-term health effects are dominated by the induction of extra cancers, genetic abnormalities and birth defects.

Cancer

There is clear evidence in humans that radiation increases the risk of cancers of nearly all types. 'Natural' and radiation-induced cancers are indistinguishable. Radiation simply increases the probability that an individual will contract cancer. Since the frequency of cancer in the population is normally high, attempts to detect radiation-induced disease are statistically difficult.

The statistical problems, the limited populations exposed to radiation that can be studied, and imprecise dose estimates in those populations mean that any assessment of the risk is highly uncertain. Risk clearly increases with increasing dose (Figure 2). There is evidence that the risk increases in direct proportion to the dose and that there is no 'safe' dose (that is, even the lowest doses carry some, albeit small, risk). This proportionality is usually assumed in assessing risk over the whole dose range of interest, although most data comes from exposures greater than 25 rem.

Various estimates of the risk from exposure of the whole body span a fifty-fold range. Exposures involving only part of the body, or even a single organ, involve risks known with even less certainty. The age and sex of those exposed also help to determine the risk incurred. For the purposes of this issue paper we acknowledge these uncertainties, but use a single risk estimate near the upper end of the range. The overall conclusions reached are not affected by this simplification.

The risk estimate used is that 1 rem to the whole body of every New Zealander (3.3 million people) would lead to 1000 extra cancers. These cancers involve the usual spectrum of cancer types. Given normal medical attention only about 300 of these would be fatal. The extra cancers, representing 0.03% of the population, should be compared with a 'normal' incidence of about 20%. Assuming the risk to be proportional to dose, a dose of 100 rem leads to a 3% incidence of radiation-induced cancers. Even doses approaching those lethal in the short term do not involve cancer as an inevitable outcome. (The doses likely to be received in New Zealand (less than 3 rem) are discussed in Section Two.)

The extra cancers would take many years to develop and appear. Leukemias and bone cancers appear between 2 and 25 years after exposure. Other cancers occur between 10 and 40 years after exposure.

Genetic Disease

Genetic diseases are health disorders seen in the descendants of those exposed to radiation. There is no direct evidence for radiation-induced genetic disease in human populations. However the evidence from tests on animals is so convincing that its existence is not doubted. General comments about genetic disease are similar to those for cancer induction. Even the eventual number of extra genetic diseases is comparable to the extra cancers for the same dose to the population. There is one crucial difference: the extra genetic cases occur over many generations. This dilutes their impact, which is why they are so hard to detect.

Effects from in utero exposure

Exposure while in the womb deserves special mention. This is a special case of exposure at a sensitive stage of development (the embryo or foetus). The effects caused are not genetic defects as they are not inherited. Again radiation causes an increase in the frequency of health effects that are seen normally. A recent estimate suggested that two extra health problems would occur in every 1000 newborn children who had been exposed to one rem before birth. This compares with 60 similar effects per 1000 children found normally.

A wide variety of health effects are possible, including pre-natal death, defects of the skeleton, mental retardation, leukaemia and other cancers. Some effects are obvious at birth but many are only recognised in later life.

An elevated cancer risk in children exposed *in utero* is well established, and provides almost the only convincing human evidence for radiation-induced cancer at low doses in the region of 1 rem. For other health effects the evidence available relates to far higher doses, and estimates at low doses are probably too high. There is strong evidence, for effects such as mental retardation and some growth abnormalities, that exposure in the first 3 months after conception is particularly dangerous.

3. ENVIRONMENTAL EFFECTS

3.1 Direct effects

Radiation is generally considered to present a lesser risk to non-human than to human populations for two reasons. One is that humans, and mammals generally, are the species most easily killed by radiation (Figure 3). Several facts contribute to this (including the amount of chromosomal material, frequency of cell division, degree of cell differentiation, age, nutritional condition) but the size and complexity of the chromosomes (DNA) are particularly important.

The second reason is that we judge individuals to be of little importance in non-human populations. In contrast, individual humans are highly valued. For species other than humans, it is population survival that counts and the individual is expendable, provided the breeding population does not fall below replacement levels.

Plants and animals in water would be further protected because fallout would be diluted by mixing with large bodies of water. Water also absorbs radiation, and external radiation effects would be minimal. Most radiation effects on aquatic species arise via absorption/adsorption of radioactive isotopes by plants or by ingestion of contaminated food by animals.

On land, the greater resistance to radiation of non-human species would result in the areas covered by radiation levels lethal to such species being smaller than the areas lethal to humans. The environmental destruction within or near areas involving lethal effects would be severe. However, some plant communities can withstand quite high doses (Table 4), and some seeds can survive doses as high as 60,000 rem. Thus plants would probably re-establish quite rapidly in the regions around nuclear explosions. However, the eco-systems would not be the same as in the pre-war environment. Radiation-resistant species and species that grow or reproduce rapidly would be favoured. Predator-prey relationships would be disrupted. Many insect species would be more successful than usual. Those insects that are 'pests' could cause additional damage by spreading unchecked through areas which, though not devastated, had been stressed and weakened.

Areas with severe environmental damage would be widespread in combatant countries. However, the majority of the land and oceans would be subjected to levels of radiation that are raised above normal but not immediately life-threatening. This would add a further stress on their viability at a time of several other, probably greater, stresses. In particular, increased radiation exposure would result in more frequent mutations. Only a few mutations are beneficial. Indeed, radiation would be a useful technique in plant breeding - but post-war conditions are unlikely to allow advantage to be taken of this. Most mutations are 'bad', and under normal conditions disappear from the population over a few generations (that is, they are selected out).

3.2 Movement of radioactive isotopes

3.2.1 On land

Fallout would be deposited initially on plant and ground surfaces. Subsequent movement into the root-upper soil system would be dependent upon rainfall, particle size and the roughness of the plant/ground surface. Thereafter, movement would be dictated by the chemical properties of each radioactive isotope. These properties are identical to the stable, non-radioactive form of the element. If the stable form is soluble or highly mobile or discriminated against by tissues, then so is the radioactive form.

Three isotopes dominate the properties of delayed fallout on land. Iodine-131 (half-life 8 days, beta-emitter, thyroid-seeking) would be important for 2 to 3 months after explosions, after which time it would have decayed to insignificant levels. Deposition on pasture results in ingestion by domestic grazing animals and subsequent contamination of milk. Longer-term and more general environmental consequences stem from cesium-137 (half-life 30 years, gamma-emitter, whole body exposures from external or internal sources) and strontium-90 (half-life 28 years, beta-emitter, bone-seeking).

Chemically, cesium resembles the essential nutrient potassium; strontium resembles calcium. Their movement and availability to plants and animals depends upon rainfall, and upon soil and vegetation characteristics. For example, high rainfall would tend to wash cesium to soil regions below root areas. Soils may counteract this by retaining cesium. Humus and clay-rich soils retain cesium strongly in the upper soil region. Availability for uptake into plants is greatest in soils that are sandy, and low in clay, potassium and ability to bind positive ions. Plants that are deficient in potassium tend to absorb more cesium from the soil.

The ability of species to concentrate or discriminate against certain isotopes is critical to their movement in the environment. The levels found in a species can be greater or less than measured in its immediate environment or food source. Concentration is usually more important than discrimination. For example, cesium-137 would be taken into cells with potassium, with the ratio of cesium-137 to potassium usually constant within a species. However, the ratio is about threefold greater in favour of cesium-137 in most species when compared with their food. This can occur at each level in a food chain leading to "bioaccumulation" of cesium-137 in complex chains of hundredfold or greater. Such bioaccumulation would be less significant for strontium-90 than cesium-137.

3.2.2 In freshwater

Freshwater lakes and rivers can be contaminated by fallout particles deposited under gravity or in rain, by surface runoff and by slower percolation through the sub-soil. Insoluble radioactive materials or those trapped in larger particles settle onto sediments. They can become available to plants and animals via slow solubilization or via plants or animals which 'graze' or live in the sediments, and which form the basis of a food chain.

Cesium-137 and strontium-90 are the radioactive isotopes of greatest significance. Bioaccumulation occurs and at each level of the food chain is usually greater than found on land. The concentration of cesium-137 in fish, for example, can be up to 10,000 times greater than in the water itself (Table 5).

3.2.3 In the sea

The consequences of radioactive contamination would be greater in coastal margins and estuaries than in the deep ocean. Coastal regions are rich in diverse, densely-populated and highly interdependent species.

Fallout distributes rapidly (days to weeks) in the surface layers of the ocean (up to 100 m). Subsequent behaviour in deep waters is poorly understood. It certainly depends upon solubility, particle size and, particularly, on the complex movements of large water masses in the various ocean layers. At least in parts of the North Atlantic, cesium-137 and strontium-90 remain in the ocean layers above 1000 m for several years. Plutonium-239, however, would be usually in insoluble form, and becomes incorporated rapidly in sediments. A surprising amount may be remobilized eventually by the action of sedimentary species and the food chain.

The ratio of the concentrations of cesium-137 or strontium-90 in marine species to the concentrations in the water are usually less than found for freshwater species. High salt concentrations (e.g. sodium, potassium, magnesium and calcium salts) in the sea cause this. As a result, insoluble radioactive isotopes such as plutonium-239 take on more importance in the marine environment. They may exhibit very high ratios, with 10,000 being common for species living in the bottom sediments and for filter feeders (Table 5).

3.3 Human exposures via the food chain

Humankind is inseparable from the living environment. Our cursory examination of environmental effects has revealed many complexities and unknowns. Among these are the movement and reconcentration of radioactivity along the food chain (e.g. grass to cows to milk to people).

Human populations are at the end of many food chains. Estimates of radiation doses to be received via diet depend on the composition of the diet, on the nature and amount of radioactive fallout causing the contamination and on the bioaccumulation and retention in tissues of several radioactive isotopes. Any estimate would be crude. For westernised countries, in areas away from initial radiation and early fallout, a useful estimate is that diet would contribute a dose similar to that of external radioactivity. In areas exposed to early fallout, diet would be a minor contributor to the dose.

Examples showing the caution required in applying such a rough estimate are numerous. In harsh Arctic and sub-Arctic conditions, lichen obtain an unusual proportion of their nutrients direct from the air and rainfall. Cesium-137 levels are unusually high in these lichen. Reindeer graze the lichen as a principal food source in winter and early spring. Some human populations (e.g. Laplanders) hunt and farm reindeer as a major protein source. At each stage in the lichen-reindeer-people chain, cesium-137 levels increase. Finnish Lapps have levels up to 50 times greater than non-reindeer-eating Finns.

Plutonium-239 would not be a major dietary hazard since it does not dissolve into the blood easily and would mostly be excreted. However, bioaccumulation would be great in seaweeds. People in South Wales mill seaweed to produce a bread-like cake. Plutonium levels in such groups can be several times greater than the average. Other examples of special exposures are known; many may be unknown.

Drinking water is an essential part of our diet. Water drawn from deep groundwater sources should be safe to drink even in areas of quite high surface contamination. The ability of the surface and sub-surface soils to retain radioactive isotopes ensures that leaching into groundwaters would be long-term and gradual. Once present, however, contamination would be also long-term. Supplies from surface water reservoirs would be contaminated immediately following arrival of the fallout. The risk would obviously depend on the amount of radioactivity deposited. In regions subject only to delayed (global) fallout, such as New Zealand, it would not be an immediate risk to life, but would provide an extra dietary intake of radioactive material. This radioactivity and its potential dose to consumers can, however, be estimated.

SECTION TWO

IMPACTS OF NUCLEAR WAR

In this section one-third of the available nuclear arsenals are presumed to have been used. This involves some 5000 Mt, with about half of this provided by fission. Half the weapons are used in surface bursts and half in airbursts.

1. War limited to the Northern Hemisphere

In this scenario, New Zealand is at such a distance from the war zone that it could not be affected by initial radiation or early (local) fallout. Radioactive fallout would arrive only after being diluted in the atmosphere, and after substantial depletion and decay in transit. Therefore, radiation doses would remain far below those required to cause death within a short period (200 rem) or even sickness. No immediate health effects would occur.

New Zealand would receive stratospheric fallout and the resulting doses and long-term health effects from this are estimated as follows.

1.1 Dose estimates

Several estimates are available of the dose in New Zealand from delayed fallout as a result of a Northern Hemisphere war. All involve a total dose of less (some considerably less) than 2 rem, accumulated over 50 years. However because of the uncertainties involved we choose to use a pessimistic value of 2 rem. This accumulated dose would be made up, very approximately, as follows:

- 1 rem from cesium-137 deposited on the ground ('external dose'). About half of this dose would be received in the first 10-15 years;
- 1 rem from diet over 50 years, mainly from cesium-137 and strontium-90.

The dose-estimates available used several approaches. Cesium-137 external doses were estimated from:

- measurements of fallout in New Zealand from weapons tests (which totalled 550 Mt total energy, approximately 50% fission yield);
- models of atmospheric circulation and calculations on fallout distribution.

The dietary component was estimated from:

- a suggestion that in areas subject only to delayed fallout, eventual dietary doses are comparable to the external dose;
- calculations on expected cesium-137 and strontium-90 levels in milk, based on models using fallout data.

The results agree well, although considerable uncertainties must be acknowledged (Section 5). One uncertainty would be the extent to which the effects of smoke and soot can destroy the usual tropospheric barrier to transfer of material between the hemispheres. Destruction would lead to increased tropospheric fallout in New Zealand. The resulting small increase in dose is thought to be small and is allowed for in our estimate. "Hot spots" - areas where deposition would be unusually high - are not likely to occur in this scenario.

Some comparisons to illustrate the likely importance of the 50-year accumulated dose of 2 rem are useful. New Zealanders are exposed now to radiation from a variety of sources, both natural and technological. Our current exposure to such sources amounts to 10 rem over 50 years (Table 6). Natural radiation exposures can vary from place to place. Twofold variations are common and far greater variations are known overseas. Thus, delayed fallout under this scenario would, over a 50-year period, deposit about 20% of the natural fallout expected over this time.

Health authorities regulate exposure of the public to human-generated sources of radiation to 0.5 rem in any year or 0.1 rem annually if the exposure is prolonged. Some countries have set guidelines for doses which, when likely to be received in an *emergency*, trigger a specified countermeasure such as evacuation or the impounding of milk supplies. In the UK, countermeasures would be considered if the situation over the first 14 days could lead to an accumulated whole body dose of 10 rem. Countermeasures would definitely be expected if accumulated doses of 50 rem were predicted.

1.2 Health effects

Such comparisons suggest that the number of health effects would not be overwhelming in the event of a war restricted to the Northern Hemisphere. For the risk of cancer induction, we use the estimate that 1000 extra cancers would occur for every rem accumulated in the current New Zealand population. For accumulated fallout doses of 2 rem over 50 years, we therefore estimate about 2000 extra cancers in New Zealand. These would be distributed among the common cancer types. Because of the long delay before these cancers would actually appear, say 20 years on average, their impact is more accurately measured over a 70-year period. Thus the radiation dose will be estimated over 50 years, the human effects over 70 years (Table 7). Provided present medical standards are maintained, only about 700 of these cases would be fatal. Mortalities would rise if medical care were to fall. Currently, the rate of new cancer cases in New Zealand is about 10,000 annually. The 2000 extra cases would, therefore, be swamped by the 700,000 cases expected normally over 70 years. A similar calculation indicates that 10,000 of the expected 700,000 cases might be due to existing natural background radiation.

Extra genetic abnormalities could be comparable in number to the extra cancers (2000) but are more likely to be somewhat less. They would be spread over several generations. On the basis of current birth rates, population size and genetic abnormality estimates, over five generations more than half a million babies would be born with spontaneous abnormalities similar to those induced by radiation.

The dose delivered to pregnant women would be unlikely to exceed 0.05 rem per pregnancy. This could lead to one extra health problem in each 10,000 births. Six hundred similar problems would be expected normally in this number of births.

2. War expanded to Southern Hemisphere

The most serious situation short of a direct attack on New Zealand would arise if cities or installations in south-eastern Australia were hit. A predominantly westerly weather pattern for this region could result in fallout reaching New Zealand within 48-72 hours. This situation would involve little time for assessment and response, and would involve the highest possible doses to the population.

Other regions of Australia have either prevailing easterly weather patterns or very light winds. Fallout from these regions and from other, more distant, Southern Hemisphere targets (South America, South Africa) would be delayed atmospheric fallout that has circled the globe before settling on New Zealand.

2.1 If Southeast Australia is not a target

The impact would depend on the scale of Southern Hemisphere attacks. To produce an estimate we have assumed 15 Mt (50% fission fraction) has been used. This is less than 1% of that assumed to be used in the north.

Estimates of the dose from Southern Hemisphere detonations can be made using some very approximate assumptions:

- Stratospheric fallout can be estimated in the way used to calculate fallout originating in northern latitudes. Allowance is made for the relative Mts used in each hemisphere and the fact that 75% of stratospheric fallout would be deposited in the hemisphere of origin.
- All tropospheric fallout originates and deposits within the 30^{o}-50^{o} S latitude band. Models used in global studies can then be applied to this special case with the further assumption that the bombs are used equally in surface and air bursts.

We conclude on this basis that the Southern Hemisphere contribution to the 50-year accumulated dose would be about 10% of that calculated for the Northern Hemisphere contributions, or 0.2 rem. There may be radioactive 'hot spots' in areas where there would be heavy rainfall at the time when clouds of radioactivity are over New Zealand, particularly on their first pass around the globe. To allow for hot spots we treble the estimate above. Therefore, we assume Southern Hemisphere explosions excluding Southeast Australia would add about 0.6 rem and 600 extra cancers to the values calculated for the Northern Hemisphere contribution. This is an increase of 30%.

2.2 If Southeast Australia is a target

We have considered a pessimistic situation for a total of 3 Mt (50% fission fraction) dropped as ground bursts on Southeast Australia. All the early fallout and half the delayed fallout (totalling 75% of the fission products) would be regarded as potentially available for early deposition on New Zealand. Meteorological data suggests that a maximum of 40% of this might actually be within an air mass which crosses New Zealand. It takes 80 hours on average for air masses to cross the Tasman Sea. In this time the fallout would be depleted as the particles settle under gravity. However, it is assumed that depletion due to rain does not occur over the Tasman Sea. All the fallout reaching the New Zealand coast is then assumed to be completely and uniformly deposited in rain over the whole country. In practice all the fallout would not be deposited. However, the weather pattern and rainfall would combine to produce 'hot spots', in which the local deposition could be perhaps 10 times greater than the average.

2.2.1 Fission products other than Iodine-131

Because of the rapid arrival of the fallout, cesium-137 no longer dominates the external dose due to ground deposition. Fission products with shorter half-lives contribute to the dose (Table 8). Contributions from non-iodine sources in the diet are again regarded as comparable to the cesium-137 external dose. The accumulated 50-year dose would be about 0.45 rem; 90% of this would be from external sources, about half of which would be received within about 1 month from short-lived fission products. This dose indicates health effects typified by about 450 extra cancers in the whole of New Zealand. There would be, in addition, a dose delivered to the lung, via inhalation as the fallout comes to earth. However this would be about 20 times less than the whole body dose from external and dietary sources.

2.2.2 Iodine-131 contribution

Iodine-131 would be produced in relatively large quantities during fission. In spite of its 8-day half-life, this yield makes it a dominant fission product in the first 2-3 months after a war. It localizes in the thyroid which would be the only organ significantly exposed to the beta-rays. The pathway of importance to people would be via deposition on pasture, and thence to cows and milk.

The thyroid dose from iodine-131 would far exceed the whole body dose from cesium-137 via milk. This thyroid dose could be 15 rem. Doses from strontium-90 to the bone and from cesium-137 to the whole body under this scenario would each be about 0.006 rem over 50 years. The thyroid disorders expected in the New Zealand population from such a dose would be about 400 fatal cancers, 3600 non-fatal cancers and 12,000 benign tumours. These would occur between 10 and 40 years after exposure.

At this level of exposure serious consideration would be given to the impounding of milk supplies for 2-3 months. Alternatively, distribution of potassium iodate pills could be considered. The pills reduce uptake of iodine-131 if taken before or shortly after exposure. In the UK, distribution of pills would be considered if thyroid doses were projected to reach 5 rem and certainly implemented at doses of 25 rem.

In total, therefore, a 3 Mt attack on Southeast Australia could add a further 450 non-thyroid cancers, and 16,000 thyroid tumours of which 4,000 would be cancerous and 400 fatal. Milk could be impounded for up to 3 months to avoid the thyroid disorders. It must be noted again, however, that such effects would be an overestimate, since an unrealistically high proportion of fallout has been assumed to land in New Zealand.

3. Summary

The doses accumulated over 50 years and the resulting extra cancers appearing over 70 years for various scenarios are summarized in Table 7. Under present levels of medical care, about one-third of the non-thyroid cancers and less than one-tenth of the thyroid cancers are fatal. Other health effects from radiation would also occur, but their impact would be considerably less than that of extra cancers.

SECTION THREE

POST-WAR ADJUSTMENTS

The paramount questions in the immediate post-nuclear war period would be: What was the scale of the war? Are the radiation impacts on New Zealand really as low as supposed? Will the population believe the impact has been low? In addition, many cases of nausea, vomiting and diarrhoea in this period would be ascribed to radiation effects when due, in fact, to traditional causes. The answer to these questions and problems lies in comprehensive monitoring of radioactivity and radiation levels. Part of the mystique surrounding radiation concerns people's inability to observe it. They must be assured, however, that instruments exist in New Zealand to detect and measure radioactivity and radiation levels quite easily.

The National Radiation Laboratory (NRL) in Christchurch has operated a fallout monitoring service for:

- continuous air and rainwater beta-emitters (5 Pacific and 4 New Zealand sites)
- strontium-90 in rainwater plus a cesium-137 assessment (9 New Zealand and 2 Pacific sites)
- strontium-90 and cesium-137 in dairy milk (9 regions in New Zealand).

This programme has been reduced since 1985 to 3 sites (though the sensitivity of the equipment has been increased), as fallout levels have become very low since atmospheric tests ceased. However, surplus equipment could be reactivated if required. In addition, since the Chernobyl disaster, NRL has expanded its ability to detect radioactivity in general foodstuffs. These programmes, provided they could be expanded and not swamped by trivial requests, could form the basis of a good post-war monitoring programme. Local health inspectors, the armed forces and the universities also hold equipment capable of assisting with preliminary monitoring. DSIR, which runs a limited fallout monitoring programme for Pacific and New Zealand seawaters, could also provide useful assistance.

Given the widespread and long-held fears many people have of fallout it should be recognised that allaying unjustified concerns about fallout levels should be a high priority task. The need for information on local fallout levels and possible disruptions to communications would make adequate regional responses essential. If the war were restricted to the Northern Hemisphere there would be several weeks to months before significant fallout arrived in New Zealand. However, if Australia, particularly eastern cities, were targeted, then only a few days would elapse. The initial greatest hazard would then be iodine-131, and monitoring the contamination of pasture and milk would be critical. Hot spots in high rainfall areas would need identification. This would require effective co-ordination between NRL and meteorological services.

If Southeast Australia were attacked, iodine-131 levels could approach levels at which milk would be impounded under peacetime rules. Essential needs for milk could be met by supplies of dried pre-war milk, providing distribution were possible, or from areas with the lowest deposition levels. Contamination from iodine-131 could be countered by processing the milk into dried powder or cheese, forms which could then be stored for 3 months or more before use. Strontium-90 and cesium-137 would pose a lesser threat. Farming patterns could be altered in time to concentrate dairying in areas of low contamination or cesium and strontium uptake, if the risk were considered unacceptable.

A variety of methods can be used to reduce the consequences of radioactivity from fallout in foodstuffs. These include simple washing of vegetables and fruit with water from deep groundwaters, avoidance of certain foods (dairy produce, freshwater fish), using stored pre-war food and animal feed, water purifiers (commercial or home-made) and deep ploughing. This information would be required and might be implemented by a significant fraction of a concerned public. Such actions would not reduce overall radiation exposures by a large fraction. As the overall risk would probably not be great, the priority assigned to such actions in the post-war world would be unlikely to be high.

In summary, the post-nuclear war period would require a greatly expanded programme of environmental monitoring because of unknowns in the movement of radioactive isotopes through the environment in general, and the food chain in particular.

SECTION FOUR

PRE-WAR PLANNING OPTIONS

The aim of pre-nuclear war planning should be to:

- Ensure accurate, comprehensive monitoring of fallout in the environment.
- Provide cohesive and coherent channels of information for policy-makers and the public.

We assume that overall pre-planning includes the means to obtain as much information as possible on the extent of the war, and to provide that information to, in the first instance, the Director of the National Radiation Laboratory or the deputy. The further pre-planning options we recommend are:

- Evaluation of the extra equipment and staff needed to provide an adequate and effective monitoring service for all regions. Trained staff is expected to be the greater problem.
- Evaluation of the need for EMP-hardened equipment. The effect of EMP on current monitoring equipment is unknown.
- Possible disruptions to normal communications should be considered. Clearly defined routes to transport samples to NRL in Christchurch in an emergency are needed. Much of the monitoring programme depends on specialized equipment held only in Christchurch. Consideration could be given to providing duplicate facilities in a North Island centre such as DSIR's Institute of Nuclear Sciences. Communication difficulties would increase the importance of regional monitoring units.
- Clear definition of levels of radioactivity in the environment which lead to specified countermeasures. An agreed official statement on the risks associated with the radioactivity and the risks and benefits of the countermeasures should be part of this policy. The Chernobyl disaster revealed official confusion and public exasperation and mistrust, with a bewildering variety of actions and rationales among the affected nations. A period of panic is not the time to debate the differences between acute and long-term health effects or whether an inability to detect health consequences equates to no health concern.
- Evaluation of the usefulness of maintaining protected stocks of food, particularly dried milk and animal feed. Storage of potassium iodate tablets, a defence against uptake of iodine-131 in the thyroid, could also be discussed. It would appear that likely levels would not warrant their use and pre-war dried milk would be the preferred alternative.
- Identification of possible pathways leading to well-above-average exposures in sections of the community (equivalent to seaweed and reindeer meat consumers overseas). Identification of such pathways protects those susceptible communities. It also provides a critical monitoring point capable of early warning of wider problems.
- Further examination of the regional properties of soils in relation to retaining cesium-137 and strontium-90, and relating them to contamination of pastures and

crops. Such information would be useful for planning post-war agriculture.

* Consideration to extending still further the database on current fallout levels in New Zealand, although these are known to be very low in general.

SECTION FIVE

UNCERTAINTIES IN THE ASSESSMENT

The uncertainties, as they relate to New Zealand, are in three main areas.

5.1 Dose assessment

Major uncertainties involve:

- The actual nuclear war scenario - the total fission energy used, the mix of small and large weapons and of surface and air bursts would all affect the amount of radioactivity reaching New Zealand.
- Contribution to delayed, particularly stratospheric, fallout from attacks on civil and military nuclear reactors.
- Disruption to normal air-mass movements - if smoke and soot cause a breakdown in the normal tropospheric barrier between the hemispheres, more early fallout could reach New Zealand.
- Contribution of contaminated diet to the accumulated dose.
- Dose reduction due to shielding by buildings, rough ground and weathering of Cs-137. These factors were ignored in our dose estimates.
- A contribution to the dose from carbon-14 has been ignored. Its contribution would be low compared to that from other radioactive isotopes over 50 years. However, it has a 5600 year half-life, and its contribution can affect many future generations.

5.2 Health effects

The health consequences are predicted only with considerable uncertainty. This is mainly because doses far lower than those for which there would be direct information are involved in our scenarios. The estimates also apply to a mythical average population. Groups that are especially susceptible due to inherent sensitivity or to non-typical exposures due to 'hot spots' or behavioural patterns remain mostly unidentified.

Evidence would be scanty for health effects that are less serious to the individual than those quoted here (e.g. increased susceptibility to chronic illnesses or allergies). If they were to occur, the cost to society (rather than the individual) could be considerable, particularly if our ability to provide modern standards of health care was also impaired.

5.3 Environmental effects

The major uncertainties involve:

- Movement and availability of radioactive isotopes through the environment.
- Concentration of radioactive isotopes in parts of the food chain.

- Effects on already threatened, or stressed, communities.

5.4 Summary

The uncertainties are great, and the consequences of nuclear war as depicted may have been under- or overestimated. To some extent we have allowed for this by the use of pessimistic assumptions in calculating exposures. Therefore, overestimation would be more likely, especially for a scenario involving fallout from Southeastern Australia. Any underestimate would be unlikely to invalidate the main conclusions given in the next section.

SECTION SIX

MAIN FINDINGS

We stress that our findings relate to the scenarios considered, namely a nuclear war using about one-third of the total weapons stockpile, with less than 1% of the weapons used targeted on the Southern Hemisphere.

6.1 Human health effects

1. In the absence of a direct attack on New Zealand, there would be no immediate or short-term effects on human health from radioactive fallout.

2. During the decades following the war, cancers would become more common in the population. As the extra cancers would be no different medically from those occurring normally, there is no way an individual would know whether or not his or her cancer is radiation-related. However, the probable increase in cancers would be fewer than 7000 cases over 70 years, or less than 1% of the cases expected without a war. This increase would be undetectable.

3. Over half of the extra cancers would occur only if Southeast Australia were attacked and would be thyroid cancers due to the ingestion of iodine-131 in milk. These cancers could be avoided by impounding milk supplies for up to three months and using stocks of pre-war dried milk.

4. We estimate that over 70 years fallout could lead to between 650 and 1500 extra deaths due to cancer. The remaining cancers would be cured provided levels of medical care equivalent to those existing now could be supplied. During the same 70-year period almost 400,000 deaths due to cancer would be expected normally.

5. There are many uncertainties associated with these estimates. Thus, the number of cancer cases and deaths could have been underestimated. However, we believe that any underestimate would be unlikely to be sufficient for a far larger than predicted numbers of cancers to occur. It would be more likely that the numbers have been overestimated.

6. Birth defects and genetic abnormalities may also increase in frequency, but the increase would be even harder to observe than for cancer.

7. These findings arise from the fact that radiation exposures are not expected to increase greatly due to nuclear war. Exposures could approach or even exceed those experienced from unavoidable natural radiation for a few months in the worst situation of attacks on Southeast Australia. Over 50 years, however, radiation exposure due to the war would be considerably less than that due to background radiation.

8. There are many uncertainties in the estimates of the health effects resulting from a nuclear war in other countries. The numbers could be underestimated, therefore, but not to such an extent that a far larger number of extra health effects should be expected. It would be more likely that the effects have been overestimated.

6.2 Environmental effects

1. Radiation levels in New Zealand following the war would lead to no immediate environmental effects and would not seriously threaten the existence of other species.

2. Long-term movement of radioactive fallout in the environment is poorly understood and must be monitored. The results of monitoring could influence the planning of post-war agriculture by identifying regions in which crop or pasture contamination could be minimized.

6.3 General

1. Comprehensive monitoring of fallout in New Zealand would be required, and pre-war planning is necessary to ensure this.

2. The monitoring system must be independent of possible disruption from an electromagnetic pulse, and capable of operating despite immediate post-war confusion.

3. If the war were limited to the Northern Hemisphere there would be several weeks in which to initiate monitoring programmes. If Southeast Australia were a target there could be as little as 48 hours before monitoring would be required.

4. Particular efforts must be devoted to identifying areas or groups of people in which the consequences of radioactive fallout could be well above average. Areas with well above average fallout levels - 'hot spots' - are most likely after a war involving targets in Southeast Australia and, to a lesser extent, other targets in the Southern Hemisphere. Groups of people could receive above average exposures via special dietary or behavioural patterns.

6.4 Conclusions

The individual health effects described are among the tragic consequences of a nuclear war. However, if New Zealand were not a target then the radiation levels and effects in this country would not be one of the more important consequences of the war. The social and environmental disruption depicted in other issue papers and their indirect effects on human well-being, would be of far greater concern.

SECTION SEVEN

BIBLIOGRAPHY

This chapter is drawn from a large body of original data, review papers and opinions. In the interests of simplicity most of the quantities and numerical examples are highly selective; it is believed that those selected represent a fair compromise. Such a presentation does not lend itself to traditional scientific reference and acknowledgement. Instead a list is provided of those books and articles found most useful and which are recommended to those requiring greater detail.

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TABLE 1

Areas of Lethal Damage from Blast, Heat and Initial Ionizing Radiation (in km^2)

	Explosive Yield *		
	1 kt	100 kt	1 Mt
Blast	1.5	17.7	71
Heat	1.3	74.2	391
Radiation	2.9	11.5	22

* 1 Kt = 1000 tonnes of TNT equivalent
1 Mt = 1 million tonnes of TNT equivalent

TABLE 2

Some Important Fission Products and Other Radioactive Isotopes : Approximate Yield per Mt (fission), Half-Lives and Principal Radiation Emitted

Isotope	Half-life (years)	MCi (PBq)*	Principle Radiations
Fission Products			
Strontium-89	0.14	16 (590)	Beta
Strontium-90	28	0.1 (3.9)	Beta
Zirconium-95	0.18	25 (920)	Beta, Gamma
Ruthenium-103	0.11	40 (1500)	Beta, Gamma
Ruthenium-106	1.0	2 (78)	Beta
Iodine-131	0.02	114 (4200)	Beta, gamma
Cesium-134	0.04	0.9 (32)	Gamma
Cesium-137	30	0.16 (5.9)	Gamma
Barium-140	0.04	127 (4700)	Beta, Gamma
Cerium-144	0.78	5.1 (190)	Beta, gamma
Other Isotopes			
Carbon-14	5,600	3.4×10^4 (1.3×10^6)	Beta
Plutonium-239	24,000	0.003 (0.13)	Alpha

*Activity is measured in Becquerels (Bq). 1 Bq = 1 decay per second. Large activities are PBq.
1 PBq = 10^{15} Bq. 3.7×10^{10} Bq = 1 Curie (Ci), an older unit.
1 MCi = 10^6 Ci.

TABLE 3

Illustrative Total Dose Rates from a Nuclear Explosion for Various Times After Detonation.

Assumes an initial rate of 1000 rem/hour after 1 hour

Time (hours)	Dose Rate (rem/hour)
1	1000
2	400
10	63
24	23
48	10
170 (1 week)	2.3
720 (1 month)	0.35

TABLE 4

Radiation Doses Estimated to Produce Damage to Plant Communities *

Community Type	Dose (rem) Mild Damage	Moderate Damage	Severe Damage
Coniferous Forest	100 - 1,000	1,000	>2,000
Deciduous Forest	1,000 - 10,000	5,000 - 30,000	>10,000
Shrub	1,000 - 5,000	5,000 - 20,000	>20,000
Tropical Rain Forest	4,000 - 10,000	10,000 - 40,000	>40,000
Grasslands	8,000 - 10,000	10,000 - 100,000	>100,000
Moss-Lichen	10,000 - 100,000	50,000 - 500,000	>200,000

* Whicker, F.W. and Schultz, V. (1982)

TABLE 5

Average Ratios (with range) for the Concentrations of Three Radioactive Isotopes in Freshwater and Marine Species to the Concentration in the Water

	Concentration Ratio		
Freshwater	Cesium-137	Strontium-90	Plutonium-239
Plants	1000 (80-4000)	200 (100-400)	-
Molluscs	600	600	-
Crustaceae	4000	200	-
Fish (Muscle)	3000 (100-20000)	14 (1-100)	-
<u>Marine</u>			
Seaweed	-	-	3000 (1000-10,000)
Plants	50 (10-300)	20 (0.2-80)	1000
Molluscs	15 (3-28)	2 (0.1-10)	500 (300-2,000)
Crustaceae	20 (0.5-30)	2 (0.1 -3)	-
Fish (Muscle)	20 (5-244)	0.1 (0.1-1.5)	10 (1-30)

TABLE 6

Average Doses over 50 years to the New Zealand Population from Various Sources of Radiation *

Source	Dose (rem)
Natural	8.3
Medical	2.5
Fallout	0.05
Air Travel	0.03
Occupational	0.01
Miscellaneous	0.01

*from information supplied by National Radiation Laboratory, Christchurch.

TABLE 7

Accumulated Doses (50 years) and Cancer Estimates for Different Scenarios over 70 years 1

			Number of Cancers	
Scenario*		Dose (rem) (Approx)	Sub-Total	Total Overall
0	Background	8.0	8,000	
	Technological (Medical etc)	2.0	2,000	
	Sub-Total	10.0	10,000	
	Causes other than radiation	-	690,000	700,000
1	External	1	1,000	
	Diet	1	1,000	
	Total	2	2,000	702,000
2A	External Dose	1.3	1,300	
	Diet	1.3	1,300	
	Total	2.6	2,600	702,600
2B	External Dose	1.7	1,700	
	Diet	1.4	1,400	
	Total	3.1	3,100	703,100
2C	As per 2B plus 15 rem thyroid		As per 2B plus thyroid disorders of - 400 fatal cancers 3600 non-fatal cancers 12000 benign tumours	

[1] Cancers appear, on average, about 20 years after the radiation dose, hence the extended time of estimating the number of cancers.

*Scenario	Description
0	No Attack, ie normal background and technological inputs
1	5000 Mt on N. Hemisphere targets
2A	Scenario 1 + 15 Mt on S. Hemisphere targets excluding S.E. Australia
2B	Scenario 2A + 3 Mt on S.E. Australia + milk impounded immediately
2C	Scenario 2B but milk not impounded

(All detonations have a 50% fission fraction. Half the weapons are used in surface bursts, half in air bursts.)

TABLE 8

Major Fission Products Contributing to External Dose and the Resulting 50-year Dose after 3 Mt (50% fission) on South-eastern Australia

Radionuclide	50-year Dose (mrem)
Zirconium-95	108
Ruthenium-103	36
Cesium-137	47
Barium-140	150

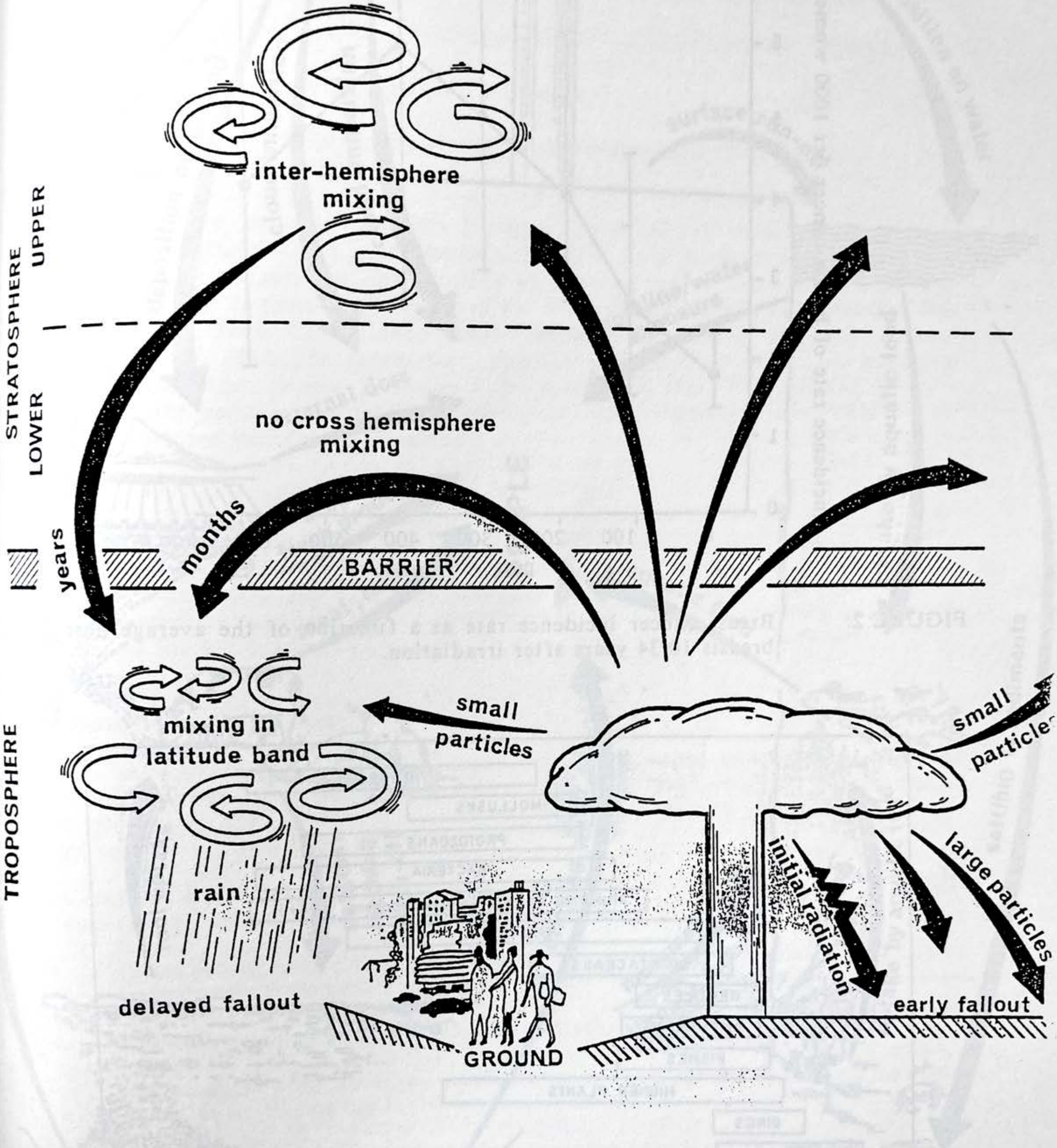

FIGURE 1: Dispersal and transport of fallout in the atmosphere

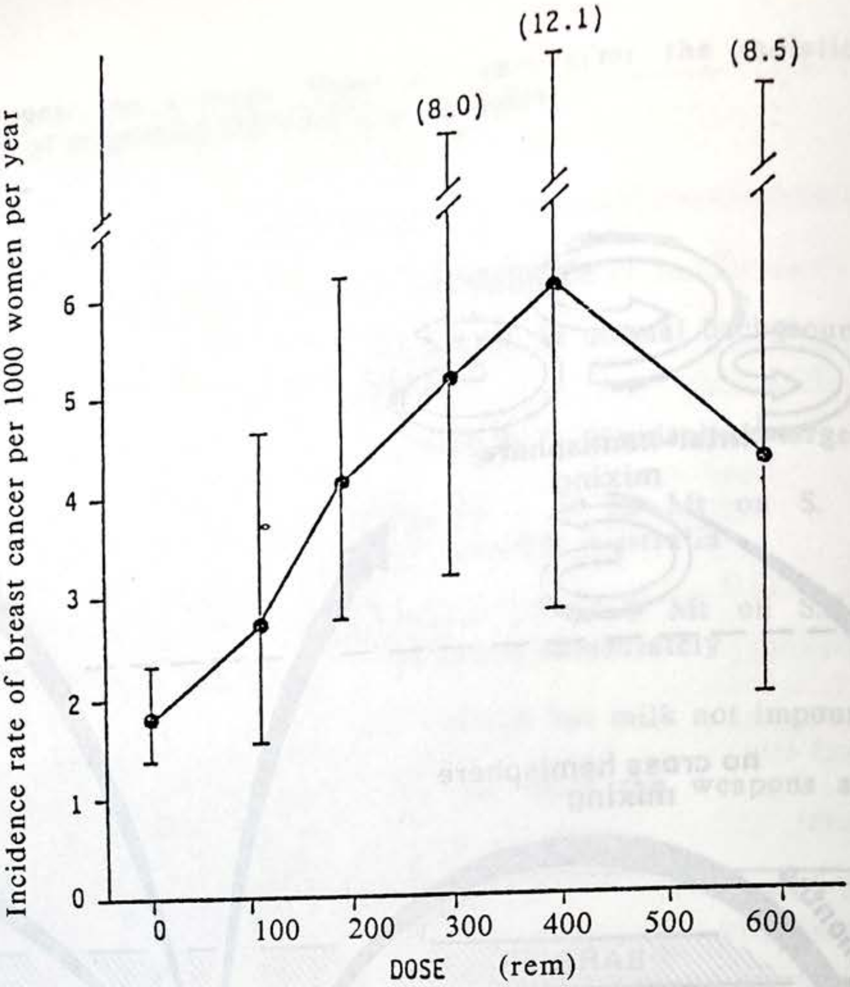

FIGURE 2: Breast cancer incidence rate as a function of the average dose to both breasts 10-34 years after irradiation.

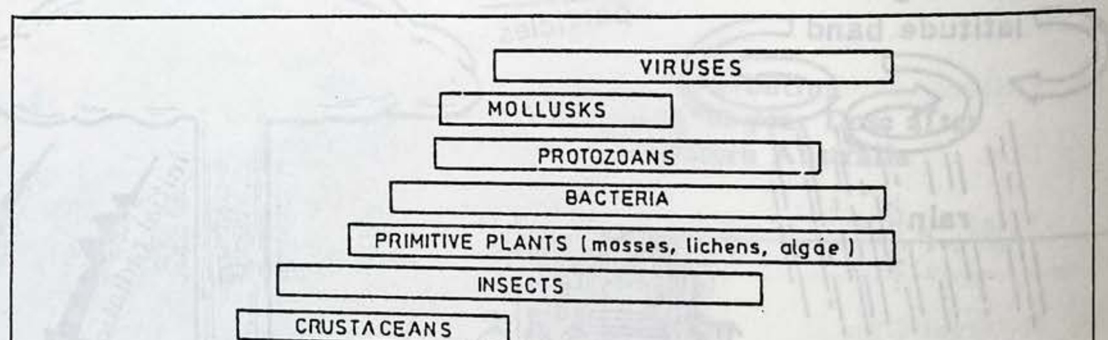

FIGURE 3: Approximate acute lethal dose ranges for various species. From Whicker and Schuetz (1982)

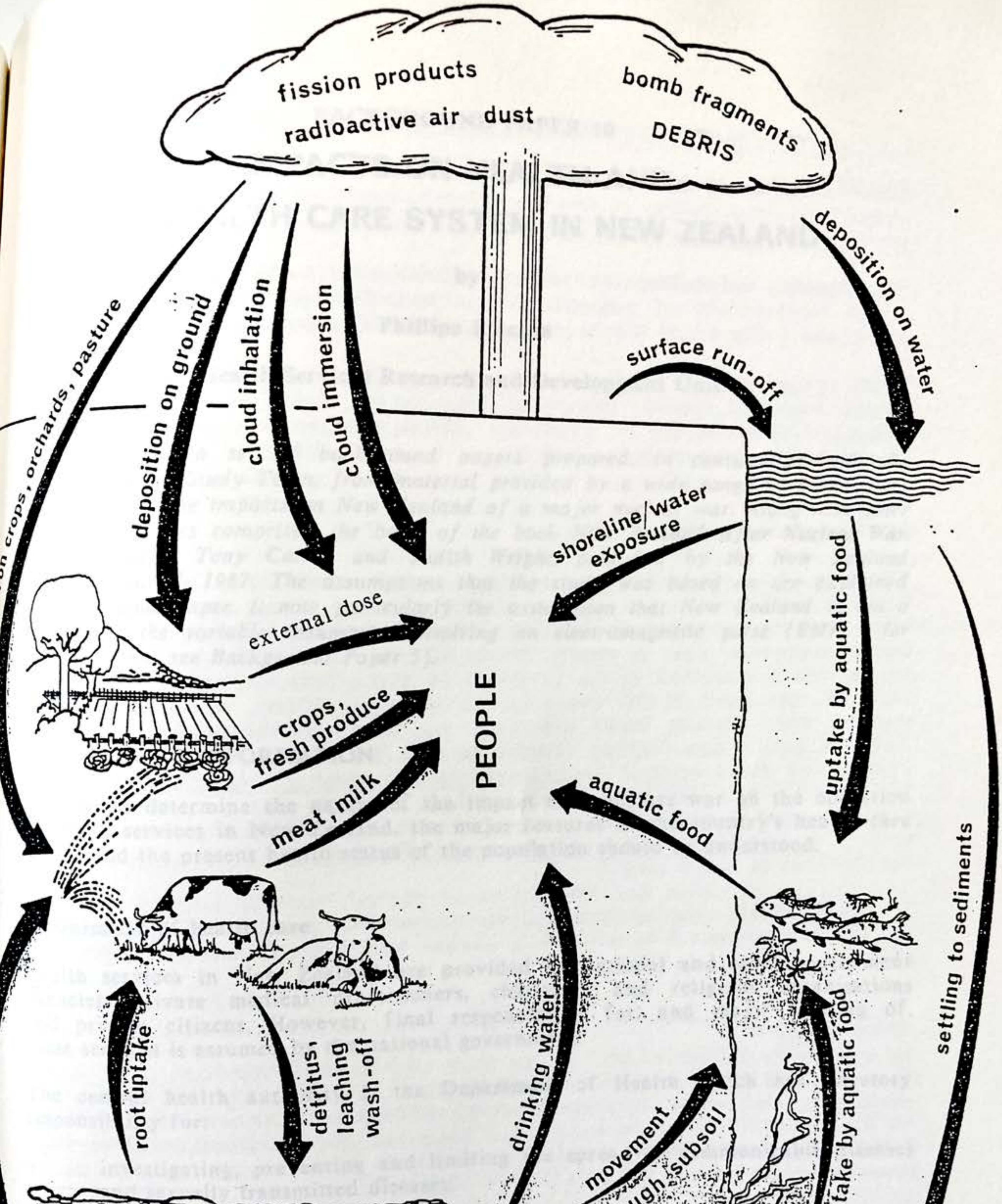

FIGURE 4: Environmental radioactivity : pathways to people