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ABSTRACT

The first part of this report gives a short description of the different basic types of nuclear weapon and lists Chinese weapons tests in the northern hemisphere and French weapons tests in the South Pacific by date, together with an indication of the power of each device where such information is available.

The second section of the report discusses the measurement of radiation and what dose units are appropriate for assessment of the significance of fallout exposure to man, and outlines the background of natural and man-made radiation to which man is inevitably subject. The principal biological effects

of radiation are then identified and the nature of the relationship between radiation dose and the incidence of effects is examined. Conventional radiation protection philosophy assures a linear relationship between dose and effect, which is independent of dose rate. On this assumption it is possible to derive, from the limited high-dose data available, risk coefficients for radiation effects which may be used to calculate the incidence of harmful effects from the low radiation doses relevant to fallout studies. The difficulties and inaccuracies inherent in this extrapolation mean that estimates made in this way are essentially of the upper limits of possible damage, not the most likely value which may often be zero.

The final section assesses the magnitude of fallout in Australia from the French and Chinese series of tests and expresses this in the form of dose commitments to man; the dose commitment for any radionuclide being the dose received to date plus the dose to be received in the future from residual long-lived activity already incorporated in the body and remaining in the environment. From these dose commitments, using generally accepted risk coefficients, estimates of the upper limits of the magnitude of the harmful effects, carcinogenesis and mutagenesis, which may be attributed to fallout from the respective series have been derived for the Australian population.

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The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA–INIS–12 (INIS: Manual for Indexing) and IAEA–INIS–13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

ATMOSPHERIC EXPLOSIONS; AUSTRALIA; BIOLOGICAL RADIATION EFFECTS; CHINA MAINLAND; DELAYED RADIATION EFFECTS; FALLOUT; FISSION PRODUCTS; FRANCE; HAZARDS; NEOPLASMS; NUCLEAR EXPLOSIONS; NUCLEAR WEAPONS; PACIFIC OCEAN; RADIATION DOSE DISTRIBUTIONS; RADIATION MONITORING.

CONTENTS

INTRODUCTION

1. This paper has been prepared in answer to a request for an assessment of the short and long term dangers to Australia of ionising radiations arising from radioactive fallout, originating from nuclear weapon testing in the atmosphere, on or near the surface of the earth, or completely contained underground. It presents basic information on nuclear weapon types, the production and circulation of radioactive contamination, the biological effects of such contamination and an assessment of their significance as hazards to the Australian population.

NUCLEAR WEAPONS AND THE PRODUCTION OF RADIOACTIVE DEBRIS

2. A large, rapid release of energy is possible from two separate types of nuclear reactions. The first is the fission reaction where heavy nuclei, such as uranium and plutonium, absorb a neutron and split into two smaller nuclei (fission products). The many fission products thus produced are radioactive and can be emitters of particulate radiation (alpha or beta), or of electromagnetic radiation (gamma) of varying penetrating powers. The principal risks which may be encountered in areas remote in space or time from the scene of the explosion come from several beta or beta-gamma emitters.

3. The second reaction type involves the fusion of two light nuclei, such as heavy hydrogen (deuterium and/or tritium), to form a heavier nucleus such as helium. The fusion reactions produce further tritium, a radioactive isotope of hydrogen, and at the same time generate very energetic neutrons which interact with atmospheric nitrogen to produce a radioactive carbon isotope, carbon-14 (C-14).

4. It is usual to express the energy release (yield) of a nuclear weapon in terms of an equivalent mass of TNT - kilotons (kt = 1000 tons), megatons (Mt = 1 million tons).

5. The complete fission of one kilogram of uranium releases energy equivalent to about 16 kt of TNT and, in the process, roughly one kilogram of fission products would be formed. The complete fusion of one kilogram of deuterium would be roughly equivalent to 50 kt of TNT.

6. If the nuclear explosion takes place at or near ground level, appreciable quantities of fragmented ground material can be incorporated in the 'fireball' and these may become radioactive as a result of neutron reactions with them.

7. Thus, the radioactive debris from nuclear explosions may include not only fission products (see paragraphs 25-27) but activated elements from the ground, the atmosphere and the weapon constructional material. Fission products are usually the more important.

Nuclear Weapon Types

(i) Fission Weapons

8. The basic fission weapon uses uranium-235 or plutonium-239 (the latter being formed in nuclear reactors from uranium-238). To permit a rapid self-sustaining chain reaction to produce a nuclear explosion, fissionable material well in excess of a 'critical mass' is required. The critical mass of a bare sphere of U-235 (i.e. without a reflector) is about 40 kg and of Pu-239, about 16 kg. This may be reduced to 5 kg or thereabouts by the use of a 'reflector' round the sphere. The reflector can be made of natural uranium, or U-238.

9. Energetic neutrons produced during the nuclear explosion may also cause fission of U-238 in the reflector, thus adding not only to the yield of the weapon but also to the fission products formed.

10. Fission weapons, such as were used over Japan, produce about one kilogram of fission products from a yield of 20 kt. Such weapons are now known as 'low yield' but, with some designs, it is practicable to achieve fission weapon yields in the range of 200-500 kt (so-called 'medium yields') with the consequent production of about 25 kg of fission products. In such cases, a considerable fraction of the fission products arise from the fission of U-238 in the reflector, making the contamination levels high (compare the relatively low figure for fusion weapons).

(ii) Fission-Fusion Weapons

11. Fusion (or thermonuclear) weapons depend for their operation on raising the deuterium - tritium materials in the weapon to very high temperatures (at least 1-10 million degrees Celsius). The only practical method at present known for achieving such temperatures is by means of a fission explosion. Once the fusion reactions start, the temperature rapidly rises even further, fusing the light elements in the weapon.

12. The initial fission system may produce as little as one kilogram of fission products though the fusion reactions also produce appreciable quantities of other radioactive substances, tritium and carbon-14. The radioactive carbon is produced from the surrounding atmospheric nitrogen through interaction with very energetic neutrons arising from the fusion reactions.

13. Fusion weapons range from medium yield to high yield (up to 5 Mt) though higher yields are possible. Yields in the range 1-3 Mt were produced in Chinese and French tests of recent years. It should be emphasised that fission product fallout will be relatively low for such fusion weapon yields, compared with comparable fission weapons yields. Such fusion weapons are known as 'clean' weapons.

(iii) Fission-Fusion-Fission Weapons

14. By including a U-238 reflector in a fission-fusion weapon, it is possible to utilise the large number of very energetic neutrons, produced during fusion, to cause U-238 fissions which add to the overall energy yield of the weapon. Though such systems give very large yields up to and even in excess of 10 Mt, the extra energy is produced at the expense of generating fission products at levels of more than 100 kg (compare 1 kg for a 1 Mt fusion weapon). These are classed as very 'dirty' weapons where an appreciable fraction of the yield is generated by fission.

TABLE 1

SUMMARY OF NUCLEAR WEAPON CHARACTERISTICS

Type	Yield	Fission Products	
		Mass*	Activity Sr-90*
Fission	Low (20 kt)	1 kg	2 kCi
	Medium (200 kt)	10 kg	20 kCi
Fission-Fusion	Medium (200 kt)	1 kg	2 kCi
	High (2 Mt)	2 kg	4 kCi
Fission-Fusion-Fission	High (10 Mt)	200 kg	400 kCi

*Approximate quantities only.

Contained Explosions

15. We have excluded from the discussion underground nuclear explosions which are carried out at such depth that no breakthrough (venting) to the atmosphere occurs.

Atmospheric and Surface Explosions

16. In considering the environmental effects of nuclear weapons tests, two main factors are important in determining the level of radioactive contamination of the atmosphere:

(i) the type of weapon - fission, fusion or combinations of both - and its yield;

(ii) the altitude or subsurface depth at which the weapon is detonated.

17. Immediately following detonation, an intensely hot luminous fireball forms, in which are the fission products and construction materials in gaseous form. As the fireball expands, rises and cools, air is drawn up into the hot cloud. Later, small particles form by condensation and coagulation.

18. With explosions at the surface or at such heights that the fireball touches the surface, the strong up-draft will cause large amounts of ground material to be incorporated in the fireball as molten or vaporised material, activated by neutrons. Local fallout will be appreciable and will be composed of condensed and coagulated material forming over the molten ground particles.

19. 'Air bursts' do not have the fireball touching the ground and any dust or debris drawn up subsequently by the updraft does not intermix with weapon products in the fireball. Such air-bursts are accomplished by the use of tethered balloons or by drops from high-flying aircraft. For example, little local fallout would be expected from a 1 Mt nuclear weapon detonated 1000 m above ground level. French high yield devices are suspended by balloon, 600 m above a lagoon.

Atmospheric Transport of Radioactive Debris

20. Within 10 minutes, the residues of a nuclear weapon will be distributed in a column through the lower atmosphere (troposphere) and an appreciable fraction (certainly greater than 50%) will go into the stratosphere. The subsequent movement and ultimate fallout of the radioactive material depends on the very complex circulation and mixing processes within the atmosphere.

21. *Tropospheric residues* descend gradually over a period up to several months during which fine particles may be scavenged by rain. Dry deposition is a significant contribution to deposited activity only in areas of low rainfall. The 'half-residence' time (i.e. the time for half the suspended material to reach ground level) is 2 to 6 weeks. There is little N-S mixing between hemispheres at tropospheric levels. During its suspension, the bulk of tropospheric residues are carried round the earth by strong westerly winds in a belt about 30^{o} latitude in width. Thus a detonation in the South Pacific will produce fallout over Australia some 10 days later, after passing roughly three-quarters of the way round the world.

22. *Stratospheric residues* descend more slowly into the troposphere and are then deposited with a general half-residence time of six months to several years, depending on the altitude to which debris rose. High yield explosions, which penetrate well into the stratosphere, lead to debris in both hemispheres. While the stratospheric debris does tend to fall out in the hemisphere of origin, there is nevertheless some N-S mixing so that, for example, Australia is subject to fallout from tests in continental Asia as well as that from tests in the Southern Hemisphere. However, regardless of where it is injected into the stratosphere, the major proportion of stratospheric fallout will reach ground level at temperate latitudes mainly in high rainfall regions (about 45^{o}

latitude in summer, 30° in winter).

Recent Atmospheric Tests

23. Since 1964, the Chinese have been carrying out an annual series of tests at Lop Nor, latitude 40°N. Four hydrogen bombs of yields around 3 Mt have been included in these tests which are listed in Table 3.

24. The French began testing at Mururoa Atoll (latitude 22°S) in 1966 since when they have conducted a test series each year except in 1969. The French tests are summarised in Table 2. A number of high power weapons and devices have been included in these tests to date.

TABLE 2

FRENCH NUCLEAR TESTS IN THE SOUTH PACIFIC, 1966 - 1972

Year	Date	Power of Device
1966	3 July	25-30 kiloton
	20 July	70-80 kiloton
	12 September	about 120 kiloton
	25 September	about 150 kiloton
	5 October	200-300 kiloton
1967	6 June	low yield
	28 June	low yield
	3 July	low yield
1968	8 July	medium power
	16 July	medium power
	4 August	medium energy
	25 August	Hydrogen Bomb (2 megaton)
	9 September	Hydrogen Bomb (2 megaton)
1969	NO NUCLEAR TESTS IN THE PACIFIC	
1970	16 May	low power
	23 May	low power
	31 May	high power
	25 June	low power
	4 July	Hydrogen Bomb
	28 July	low power
	3 August	low power
	7 August	low power
1971	6 June	low power
	13 June	middle power
	5 July	low intensity
	9 August	low intensity
	15 August	Hydrogen Bomb (1 megaton)
1972	26 June	very low power
	1 July	low yield
	28 July	low yield

TABLE 3

CHINESE TESTS IN THE NORTHERN HEMISPHERE, 1964 - 1972

Year	Date	Power of Device
1964	16 October	Low yield
1965	14 May	Low yield
1966	9 May 27 October 28 December	Medium yield Low yield Medium yield
1967	17 June 24 December	Hydrogen weapon Low yield
1968	27 December	Hydrogen weapon
1969	22 September 29 September	Low yield Hydrogen weapon
1970	17 October	Hydrogen weapon
1971	18 November	Low yield
1972	17 January 18 March	Low yield Medium yield

Biologically Important Nuclides and Their Measurement

25. Most of the radioactive elements formed in a nuclear explosion have a short life and soon lose any biological significance; a few are long-lived and require long-term consideration. The principal long-term risks come from strontium-90, which is concentrated in bone, and caesium-137 which is widely distributed in the body. Caesium-137 contributes to genetic and whole-body irradiation but the effects of strontium-90 are limited to bone and bone marrow.

26. With one exception, any risk arising from the presence of short-lived radioactivity in fallout can be attributed to external whole-body exposure from gamma-emitters. The exception is radioactive iodine-131 (I-131) which has a half-life of about eight days, and may enter the body through a natural food chain and concentrate in the thyroid gland, just as does natural iodine, leading to selective irradiation of that gland.

27. In Australia, as elsewhere in the world, monitoring of fallout has been concerned principally with strontium-90, caesium-137 and iodine-131 because these are the main ingredients of fallout which involve possible health hazards.

28. Programmes for monitoring radioactive contaminants in the environment are carried out in Australia under the auspices of the Atomic Weapons Tests Safety Committee (AWTSC) whose reports are published yearly with all available data on

Sr-90, Cs-137 and I-131. An analysis of these data and an assessment of them are given each year by the National Radiation Advisory Committee (NRAC) which also can draw on the quarterly reports of the USAEC Fallout Program, the yearly reports of the United Kingdom Atomic Energy Authority (UKAEA) Health Physics and Medical Division and the reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Other countries also have monitoring programmes but the USAEC, UKAEA and UNSCEAR reports cover these data very adequately.

29. In this report we have drawn on all this background information to give what is a brief but we hope adequate account of what is known.

MEASUREMENT OF RADIATION

30. Radiation dosimetry is a complex subject on which only enough need be said here to provide some meaning and significance to the numbers given in the text.

31. Quantities of radioactive materials are expressed in terms of a unit, the curie, defined simply as a rate of radioactive disintegration. Multiples or submultiples of the curie in powers of ten are used, thus:

1 megacurie (1 MCi) = 1 million curies

1 kilocurie (1 kCi) = 1 thousand curies

1 picocurie (1 pCi) = 1 million millionth of a curie

The quantities of fission or activation products from nuclear explosions will necessarily be expressed in curie units, as will the initial measurement of their concentrations in materials analysed for radioactive fallout.

32. Quantities expressed in curie units cannot be directly translated into harmful effects when radioactive materials are ingested or inhaled. This is because the effective radiation dose from a radioactive element in the body depends not only on its quantity, in curie terms, but also on the energy of its disintegrations, its half-life, the nature of its anatomical distribution within the body, and the rate at which it is excreted from the body. Therefore it is necessary to express fallout measurements as radiation doses, to the whole-body or to specific organs, which can then be related to specific harmful effects.

33. The basic unit of absorbed radiation dose is a rad, which is defined in terms of energy per unit mass. This is insufficient for our purposes because radiations of different types, e.g. alpha and gamma, given in similar rad doses, will produce biological effects of different magnitude. This difficulty has been overcome by the introduction of a further unit, the rem, corresponding to the product of the dose absorbed (expressed in rads) and a coefficient, the quality factor, appropriate to the radiation in question. Properly speaking, the rem is the unit of 'dose equivalent', but will be referred to here as 'dose'.

For our purposes, the rem is rather a large dose; a convenient subunit is the 'millirem', one one-thousandth part of a rem, and this unit will frequently be used in the text.

34. Absorbed dose as conventionally measured is a macroscopic quantity; it does not allow for spatial variations in dose. It is not thought that any difficulties of this sort have influenced estimates of dose from weapons fallout. In one particular instance where this might be thought to be the case, the deposition of iodine-131 in the thyroid, it is widely believed that internal irradiation from iodine-131 is less effective as a carcinogen than an equivalent amount of radiation from an external source.

Background Radiation

35. It is necessary to put these units into an everyday perspective. Perhaps the simplest way to do this is in terms of natural background radiation. Man lives always in a variable field of ionising radiation. This involuntary exposure has three principal components: cosmic radiation which varies with altitude and latitude; terrestrial gamma radiation arising from natural radioactivity in the ground which varies with soil or rock types; and the naturally radioactive constituents of the body, of which potassium-40 is the most important. In most parts of the world, natural background radiation levels are about 100 millirem per year, made up of about 40 millirem from cosmic rays, 40 millirem from terrestrial gamma sources, and about 20 millirem from potassium-40 (see Table 4). There are considerable variations in these figures depending on where people live and the type of housing construction in use. An individual's annual background dose is quite likely to fluctuate by 10 or 20 millirem according to his behaviour. In some cities, for example those in granite areas, background levels may be around 200 millirem, and in a few areas of the world considerably higher levels, of 1000 or more millirem annually, are found. In none of these instances have harmful effects been shown to be attributable to the increased background.

36. There are various minor sources of man-made radiation such as luminous dials, electronic equipment of certain kinds, and industrial applications of radiation, but the second major contribution to man's radiation burden comes from exposures incurred in diagnostic medical radiology. No reliable figures exist for Australia, but recent figures from other Western countries are in the range 14 to 64 millirem a year for the average genetically significant dose. There is no reason to expect Australian medical practice to differ substantially. Table 5 summarises these figures.

TABLE 4

ESTIMATED ANNUAL DOSES (WHOLE BODY) FROM NATURAL RADIATION IN AUSTRALIA

Source	Average Annual Dose (mrem/yr)	Variations
Cosmic Rays	40	Altitude: 0-10,000 ft: x 4 Latitude: 0-50°: + 12% Pressure: 4% cm Hg
Terrestrial External	44	Gamma Dose Building Materials: 11-190 mrem/yr. Up to 500 mrem/yr in monazite areas.
Internal (K-40, etc.)	18	
TOTAL	102 mrem/yr	

TABLE 5

SUMMARY OF ESTIMATED ANNUAL WHOLE-BODY DOSE IN AUSTRALIA

Source	Average Annual Dose (mrem/yr)
Environmental	
Natural	102
Global Fallout	1
SUB TOTAL	103
Medical	
Diagnostic	50*
Miscellaneous (including occupational)	2
TOTAL	155

*Assumed by comparison with other countries. The only Australian survey was in 1957, giving a figure of 162 mrem/yr, but it is assumed that action to reduce medical exposures has been effective to some degree.

37. Man has evolved in the presence of background radiation and may be presumed to be in some sort of equilibrium with it. Therefore the magnitude of

this background, and of the natural variations of it, have often been suggested as criteria of the significance of man-made radiation exposure. It is proper to consider the significance of any whole-body radiation doses which may be attributed to fallout exposure, and for that matter to other man-made radiation sources, by comparison with natural radiation background levels, though other criteria have been suggested. In particular, attempts are sometimes made to calculate the injury induced in an irradiated population on the basis of certain radiation risk coefficients. The difficulties and inaccuracies inherent in this procedure, deriving from our lack of knowledge of the effects of very low levels of radiation on human populations, are discussed in paragraph 47. Essentially such calculations can only lead to upper estimates of the limit of damage that might be thought to occur; the lower limit, which is thought in many cases to be the more likely estimate of damage in these cases, is zero.

BIOLOGICAL EFFECTS OF RADIATION

38. Large doses of radiation, doses,that is,of hundreds of rems, may cause early illness or death if to the whole body, or local injury if to part of it. Such doses are not a conceivable consequence in Australia of nuclear weapons tests; therefore radiation injury of this sort will not be further considered here.

39. The radiation effects that do concern us are delayed ones, which appear months or years after exposure to small or moderate doses. Two of no importance in the present context are cataract (opacity of the eye lens) which can be a sequel of moderately large doses, and premature ageing which can be demonstrated in laboratory animals only after substantial doses far exceeding weapons test fallout. The important effects which must be considered are the induction of cancer in irradiated persons (a 'somatic' effect) and the induction of genetic effects in the offspring or descendants of irradiated persons.

40. The induction of cancer or of genetic change is not limited to radiation; many chemical agents will produce either or both effects. The precise mechanisms by which radiation induces cancer or mutation are not understood, any more than they are for chemical agents. Nevertheless a mass of experimental work with laboratory animals, and study of the available data relating to human radiation exposure, allow something to be said about possible dose-response relationships. Unfortunately, the lower the dose the more difficult it becomes to collect reliable information about its effectiveness in producing cancer or genetic change. This is because effects possibly attributable to the radiation cannot be distinguished from those due to natural causes - none of the effects of radiation are peculiar to it; they are all conditions which occur naturally.

41. The nature of possible dose-response relationships is illustrated in Figure 1.

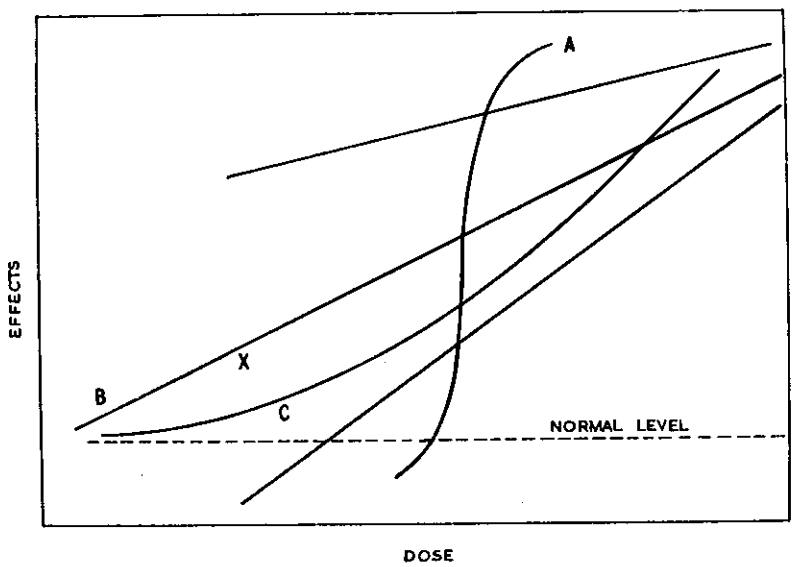

FIGURE 1. TYPES OF DOSE-EFFECT RESPONSE

42. There are several types of response. Curve A in the figure is a 'threshold' response, that is effects are not seen until the dose has exceeded some specific level. Agents with chemical or pharmacological toxicity are usually found to exhibit this threshold type of response, and such data allow the setting of 'safe levels' for industrial pollutants, that is,levels below which the unwanted effects are not seen. If the response to radiation is measured in terms of acute illness or death, the dose-response curve is also of the threshold type A. If the measured effect is the incidence of cancer or of mutations, there is an unavoidable uncertainty, in most cases, of the precise form of the dose-response curve.

43. At points where the radiation dose is high, at the right of the diagram, the response can be measured fairly accurately. At dose levels at the left of the figure, the uncertainty in the magnitude of the response increases, and it is not usually possible to get reliable figures for low doses.

44. In consequence, to calculate the magnitude of effects at low doses, it is necessary to extrapolate in some way from the more reliable estimates available for high dose levels. The usual convention for doing this is to assume a linear relationship between dose and effect; in other words it is assumed that effect is proportional to dose at all levels, i.e. if 1000 rem produce ten cases of leukaemia, 100 rem will produce one, and so on. This is a conservative

assumption; it is quite likely to overestimate incidence at low doses but unlikely to underestimate incidence. Underestimation would imply that radiation would become more effective at lower doses and this is contrary to any reasonable physical model of its action.

45. Curve B in the figure illustrates a linear model of this sort. It is possible to seek experimental confirmation of its form up to a point, but as the dose is reduced the experimental (or observational) uncertainty of points on such curves increases. This is illustrated in the figure, in an arbitrary manner, by putting in two straight lines diverging from the linear model to show the increasing margin of uncertainty at lower doses.

46. At doses below some level it is impossible to collect meaningful data; this is shown in the figure as point X on the linear curve. In dose units, the value of X is likely to be quite high in relation to the values considered in radiation protection standards or in fallout studies. It is evident that the margin of uncertainty in data collected at very low doses is likely to mean that they could equally well be fitted to some other kind of response curve, for example the quadratic one shown as curve C. In that case, there would be an effective threshold, since at low doses the response would be indistinguishable from natural incidence. Natural incidence may be zero, but is usually at some positive level as illustrated here.

47. The discussion above on dose-response relationships applies equally to both the carcinogenic and the genetic consequences of radiation exposure. If we accept the linear relationship, it is not too difficult to arrive at numerical estimates of the numbers of cases of cancer which may arise when a substantial population is given small doses of radiation. In doing this it is necessary to remember two things. Firstly, the data from which the extrapolation can be made in man come from a very limited experience - the incidence of leukaemia and other malignant diseases in survivors of the atomic bombs dropped on Japan (there were about sixty cases of leukaemia in the study group of 100,000 people, in addition to the 60 or so normally expected), and a somewhat larger group from persons exposed to radiation for medical reasons. Secondly, in all these cases the radiation dose was large and given rapidly. These points are significant in two respects:

- There is no positive evidence of the carcinogenicity in man of small doses of radiation.
- There is experimental evidence from animal studies that radiation given at low total doses and low dose rates is less effective (as measured by the slope of the dose-response curve) than is radiation given in large doses or at high dose rates.

48. It is therefore reasonable to regard estimates of cancer incidence, based on the linear model, as estimates of the upper limit of the possible, when the extrapolation is made to low doses or dose rates. It is quite possible that, in some instances, the actual incidence can be zero for low doses or dose rates. The qualification, 'in some instances', is made because experimental work suggests there are differences in this respect between certain different types of radiation.

The Regulation of Radiation Exposure

49. Almost all countries, or states within federal countries, legislate to protect their citizens from the misuse of radiation. Most such legislation provides regulations on individual radiation dose which are either identical with, or vary only slightly from the Recommendations of the International Commission on Radiological Protection (ICRP). The ICRP is a non-governmental body created in 1928 primarily to provide guides to protect members of the medical profession making diagnostic and therapeutic use of X-rays and radium. In 1950 the Commission was enlarged, took on a wider international representation and broadened its area of responsibility beyond medical practice. From then on the Commission and its working committees included persons able to contribute to the problems arising from nuclear power, industrial radiography, high-energy accelerators and so on. The ICRP does not issue detailed regulations or codes of practice but does provide recommendations on dose limits for persons occupationally exposed to radiation and for members of the public. The ICRP has no political bias and its advice is universally accepted.

50. The dose limits provided or understood in the radioactive substances acts, and corresponding regulations, of the Australian states are essentially those recommended by the ICRP. The same values have been recommended by the National Health and Medical Research Council. In summary, the dose limits recommended are 5 rem (5000 millirem) annually for whole-body irradiation for workers occupationally exposed, and 500 millirem annually for members of the public. There are higher figures allowed for various separate organs. For example the recommended level for thyroid exposure is 30 rem per year for radiation workers and 3 rem per year for adult members of the general public; for children under 16 years of age it is recommended that thyroid exposure be limited to 1.5 rem per year.

51. The ICRP, in setting these limits, recognised that it would be desirable to equate risks to benefits in setting acceptable doses. Although it was unable to define risks with precision and was not in a position to make quantitative evaluations of benefits, it felt the need to provide practical guidance

to acceptable limits. In arriving at these limits, it accepted the conservative, linear, non-threshold philosophy of dose-response relationships which has been considered above. As a consequence of this assumption, it must be assumed that any exposure to radiation may involve some degree of risk and the ICRP recommends that all exposures to radiation should be reduced to the lowest practicable level; that is, any exposure should be reduced until the risks associated with it are balanced by the benefits to be expected from the activity leading to the exposure.

FALLOUT LEVELS IN AUSTRALIA

Long-Lived Activity: Sr-90, Cs-137, C-14 and Tritium

52. The stratospheric inventory of the long-lived fission product Sr-90, in each hemisphere is shown in Figure 2. It can be seen that the levels in both

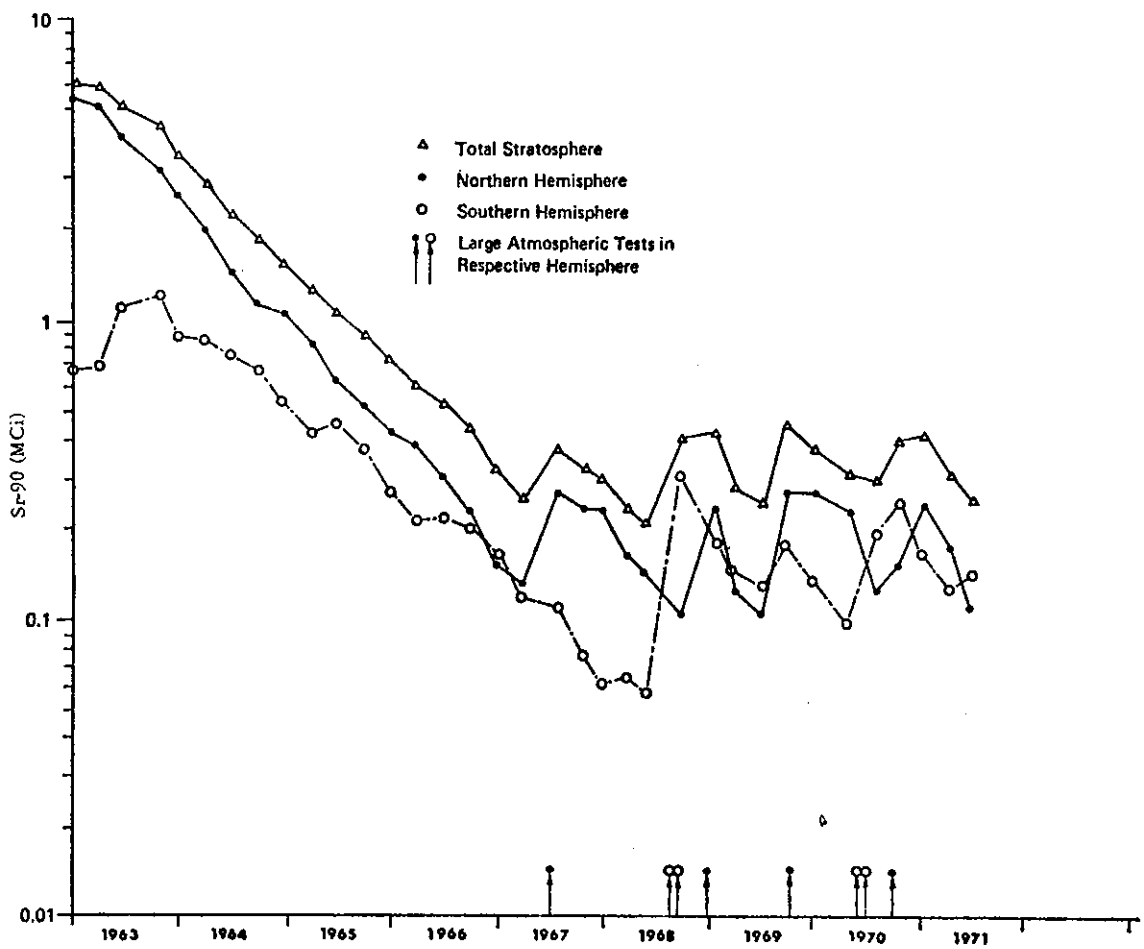

FIGURE 2. STRATOSPHERIC INVENTORY OF STRONTIUM-90 (AFTER UNSCEAR 1972)

hemispheres have dropped steadily since the cessation of atmospheric testing by the U S A and U S S R in 1963 but has remained fairly constant since 1967

due to atmospheric testing by the Chinese in the northern hemisphere and the French in the southern hemisphere. In February 1971 the inventories in the stratospheres of the northern and southern hemispheres were about 0.29 and 0.16 MCi respectively, most of this being due to recent tests. The inventory of Cs-137 follows a very similar pattern, the ratio of Cs-137 to Sr-90 inventories being about 1.5.

53. The stratospheric inventory in the southern hemisphere reached a maximum of about 1.2 MCi of Sr-90 (plus 1.8 MCi of Cs-137) in 1963 and decreased steadily until the French tests in 1968. The increase in the northern hemisphere inventory in 1967 was due to a high yield Chinese explosion on 17th June and subsequent peaks follow similar high yield Chinese tests on 27th December 1968, 29th September 1969 and 14th October 1970. These tests will have eventually contributed to the stratospheric inventory in the southern hemisphere but the major peaks in the southern hemisphere curve are due to the French tests in 1968 and 1970. For example, the French explosions in 1968 were responsible for about 70% of the Sr-90 in the stratosphere of the southern hemisphere towards the end of 1968.

Transfer of Material Between Hemispheres

54. The long-lived activity in the stratosphere eventually reaches the troposphere where, as mentioned previously, it is rapidly deposited on the earth's surface. From measurements of long-lived solid fission products in surface air made by the UKAEA in the southern hemisphere it is possible to get an estimate of the origin of the deposited activity in the southern hemisphere. These estimates are set out in the following table:

TABLE 6

THE ORIGIN OF DEPOSITED ACTIVITY IN THE SOUTHERN HEMISPHERE

Period	Proportion Sr-90, Cs-137 due to Immediate French Tests*	Source of the Activity
Late 1966	25%	July-October 1966
To Mid 1967	2%	July-October 1966
Mid 1968-March 1969	50%	July-Sept. 1968
June 1969	75%	July-Sept. 1968
June 1969-May 1970	80%	July-Sept. 1968
Sept. 1970-June 1971	60%	May-August 1970
January 1972-June 1972	40%	June-August 1971

*For each period in this table, the listed proportion of long-lived fission products is that deriving from the test series identified in the last column. There will also be, during any observation period, contributions from material of French origin coming from previous tests. Thus the ratio of total material of French origin to that from the northern hemisphere will exceed the values listed in column two.

It would appear from these data that long-lived solid material in the troposphere of the southern hemisphere originating from the French tests may on occasions reach three-quarters of the total.

55. It is however possible to obtain a more representative estimate of this fraction from the data presented in Figure 2 which shows how the stratospheric inventories in both hemispheres decreased over the period 1963 to 1966 when there was essentially no significant injection of material into either stratosphere. The amount of Sr-90 in each stratosphere decreased through deposition, but at the end of this period both stratospheres had roughly equal inventories due to interchange between hemispheres. On the basis of a simple model in which it is assumed that the rates of deposition in each hemisphere are the same and the rates of exchange from one hemisphere to the other are also equal, it may be estimated from the data in Figure 2 that the fraction of the original inventory in one hemisphere transferred and deposited in the other is 0.19 (Cook and Combe 1973).

56. For any particular explosion the exact transfer fraction will depend on the latitude of the explosion, the height reached by the debris and the time of the year during which the explosion took place. The above estimate of the transfer fraction therefore represents an average over the conditions under which the explosions prior to 1963 took place. In the absence of details of the conditions under which the subsequent French and Chinese tests occurred, it will be assumed in this paper that one-fifth of the long-lived particulate fission products (Sr-90 and Cs-137) are transferred from one hemisphere to the other.

57. This transfer fraction of one-fifth applies only to long-lived particulate fission products. For the short-lived materials, in particular iodine-131 and the short-lived gamma emitting nuclides discussed below (paragraphs 73 ff), it is assumed that no transfer occurs. The interhemispheric exchange processes are so slow that in general these short-lived activities will have decayed to immeasurable levels before reaching Australia.

58. Finally, account will be taken in the subsequent estimates of doses to

the Australian population of exposure to two long-lived gaseous radioactive elements, carbon-14 (C-14) and tritium (H-3, a radioactive nuclide of hydrogen), which are produced in significant amounts in thermonuclear explosions. These materials are well mixed between hemispheres and for them a 50 per cent transfer is assumed.

59. These estimates of transfer fractions will be used to apportion the dose being received by the Australian population from fallout in the southern hemisphere between the French and Chinese tests.

60. The rate of deposition of Sr-90 in MCi/yr in the two hemispheres is shown in Figure 3. In 1969 the annual deposition of Sr-90 in the southern hemisphere exceeded that in the north for the first time. The cumulative deposit in the southern hemisphere at the end of 1969 was still however less than one-third of that in the north.

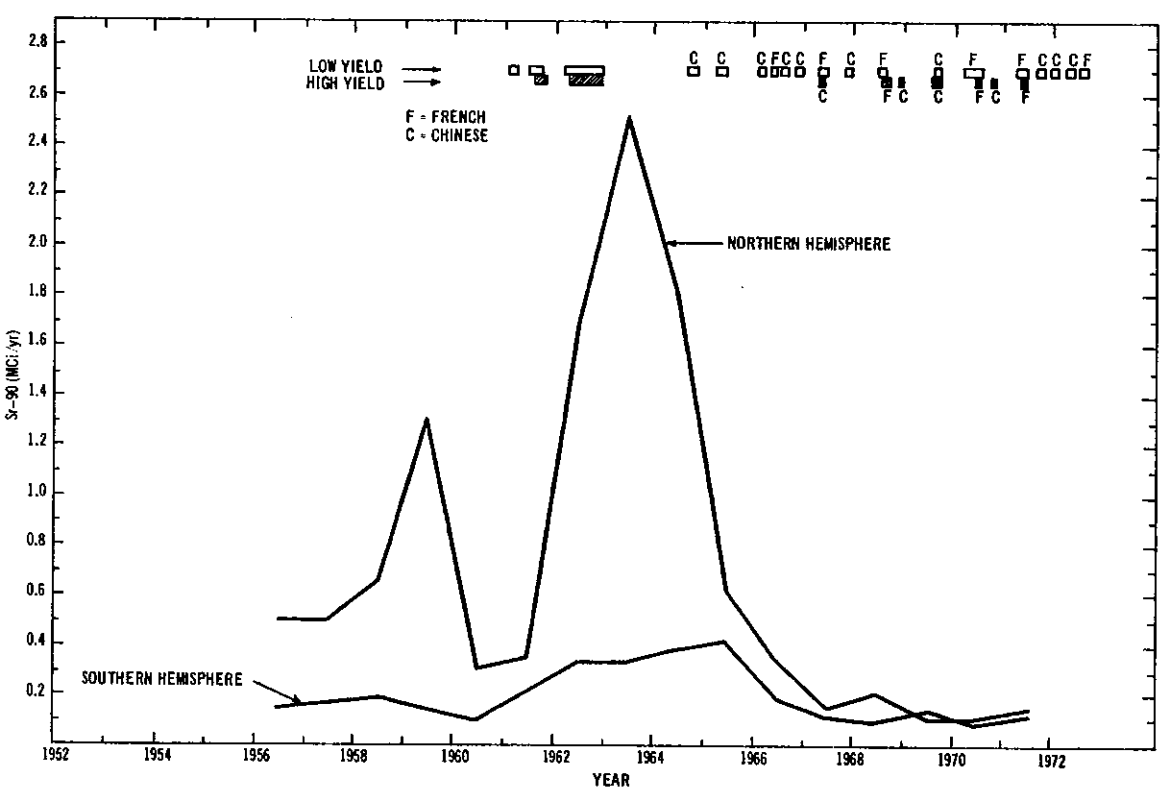

FIGURE 3. RATE OF DEPOSITION OF Sr-90 (AFTER UKAEA REPORT AERE-R7145)

Dose Commitments from Long-Lived Activity

61. Once deposited, some of the Sr-90 and Cs-137 will enter human food chains and become incorporated in the body, leading to irradiation of tissues. Sr-90, which is similar in behaviour to calcium, becomes incorporated mainly in bone.

Cs-137 on the other hand is distributed more uniformly throughout body muscle and leads to irradiation of the whole body including reproductive cells. Also, being an emitter of penetrating gamma radiation, it can lead to external irradiation of the population when it is deposited on the ground.

62. The Atomic Weapons Tests Safety Committee carries out an extensive survey programme to monitor the levels of Sr-90 and Cs-137 in the environment, foodstuffs and in humans at numerous representative centres throughout Australia. From these measurements it is possible to estimate the average radiation dose rate to the population from long-lived fission products. A summary of the AWTSC survey programme for long-lived fission product deposition will be found in the AWTSC Report No.2 (May 1971) and Report No.4 (September 1972). The mass of detailed data contained in these and previous reports of the AWTSC is briefly summarised in the following table:

TABLE 7

ESTIMATES OF DOSE RATES TO AUSTRALIAN POPULATION FROM THE LONG-LIVED FISSION PRODUCTS Sr-90 AND Cs-137 (AFTER AWTSC REPORTS)

Year	Cs-137 mrem/yr		Sr-90 mrem/yr	
	External	Internal	Bone Marrow*	Endosteal* Tissue
1961		-	2.2	2.9
1962		-	2.9	4.0
1963		-	3.0	4.1
1964	(Mean of	-	3.1	4.3
1965	0.12	2.1 (max)	4.8	6.6
1966	between	-	3.6	4.9
1967	1958 and	-	2.4	3.3
1968	1969)	-	2.8	3.9
1969	0.17	-	2.3	3.1
1970	0.17	0.4	2.3	3.1
1971	0.18	0.4	2.6	3.6

*Dose to the bone of children aged about 1 year.

63. The average external dose rate from Cs-137 in the years 1958 to 1969 was estimated at 0.12 mrem/yr. Internal dose rates from Cs-137 were not measured until 1970 but they may be estimated from some existing Cs-137 body burden measurements and measurements of Cs-137 in milk. The bone doses from Sr-90 are those applicable to children of about 1 year, at which age bone doses are

maximum.

64. The levels of Sr-90 and Cs-137 in diet, and hence in humans, are related to both the rate of fallout and the amount of fallout already deposited, Cs-137 levels being more dependent on rate of fallout than Sr-90.

65. The rate at which Sr-90 in bone levels was falling from the peak in 1965 has been retarded by the addition of Sr-90 to the southern hemisphere from the French tests, plus a contribution from the Chinese tests and the residuum from the earlier northern hemisphere atmospheric tests. The relative constancy of the bone dose rates over the past few years is a reflection of the essentially constant rate of deposition of Sr-90 that now obtains in the southern hemisphere, and which is at such a rate that it compensates for Sr-90 that has decayed on the ground. As indicated above, about four-fifths of the Sr-90 at present being deposited in the southern hemisphere comes from French tests.

66. As reported by the AWTSC, these dose rates are small relative to the natural background dose rate of about 100 mrem/yr. Thus in 1971, for example, the average whole-body dose from Cs-137 (internal plus external) was about 0.6 millirem which is only 0.6 per cent of the average natural background dose received in one year. Similarly the total bone dose rate to infants (from Cs-137 and Sr-90) is 3.2 mrem to the bone marrow and 4.1 mrem to endosteal tissues corresponding to some 3 to 4 per cent of the average background radiation from natural sources.

67. Though, as mentioned in paragraph 37, comparison of fallout exposure rates with natural background does give an indication of the significance of these exposures, it does not allow an assessment of the degree of risk that could be involved to be made. To do this it will be necessary to estimate the total dose which will be received by the Australian population integrated over all time. This will have two components; the sum of all doses that have been received to date, plus the estimated dose that will be received in the future (assuming no further tests are carried out) resulting from the radioactive material that has been injected into the atmosphere and still remains to be deposited, from radioactive material already deposited, and from the material that is already incorporated in the body and which yet remains to be eliminated or to decay radioactively. This total dose projected into the future is called the *dose commitment*.

68. In addition, since the risks associated with irradiation of the whole body and bone appear to be independent of age (except possibly for irradiation of the foetus in utero) the dose value required to estimate the consequences of exposure to Sr-90 and Cs-137 is the dose commitment averaged over the

whole Australian population for all age groups.

69. Details of the calculations leading to the dose commitments used in this paper will be found in another report (Cook and Combe 1973). They will merely be summarised here.

70. An estimate has been made of the rate at which Sr-90 injected into the stratosphere will be deposited after the tests cease. This has enabled the average rate of decrease in Australia of Sr-90 in human bone to be estimated and therefore the total dose to bone extending over all time to be estimated. Use of the bone data published by the AWTSC, taking into account the variation of Sr-90 content with age, has led to the following bone dose commitments from Sr-90:

Bone marrow = 4.8 mrad

Endosteal cells = 6.6 mrad

About one-fifth of these dose commitments results from Chinese testing in the northern hemisphere (see paragraph 56).

71. A similar calculation has led to the following dose commitments from Cs-137 deposited on the ground (i.e. external exposure) and Cs-137 ingested:

Whole-body dose (external Cs-137 including attenuation factors) = 2.1 mrad

Whole-body dose (internal Cs-137) = 2.5 mrad

The whole-body dose from Cs-137 deposited on the ground has been corrected for attenuation of its emitted gamma rays by buildings, etc., and absorption by the body itself which 'self-shields' some organs. The factor used to convert outdoor free-air dose to tissue dose is 0.32, the value recommended by UNSCEAR (1972).

72. No measurements of carbon-14 and tritium levels are made in Australia. However, it is possible to obtain an estimate of the dose commitment due to these nuclides originating in tests carried out by the French and Chinese from information published in the 1972 UNSCEAR report. In Table 45, page 95 of that report, are given dose commitments for the southern hemisphere (south temperate zone) due to *all* tests carried out before 1971. Apportioning the southern hemisphere dose commitments for C-14 and tritium in the ratio of the Sr-90 released from French and Chinese tests to the total amount of Sr-90 released from all tests to the end of 1970 leads to the following dose commitment estimates due to the French and Chinese tests:

Carbon-14:	whole-body and bone marrow	= 0.8 mrad
	endosteal cells	= 1.0 mrad
Tritium:	whole-body	= 0.2 mrad

As mentioned in paragraph 58, about half of these dose commitments are due to the French tests, half to the Chinese.

It should be noted that UNSCEAR calculate the dose commitment from C-14 only to the year 2000. C-14 has a very long radioactive half-life and will remain on earth for many thousands of years. However, it exchanges with reservoirs of stable carbon on the earth and will become unavailable in biological processes in a time scale much shorter than its radioactive half-life. Because of uncertainties in the rate at which C-14 becomes fixed and the small contribution it makes to the total dose commitment in Australia, it is considered reasonable to accept the UNSCEAR procedure.

Short-Lived Activity Including I-131

73. Although short-lived activity, especially I-131 (half-life 8 days), has been detected in Australia from tests in the northern hemisphere (in particular the USA tests at Christmas and Johnston Islands in April 1962), in general short-lived activity will only lead to significant irradiation of the Australian population if the tests are carried out in the southern hemisphere. Both I-131 and other short-lived activity have been measured in Australia after French tests.

74. Again the AWTSC has carried out an extensive monitoring programme to measure this activity, the results of which have been reported in a series of AWTSC and National Radiation Advisory Committee Reports.

75. The total beta activity measurements are of interest because they allow an estimation to be made of the external irradiation of the population from the more penetrating gamma radiation associated with this activity when it is deposited on the ground. The I-131 measurements, which comprise I-131 activity levels in a comprehensive sampling of Australian milk supplies, lead to estimates of the dose delivered to the thyroids of the Australian population. Because children drink more milk, and both because they have smaller thyroids and take up iodine more efficiently than adults, the dose to the thyroids of humans drinking milk of a given concentration is a maximum in children during their first two years of age. As recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the thyroid dose calculation is based on a milk consumption of 0.7 litres per day and an infant (up to 2 years) thyroid mass of 2 g. Adult thyroid dose calculations would be based on a smaller milk intake and a thyroid mass of 20 g leading to an average thyroid dose at least an order of magnitude less than the average infant thyroid dose.

76. The total integrated doses estimated by the AWTSC for these two exposures -

whose body doses from deposited short-lived gamma emitters and the thyroid doses to infants - are summarised in Table 8 where the maximum and minimum values (which correspond to different geographical locations within Australia) are given.

TABLE 8

ESTIMATED DOSES TO THE AUSTRALIAN POPULATION FROM SHORT-LIVED RADIOACTIVITY FROM THE FRENCH TESTS

Test Series	Whole-Body Dose (mrem)	Thyroid Doses (mrem)
July-October 1966	0.2 - 1.2	17 - 128
June-July 1967	<0.1 - 0.2	4 - 120
July-September 1968	0.2 - 1.1	9 - 53
May-August 1970	0.2 - 1.4	10 - 68
June-August 1971	0.1 - 2.2	4 - 62
June-July 1972	0.01 - 0.12	0 - 2

77. The lowest thyroid doses are recorded in Tasmania, the highest at Malanda in North Queensland where the levels are generally a few times those in the major population centres. The high levels at Malanda are related to its latitude and high rainfall during winter/spring.

78. The whole-body doses delivered as a result of each test series are a very small fraction of the radiation dose received annually from natural background. The quoted levels are also an overestimate of the biologically effective dose since no account has been taken of weathering effects and shielding afforded by buildings, roughness of terrain and the body itself. In paragraph 71 we have adopted the UNSCEAR reduction factor of 0.32 to take account of these effects.

79. The thyroid doses associated with each series (except 1972) are an appreciable fraction of the background dose of 100 mrem delivered in one year. However, for individual organs the natural background level is not an appropriate criterion, because the radiosensitivities of different organs vary. The ICRP recognises this by allotting different dose limits to specific organs. For the thyroid the limit is 3.0 rem for an adult thyroid and 1.5 rem for a child's, in comparison with the whole-body figure of 0.5 rem.

80. Some latitude for the thyroid is therefore appropriate and the AWTSC has compared doses, not with background, but with a radiation protection guide originally proposed by the UK Medical Research Council and adopted by the

NRAC in 1965. The NRAC believes that I-131 in fallout from nuclear tests 'would not constitute a significant threat to the health of the Australian community' provided that the concentration of I-131 in milk does not exceed 200 picocuries per litre, averaged over a period of 12 months. This is equivalent to accepting as a protection guide, in this instance, an infant thyroid dose of 840 mrem/yr.

81 In terms of this criterion it can be seen that even the highest doses at Malanda, which have not exceeded 226 mrem in any consecutive 12 month period between 1966 and 1972, have not exceeded about a quarter of the guide level at any time.

Dose Commitments from Short-Lived Activity and I-131

82. Again, however, in order to give some estimate of the risk to the Australian population associated with these exposures it will be necessary to convert these dose range estimates into population weighted average doses. Since we are here dealing with short-lived radioactivity, these weighted averages will also be dose commitments; the total dose is delivered within a relatively short time, certainly within a year.

83. The detailed data on whole-body doses from short-lived activity and the iodine-131 doses to the thyroid of young children given by the AWTSC for various population centres has been averaged and the results are given in Table 9.

TABLE 9

POPULATION DISTRIBUTION WEIGHTED AVERAGE DOSES FROM DEPOSITED SHORT-LIVED GAMMA EMITTERS AND FROM I-131 INGESTED BY YOUNG CHILDREN

Year	Whole-Body Dose (mrem)	Thyroid Dose (mrem)
1966	0.64*	42
1967	0.10*	10
1968	0.65	15
1969	0.0	0
1970	0.81	16
1971	1.4	13
1972	0.0	0
TOTAL	3.6	96

*As mentioned in paragraph 76, these may be underestimates.

84. In Table 9 the sum of the average population whole-body doses due to external irradiation from deposited short-lived gamma emitting activity from all French tests to date is given as 3.6 mrem. This is not, however, the biologically effective dose; the UNSCEAR attenuation factor of 0.32 (paragraph 71) must be taken into account to obtain this. Thus we have,

Whole-body dose (external, short-lived gamma emitters) = 3.6 x 0.32 = 1.2 mrem

85. The sum of the thyroid doses listed in Table 9, received by young children from ingesting I-131, i.e. due to internal exposure is:

Thyroid dose (internal, young children) = 96 mrem

Australian Dose Commitments Derived from UNSCEAR

86. Except for the C-14 and tritium dose commitments obtained in paragraph 72, the Australian dose commitments obtained above are based on measurements of fallout in Australia carried out by the AWTSC. However, the method outlined in paragraph 72 to obtain the C-14 and tritium dose commitments can also be used to derive an independent estimate of the dose commitments due to short-lived gamma emitters Sr-90 and Cs-137 from the data given in Table 45, page 95 of the 1972 UNSCEAR report. This leads to the following estimates of dose commitments to the Australian public from French and Chinese tests (for details see Cook and Combe 1973):

(i) Whole-body dose (external, short-lived gamma emitters) = 2.8 mrem
(cf. paragraph 84 above where this was estimated at 1.2 mrem)

(ii) Whole-body dose (external, Cs-137) = 2.4 mrem
Whole-body dose (internal, Cs-137) = 1.0 mrem
(cf. paragraph 71 above where these were estimated at 2.1 and 2.5 mrem respectively)

(iii) Bone marrow = 2.0 mrem
Endosteal tissue = 2.7 mrem
(cf. paragraph 70 above where these two figures were estimated at 4.8 and 6.6 mrem respectively)

87. The agreement between these two sets of estimates is considered reasonable. To assess the biological risks associated with the tests, the higher value is taken in each case.

Table 10 summarises the estimated total dose commitments for the whole-

body, bone and thyroid from the French and Chinese tests, the apportionment of dose between the French (Fr.) and the Chinese (Ch.) being carried out as discussed in paragraphs 56 to 59.

TABLE 10

ESTIMATED AUSTRALIAN DOSE COMMITMENTS FROM THE FRENCH TEST SERIES AND FROM THE CHINESE TEST SERIES

Source of Radiation	Dose Commitment (mrem)							
	Whole-Body and Gonads		Endosteal (Bone-Lining) Cells		Bone Marrow		Thyroid	
	Fr.	Ch.	Fr.	Ch.	Fr.	Ch.	Fr.	Ch.
External								
Short-Lived	2.8	0.0	2.8	0.0	2.8	0.0	2.8	0.0
Cs-137	1.9	0.5	1.9	0.5	1.9	0.5	1.9	0.5
Internal								
H-3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
C-14	0.4	0.4	0.5	0.5	0.4	0.4	0.4	0.4
Sr-90			5.3	1.3	3.8	1.0		
Cs-137	2.0	0.5	2.0	0.5	2.0	0.5	2.0	0.5
I-131							96 (a)	
TOTALS	7.2	1.5	12.6	2.9	11.0	2.5	103 (a)	1.5

(a) Young Children: less for others

SUMMARY AND DISCUSSION

Comparison with Background

88. Since the French tests began in 1966, yearly whole-body exposure from long-lived Cs-137 has been less than 1 per cent of natural background levels; on average some four-fifths of this exposure is due to fallout from the French tests. The rest comes from tests carried out in the northern hemisphere. These doses are less than normal temporal and geographical variations in the natural radiation background in Australia and cannot be considered a hazard to health of the Australian public.

89. Similarly, average dose rates to the bone of the most susceptible group (children of about 1 year) are less than 4 per cent of natural background and these also are too small to present a significant hazard to the Australian

population. Again, some contribution to these doses comes from the northern hemisphere.

90. Whole-body doses resulting directly from short-lived gamma activity from the French tests, averaged over the Australian population, are of the same order as those due to the long-lived Cs-137, i.e. less than 1 per cent of natural background and likewise present no significant health hazard.

Risk Estimates

91. Comparison of whole-body and bone dose rates from fallout with natural radiation background dose rates is legitimate in these cases to give some idea of their significance but it gives no indication of the potential risk imposed upon the Australian population as a result of these exposures. Bearing in mind the limitations of the experimental justification for such an approach (see for example paragraphs 47 and 48 above), a conservative estimate of the risk can be given on the basis of the following assumptions:

(a) There is no threshold to radiation injury (somatic and genetic) and any exposure to radiation carries with it some risk of injury.

(b) The risk of injury is proportional to dose and independent of dose rate down to the lowest levels of exposure.

92. With these assumptions and extrapolating observed effects in man at high doses and high dose rates to the low dose region, risk coefficients have been determined which relate probability of cancer induction in man with dose. These risk coefficients have recently been reviewed by UNSCEAR (1972) and an advisory committee to the USA National Academy of Sciences and the National Research Council (BEIR 1972). Representative risk factors taken from these two reports are given in Table 11. Since the risk coefficient for the induction of bone sarcoma is one-tenth or less of the figure for other specific cancers, bone sarcomas have not been estimated separately.

The thyroid risk factors given here are somewhat more detailed than will be found in either the UNSCEAR or BEIR reports, in distinguishing between internal and external exposure and proposing high values for young children. There is some evidence for both these effects (Cook and Combe 1973) but they are not well substantiated. The effect of using the coefficients in Table 11 will be slightly to overestimate the number of thyroid cancers to be expected compared with the number that would be obtained using the UNSCEAR mean value of 40 cases of thyroid cancer in 25 years per rem per million people exposed independent of age (i.e. a single risk coefficient of 1.6 per year per rem per million over 25 years).

TABLE 11

RISK FACTORS FOR CANCER RESULTING FROM RADIATION EXPOSURE

(AFTER BEIR 1972, UNSCEAR 1972)

Type of Cancer	Period Over Which Cancer May Show Up	Cases Per Year Per rem Per Million People
Leukaemia	25 years	1.5
(foetal irradiation)	(10 years)	(25)
Thyroid		
- external	30 years	6 for young children 2 for others
- internal	30 years	2 for young children 1 for others
Other	30 years	5.5
(foetal irradiation)	(10 years)	(25)

Somatic Effects - Cancer Induction

93. Using the dose commitments in Table 10 and the risk factors in Table 11, the number of cases of cancer that might be expected in an Australian population of 13 million people as a result of the French tests to date are set out in Table 12. (The detailed calculations are given in an Appendix.)

TABLE 12

POSSIBLE NUMBER OF CANCER CASES ARISING IN AUSTRALIA AS A RESULT OF FRENCH TESTS TO 1972

Type of Cancer		Total Cases in 30 Years
Leukaemia	- general population	6
	foetal irradiation	1
Thyroid	- internal irradiation	11
	- external irradiation	7
Other Cancers	- general population	16
	foetal irradiation	1
TOTAL		42

94. Of the estimated total number of about 40 possible cases of cancer that may show up in the next 30 years as a result of the French tests to date, 18 are thyroid cancers. Mortality amongst thyroid cancer cases is less than 10 per cent. Bearing in mind the uncertainties in the basic assumptions behind these calculations, it would be more accurate to state that the estimated number of cases of all forms of cancer that could arise in the Australian population as a result of the French tests carried out to date lies between zero and about 40 over the next 30 years. (The natural incidence of all forms of cancer in the Australian population will lead to some 500,000 deaths over that period.)

95. Fallout in Australia from Chinese tests to date will possibly contribute an extra 6 cases of all forms of cancer over the next 30 years.

Genetic Effects

96. Estimation of genetic injury resulting from these exposures is even more uncertain than the estimates of somatic effects. Numerical estimates of cancer casualties were based on extrapolation (with the limitations noted in the text) from high dose and high dose-rate data. These data come from the studies of the Atomic Bomb Casualty Commission at Hiroshima and Nagasaki, and from high level medical exposures for various reasons. No such data are available for man with respect to genetic effects. The Japanese studies have not shown any genetic effects in man which can be attributed to radiation from the bombs. Therefore, there is no means of extrapolating from human experience.

97. Assessments of genetic hazards must be extrapolated from experimental animal studies, although there are many limitations to such extrapolations in addition to those already noted. Estimates of various genetic consequences have however been prepared, in the main from mouse data, by such bodies as UNSCEAR and the National Academy of Sciences; the possible margins of error are large.

98. In Table 10 the estimated genetic (gonad) dose to the Australian population from French tests to date is given as 7.2 mrem. Accepting the estimates of genetic damage given in the BEIR Report (Table 4, page 57) this exposure could lead to the effects in the Australian population showing up within the next generation (i.e. over about the next 30 years) as shown in Table 13. The range of values given for the possible increase represents the uncertainty in present day knowledge of the genetic effects of radiation on human populations.

Additional cases of genetic injury will show up in subsequent generations, the total over all generations being perhaps ten times the number occurring

in the first generation.

TABLE 13

POSSIBLE GENETIC EFFECTS ARISING IN THE NEXT GENERATION OF THE AUSTRALIAN POPULATION AS A RESULT OF FRENCH TESTS TO 1972

Disease Classification	Natural Incidence	Increase Due to 7.2 mrem in One Generation
Dominant inherited disease	2,300/yr	0.02 to 0.2 cases/yr
Total diseases having genetic component	13,800/yr	0.02 to 0.3 cases/yr

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APPENDIX

CALCULATION OF THE NUMBER OF CANCER CASES

Derivation of the estimated number of cancer cases included in Table 12 is set out here. In general,

Number of cases = (population at risk) x (risk factor) x (dose commitment) x (period over which the cancer cases may appear)

A total population of 13 million is assumed.

A.1 Leukaemia

(i) General Population

Risk = 1.5×10^{-6} cases per year per rem

Dose commitment, viz. that to bone marrow = 11×10^{-3} rem

Population at risk = 13×10^{6}

Period over which leukaemia cases may appear = 25 years

Number of cases = $(13 \times 10^{6}) \times (1.5 \times 10^{-6}) \times (11 \times 10^{-3}) \times 25$

= 5.4 cases

(ii) Foetus

Risk = 25×10^{-6} cases per year per rem

Dose commitment, viz. that to bone marrow of foetus = 11×10^{-3} rem*

Population at risk = $13 \times 10^{6} \times 0.018$ (birth rate) $\times \frac{9}{12}$ = 176,000 (i.e. $\frac{9}{12}$ of the live births per year; 1.8% is Australian birth-rate)

Period over which leukaemia cases may appear = 10 years, for foetal irradiation (BEIR 1972).

Number of cases = $(0.176 \times 10^{6}) \times (25 \times 10^{-6}) \times (11 \times 10^{-3}) \times 10$

= 0.5 cases

* The Sr-90 in the bone of the foetus is less than the maximum which occurs after the child is born when it is no longer protected by the placental barrier which discriminates against strontium to some extent. Foetal bone Sr-90 levels are close to the age weighted population average so that use of the adult bone dose commitment is justified.

A.2 Thyroid

(i) External Exposure

(a) Young children (4 years and younger)

Risk = 6×10^{-6} cases per year per rem

Dose commitment = 7.2×10^{-3} rem

Population at risk = 1.23×10^{6} (9.5% of population)

Period over which thyroid cancers may appear = 30 years

Number of cases = $(1.23 \times 10^{6}) \times (6 \times 10^{-6}) \times (7.2 \times 10^{-6}) \times 30$

$= 1.6$

(b) Others (over 4 years)

Risk = 2×10^{-6} cases per year per rem

Dose commitment = 7.2×10^{-3} rem

Population at risk = 11.77×10^{6}

Period over which thyroid cancers may appear = 30 years

Number of cases = $(11.77 \times 10^{6}) \times (2 \times 10^{-6}) \times (7.2 \times 10^{-3}) \times 30 = 5.1$

(ii) Internal Exposure

(a) Young children (4 years and younger)

Risk = 2×10^{-6} cases per year per rem

Dose commitment = 96×10^{-3} rem

Population at risk = 1.23×10^{6}

Period over which thyroid cancers may appear = 30 years

Number of cases = $(1.23 \times 10^{6}) \times (2 \times 10^{-6}) \times (96 \times 10^{-3}) \times 30$

$= 7.1$

(b) Others (over 4 years)

Risk = 1×10^{-6} cases per year per rem

Dose commitment = 9.6×10^{-3} rem*

Population at risk = 11.77×10^{6}

Period over which thyroid cancers may appear = 30 years

Number of cases = $(11.77 \times 10^{6}) \times (1 \times 10^{-6}) \times (9.6 \times 10^{-3}) \times 30 = 3.4$

* Thyroid dose to those of 5 years and over is taken as 1/10 dose to children; their milk intake is less and their thyroid mass is significantly larger. Adult doses will be at least an order of magnitude smaller than doses to babies less than a year old.

A.3 Other Forms of Cancers

(i) General Population

Risk = 5.5×10^{-6} cases per year per rem

Dose commitment = 7.2×10^{-3} rem

Population at risk = 13×10^{6}

Period over which cancer cases may appear = 30 years

Number of cases = $(13 \times 10^{6}) \times (5.5 \times 10^{-6}) \times (7.2 \times 10^{-3}) \times 30$

$= 15.5$

(ii) Foetus

Risk = 25×10^{-6} cases per year per rem

Dose commitment = 7.2×10^{-3} rem

Population at risk = 0.18×10^6

Period over which cancer cases may appear = 10 years

Number of cases = $(0.18 \times 10^6) \times (25 \times 10^{-6}) \times (7.2 \times 10^{-3}) \times 10$

= 0.3 cases

A.4 Total Number of Cancer Cases

Type of Cancer		Total Cases in 30 Years
Leukaemia	- general population	5.4
	foetal irradiation	0.5
Thyroid	- internal irradiation	10.5
	external irradiation	6.7
Other cancers	- general population	15.5
	foetal irradiation	0.3
TOTAL		39