3.29 We understand that airborne discharges are measured but are not at present covered by quantitative limits although the authorisation includes a 'best practicable means' clause designed to provide an ALARA-type restriction.

3.30 'Total alpha', 'total beta' and Iodine-131 discharges to the atmosphere from Sellafield since 1964 are shown in Figures 3.9, 3.10 and 3.11 respectively. The second reprocessing plant came into operation in 1964 (Table 3.1); discharges were not routinely determined as annual figures for earlier years although stack monitoring was used for control purposes. Atmospheric discharges were highest around 1970 with peak figures of 66 Ci for 'total beta' in 1969 and 0·44 curies for 'total alpha' in 1971. Discharge levels have been substantially reduced in subsequent years.

Figure 3.9 Total alpha discharges to atmosphere since 1964 (Figure supplied by BNFL)

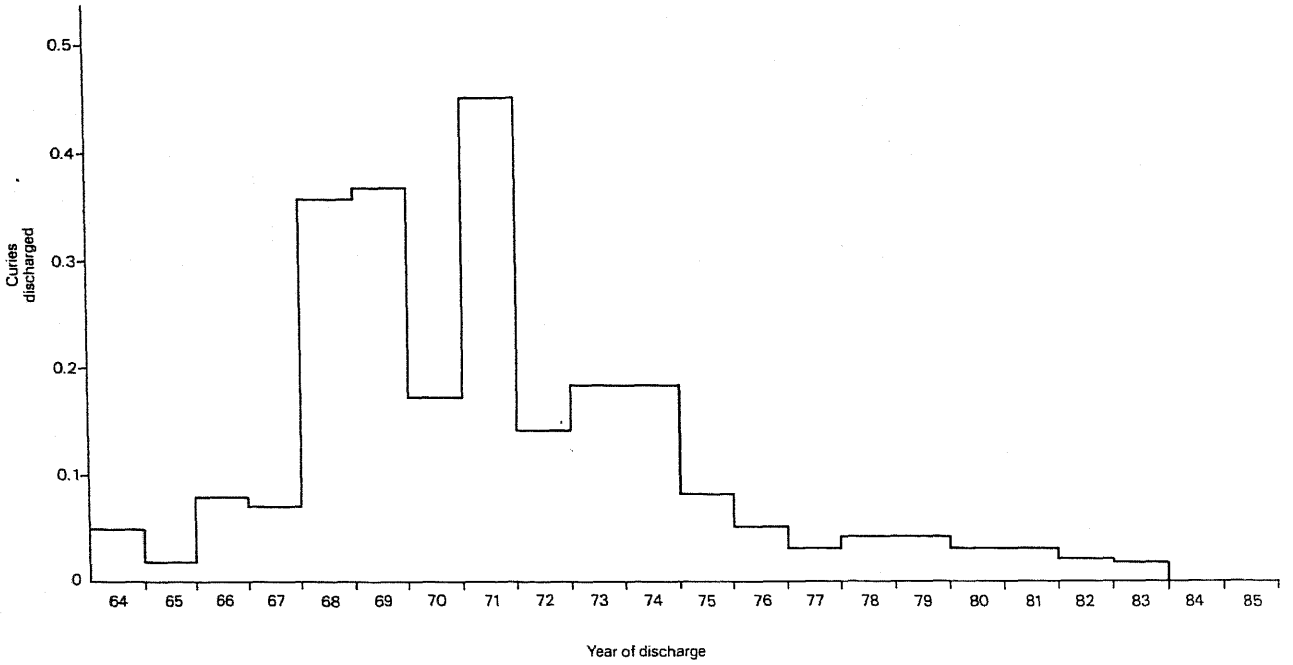
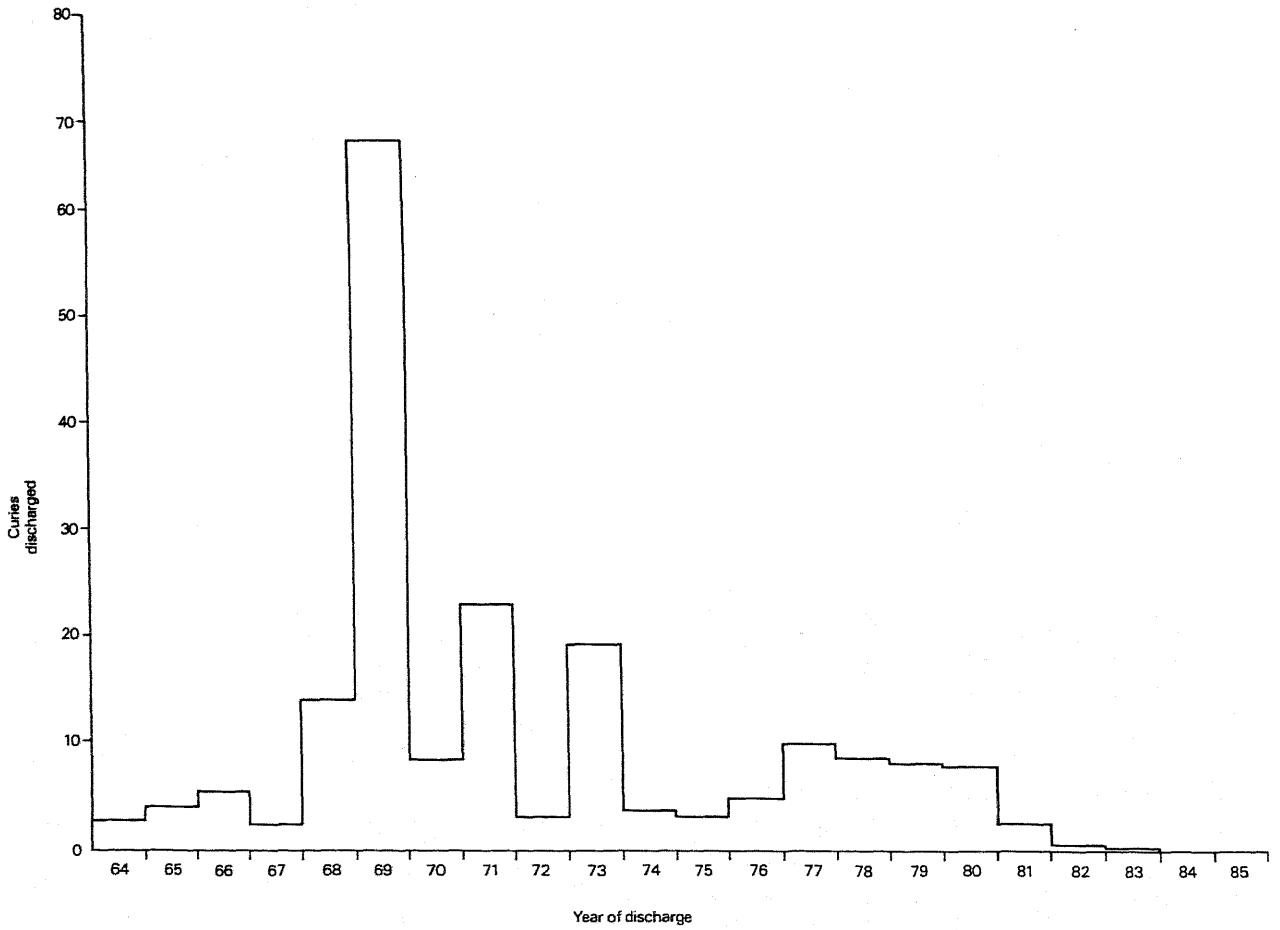


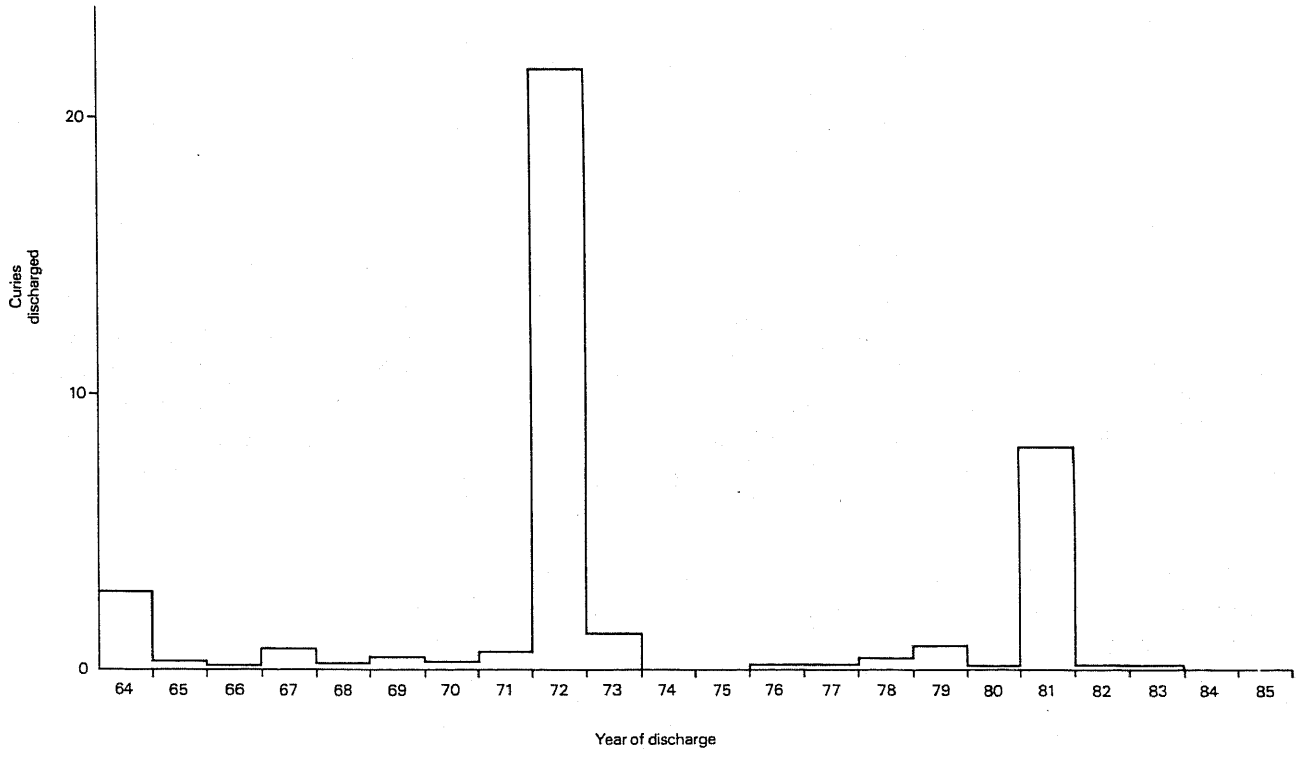
Figure 3.10 Total beta discharges to atmosphere since 1964 (Figure supplied by BNFL)



3.31 Discharges are monitored by BNFL and the results are reported to the authorising departments and published in annual reports. The consequential environmental effects are monitored by BNFL subject to the requirements of the Department of the Environment and the Ministry of Agriculture, Fisheries and Food who also carry out their own check monitoring on both the terrestrial and the marine environment. Both Government departments commission relevant research, and MAFF undertake habit surveys and define 'critical groups' for the different aquatic pathways. MAFF also publish an annual report on their marine monitoring results.

3.32 The Department of the Environment and MAFF are expected shortly to issue new authorisations for liquid discharges.

Figure 3.11 Discharges of Iodine-131 to atmosphere since 1964 (Figure supplied by BNFL)



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ANNEX TO CHAPTER 3

SOME OTHER ENVIRONMENTAL FACTORS IN WEST CUMBRIA

INTRODUCTION

A.3.1 Seascale is situated very close to the Sellafield Nuclear Site and its discharges, and radiation is a known cause of leukaemia. This does not necessarily mean that the incidence of leukaemia in the area is related to the discharges from Sellafield. We therefore sought information on other factors possibly relevant to cancer in the West Cumbrian area. We also considered the possibility that the interaction of several causes in the area might be relevant, rather than just one specific cause.

INDUSTRIAL SITES

A.3.2 It was more difficult to collect information on industrial sources of pollution than it had been to collect information on the Sellafield site. Local Factories Inspectorate records do not extend back beyond 10 years, and many of the industries had ceased to trade. We were unable to ascertain what had happened to their records. However in general West Cumbria is not and never has been a highly industrialised area and we found no special features that gave us cause for concern.

A.3.3 The two major industrial sites in the Sellafield area are BNFL, Sellafield and Allbright and Wilson (Marchon Works), Whitehaven. The Allbright and Wilson Chemical Works manufactures chemicals and intermediates. In the past there were several iron and steel works in the area, all of which have now closed, (Table A.3.1); there was also a tar factory at Lowca and several ordnance factories. We have been able to obtain details of present day discharges from only BNFL and Marchon Works.

Table A.3.1 Industry in Area around Sellafield

Type of Industry	Site	Activities	Source of Information	Closed
Iron & Steel	Millom Works	Sinter Plant Blast Furnace Oxygen Steel Process		1970
	Workington Works	Sinter Plant Blast Furnaces Coke Ovens Steel Making		1980
	Distington Engineering Company	Three Cold Blast Cupola		1980
Tar Factory	Lowca (1½ miles north of Whitehaven)		Health and Safety Inspectorate (Local Inspectorate no records)	Probably more than 10 years ago
Ordnance Factories	Sellafield		Ministry of Defence	c. 1945
	Drigg			c. 1945
Ordnance Factories	Distington (Now occupied by High Alloys Extensions Ltd.) Workington Subsequently taken over by British Steel Corporation)		Health and Safety Executive	

Industrial Discharges

A.3.4 *Marchon Works:* Details of liquid and atmospheric discharges were provided by Allbright & Wilson. Solvents used on site are efficiently reclaimed for economic reasons and therefore contribute little to the discharges. Effluent is discharged into Salton Bay at the mean low water mark.

A.3.5 *BNFL:* The major non-radioactive contaminants discharged into the environment are solvents used during nuclear reprocessing, such as tertiary butyl phosphates, odourless kerosene and Butex. Discharges preferentially occur around high tide and the pipe terminates 2·1 km out to sea from the low tide mark.

A.3.6 We found no evidence that these companies released significant quantities of potential chemical carcinogens into the West Cumbrian environment. It is probable that present day discharges into the sea around Sellafield differ substantially from those of 25 years ago. However MAFF told us that the level of pollution in the past is unlikely to have ever been as bad as in industrialised areas such as the Thames and Mersey estuaries.

Human Exposure to Industrial Discharges

A.3.7 The major route for human exposure is thought to be via consumption of seafood caught in the area. This area is not regarded by MAFF Fisheries Division as heavily polluted. MAFF have examined the effects of industrial discharges in the area on seafood, and apart from a small accumulation of cadmium in sediments, levels of pollution in marine organisms and sea water are not significant.

A.3.8 The levels of metals, organochlorines including polychlorinated biphenyls (PCBs) in fish and shellfish caught off the Cumbrian Coast, are similar to or lower than those in fish caught elsewhere around the British Isles, eg plaice caught in the area in 1981 contain up to 0·28 mg/kg mercury while plaice caught in Liverpool Bay area (an area with considerable marine pollution) contain 0·53 mg/kg of mercury; PCB levels in the livers of whiting caught in the Thames estuary are about 16 mg/kg while the level in the livers of plaice caught off the Cumbrian Coast contain 0·26 mg/kg. (MAFF, 1981).

A.3.9 The major effects of airborne pollutants relate to their eventual deposition on the ground and to their effects on plant life. Although it has been suggested that airborne industrial discharges may contribute to respiratory disease, there is no evidence for any connection with the induction of leukaemia.

A.3.10 The above survey is of necessity incomplete and significant discharges into the environment of other toxic chemicals in the past cannot be excluded. However the West Cumbrian coast is not a highly industrialised area, and we were not told of any unusual industrial activities in the past that might be expected to have posed a particular health hazard to the surrounding population.

WATER SUPPLIES*

A.3.11 Seascale's water supply came from Wastwater (which also supplied Ravenglass) between 1950–1975; from 1975 onwards its water supply has come from Ennerdale. Ennerdale, Wastwater and Crummock are lake supplies. Reservoirs are not very important in the area, and storage in service reservoirs is usually only for a few hours and is unlikely to give rise to contamination.

A.3.12 Wastwater is a natural lake whose catchment area contains extensive bracken stands. The catchment area includes Granophyre in Great Gable, and granite on the southern boundary. The rest of the catchment is underlain by Ordovician rocks including the Borrowdale volcanics. Screes and mixed superficial deposits occupy the valley slopes and bottom. Some haematite deposits are present in the upper part of the catchment area.

A.3.13 Ennerdale is also a natural lake with an extensively forested catchment area with some bracken stands on the lake margins. About 30% of the catchment area is underlain by Ennerdale Granophyre (microgranite). The remainder is made up of Skiddaw slates and Borrowdale volcanics. The valley floor above the lake is covered with a mixed suite of superficial deposits of glacial and recent origin. Haematite has been worked on the high ground to the south of the lake where vein-type deposits are found in the Granophyre. Ennerdale also supplies Whitehaven, Egremont, Arlecdon, Lamplugh and Frizington.

Possible Contaminants of Water Supplies

A.3.14 Possible contaminants of water in the context of this investigation are:—

i. radioactivity—see Chapter 4;

ii inorganic and organic chemicals such as metals, pesticides, polycyclic aromatic hydrocarbons, nitrate, nitrite and bracken carcinogen;

iii. bacteria and viruses.

* This data was provided largely by the North West Water Authority.

Inorganic and Organic Chemicals

A.3.15 The level of iron in water in the area is high due to the large quantities of iron ore in the area and the many haematite mines. There is no reason to believe this is a health hazard. The North West Water Authority informed us that they did not believe pesticide contamination of water to be significant in the area.

A.3.16 The catchment area supplying West Cumbria contains extensive areas of bracken fern (Pteridium aquilinum). Bracken fern can cause acute toxic symptoms in cattle by a direct radiomimetic effect on the haemopoietic tissues giving rise to haemorrhages, a low white blood cell and low platelet count (Pamekcu et al, 1967). More chronic exposure of cattle to bracken fern causes haematuria, and later benign and sometimes malignant bladder neoplasms (Pamekcu et al 1967, 1968, 1976, 1978). Feeding studies in rats have resulted in lymphopenia, thrombocytopenia and bone marrow suppression. Tumours were induced in the intestines, bladder and mammary glands (Schramm et al, 1970). In mice, leukaemia and pulmonary tumours have been induced (Pamakcu et al, 1972). There is some evidence that the carcinogen may be transmitted via milk (Evans et al, 1982).

A.3.17 Jarrett, (1982) has linked exposure to bracken fern to the induction of squamous cell carcinomas of the upper alimentary tract in cattle in the UK endemically infected with bovine papilloma virus.

A.3.18 Jarrett suggests that bracken fern carcinogen might act as either a promoter, inducer, mutagen or immunosuppressant in animals infected with papilloma virus. He has been able to demonstrate bovine alimentary papilloma virus DNA sequences in these squamous cell carcinomas (Campo et al 1980, Jarrett et al, 1981).

A.3.19 There is no convincing evidence for human exposure to or toxicity from bracken fern carcinogen. Seascale is only one of many areas in Cumbria whose water comes from bracken-infested hills, and we have seen in the work of Craft and Openshaw, (1984) that the electoral wards adjacent to Seascale do not have an elevated incidence of leukaemia.

BACTERIA AND VIRUSES

A.3.20 Of 19 water samples from Seascale tested in 1982 none contained an unsatisfactory level of coliforms (usually taken as an indicator of faecal contamination). No data were obtained on levels of viruses in water.

Human Viruses and Leukaemia

A.3.21 There is now a substantial body of scientific evidence concerning viruses that cause tumours in animals, and related human viruses have been implicated as aetiological agents in the induction of human cancer (Weiss, 1984a). In all cases virus infection alone appears insufficient for tumour induction and other contributory causes or co-factors such as malaria (in induction of Burkitt's lymphoma by Epstein-Barr virus), alcohol or aflatoxin (in the development of hepatocellular carcinoma following hepatitis B infection) and sunlight or inherited disorders (in the development of skin cancer from papilloma virus infection) are also necessary. New strains of human papilloma viruses (HPV-16, HPV-18) are strongly implicated in cervical cancer (Gissmann, 1984). So far there is no evidence to suggest that animal tumour viruses can cause tumours in humans.

A.3.22 Human adult T-cell leukaemia virus (HTLV-1 or ATLV) is the only human virus that has been implicated in human leukaemia to date. This is a retrovirus which induces an aggressive variant of mature T-cell leukaemia. HTLV-1 has so far been identified as occurring mainly in South West Japan, in the Caribbean basin, in Central America, and in Africa (Gallo, 1984). A related virus, HTLV-2, has been isolated from one adult patient with hairy cell leukaemia. The natural mode of transmission of these agents has not yet been established. More recently a new virus, LAV or HTLV-3, has been identified as the probable cause of Acquired Immune Deficiency Syndrome (AIDS) (Weiss, 1984b). HTLV-1 and HTLV-2 have not been detected in any cases of childhood leukaemia, but the AIDS retrovirus does affect infants of infected mothers.

A.3.23 Until 4 years ago, no human oncogenic retroviruses were known. In the last 4 years 3 such viruses have been discovered; there may well be more remaining to be discovered and there is no reason to believe any such viruses would exclusively affect adults.

A.3.24 Several authors have reported that *in utero* exposure of the foetus to virus infections contracted by the mother may be followed by cancer in the children. In 1958, Stewart et al reported an association between viral infections of pregnant women and the development of cancer in children born of the pregnancies. In 1972, Fredrick and Alberman reported that a follow-up study of maternal illness in pregnancy had demonstrated a large excess of leukaemia in infants whose mothers had reported an attack of influenza during pregnancy. The study was based on 16,750 infants born in one week in March 1958, who had survived the neonatal period. The mothers of 12% reported having influenza during the 1957–58 pandemic; 8 of these developed cancer, a five-fold increase when compared to the other children; 6 were diagnosed as suffering from leukaemia. Subsequently there have been a number of studies producing conflicting results (Hakulinen et al, (1973); Randolph and Heath, (1974); Mackenzie and Houghton, (1974); Curnew and Varma, (1974); Austin et al, (1975). Similar reports of cancer, especially leukaemia, following varicella infection in the mothers during the relevant pregnancy have been published (Adelstein and Donovan 1972).

A.3.25 In summary, therefore, there is no known human leukaemia virus that could be postulated as contributing to the observed excess leukaemia incidence in young people near Sellafield. Research in this area is very active at present, and further developments will no doubt occur rapidly. The available evidence would suggest that any virus that played a part in leukaemia induction would do so in a multifactorial manner, rather than acting in isolation; the tumour viruses so far described generally being widespread in any population and only causing malignancy as a late and rare consequence of infection, following some other additional environmental agent. Any possible transplacental effect of virus infection during pregnancy is unlikely to give rise to more than a doubling in the overall cancer incidence in childhood.

COMBINED EFFECTS

A.3.26 The joint effects of chemical, physical and biological agents are of potentially great importance, but good quality scientific data on such effects are not readily available. UNSCEAR (1982) examined the evidence for combined action of ionising radiation and carcinogens, but found available data incomplete and evidence for a promotor effect conflicting. There is some evidence that tobacco smoke results in shortening of time to the appearance of lung cancer induced by the alpha particles of radon daughters.

The mode of action of this observed effect is as yet unclear. Evidence for synergism between radiation and viruses, bacteria, or diet is either equivocal or negative (UNSCEAR 1982) but the possibility cannot be excluded either in the context of the Sellafield discharges, or in the general context. However, the difference between the radiation dose calculated as being received by those living in the area around the Sellafield site and the dose received by the same people from background radiation is probably not sufficient to make a synergistic effect likely at Seascale or in Millom Rural District (see Chapter 4).

CONCLUSION

A.3.27 While it is possible to postulate agents that might act synergistically with radiation, we have found no convincing evidence for any unexpected environmental carcinogen or agent peculiar to the area around Sellafield.

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CHAPTER 4

RADIATION EXPOSURE OF YOUNG PEOPLE IN SEASCALE AND RECOMMENDATIONS

SUMMARY

4.1 The sources of radiation to which the general public around Sellafield are exposed are considered in turn, and the dose to the red bone marrow from each source is calculated for the under 20-year old population of Seascale. (It is irradiation of the red bone marrow that is responsible for radiation-induced leukaemia.) The contributions to this dose from low Linear Energy Transfer (LET) radiation (ie beta and gamma rays) and high LET radiation (ie alpha rays) are also calculated separately. (See Annex to this Chapter for a discussion of the biological significance of these different types of radiation.) Only the course of our argument is given here, the evidence upon which it is based is contained in this Chapter and in the three NRPB documents to be published at the same time as this Report (NRPB R170; R171; R172; 1984). The units for measuring radiation and its effects are defined in the Table at the end of the Glossary and are explained in the Glossary.

4.2 Table 4.3 summarises the calculated doses to the red bone marrow of the estimated 175 children born in Seascale in the five years from 1950 and resident there until 1970 (the 1950 cohort), from natural background, medical radiation and nuclear fallout. The total dose equivalent to the red bone marrow from low LET radiation is 26 mSv, while that from high LET radiation is 0·98 mSv. The total red bone marrow dose equivalent is therefore about 27 mSv. This figure is about average for radiation exposure from these sources in the United Kingdom.

4.3 Radiation is a known cause of leukaemia. Since we are all exposed to background radiation, it has been postulated that this radiation causes at least some of the leukaemias occurring in the UK. We do not know what proportion of the leukaemias are caused by background radiation, but it cannot be more than all of them. If it is assumed that all deaths from leukaemia in the UK are caused by background radiation then we can calculate that the 27 mSv exposure experienced by the 175 individuals in the 1950 cohort from all background sources excluding discharges from Sellafield whether accidental or planned, would be expected to have given rise to 0·1 deaths from leukaemia in the 20 years from 1950, based on the death rate from leukaemia in young people in England and Wales (paragraph 4.45).

4.4 The Seascale young people are exposed to additional radiation due to the discharges of radioactivity from Sellafield. The red bone marrow dose equivalent from the Sellafield site discharges for an individual in the 1950 cohort from 1950–1970 has been calculated as being 3·5 mSv, which is 13% of the dose equivalent calculated above as occurring from background radiation. This includes a dose equivalent of 0·8 mSv from the Windscale fire in 1957, (3% of the dose equivalent from background radiation) (paragraph 4.46).

4.5 Assuming a linear relationship between dose received and risk of death from leukaemia, this means that the dose received by the 1950 cohort from the Sellafield discharges would be expected to give rise to a maximum of 13% of 0·1 additional deaths from leukaemia, ie 0·013 cases. In their report, NRPB consider seven similar 5 year cohorts between 1945 and 1975 in Seascale. For these seven cohorts the expected risk of death from leukaemia from the discharges will be less than $0{\cdot}013 \times 7 = 0{\cdot}091$ additional deaths (paragraph 4.47). In fact we are aware of 4 deaths from leukaemia before the age of 20 years in Seascale since 1945 (cases 1, 3, 5 and 6, Table 2.1), while 0·5 deaths would be expected in the same population using OPCS figures for England and Wales. Therefore there are 3·5 additional deaths from leukaemia in Seascale. This is approximately 40 times more than can be calculated as likely to arise from exposure of the population to the radioactive discharges from the Sellafield site (paragraph 4.48).

4.6 In calculating the expected number of deaths from leukaemia in this way we are using actually observed levels of background, ie low dose-rate, radiation to give us the maximum possible risk factor, unless there is, in Seascale, an unusual concentration of highly susceptible children. We are, however, making the following assumptions:

a. that conclusions on quantities of food consumed derived from habit surveys and other sources are reasonably accurate (paragraph 4.59);

b. that the gut transfer factors for the actinides and other isotopes such as Ruthenium, which are believed to cross the gut wall poorly, are reasonably accurate (paragraph 4.60 et seq);

c. that the model used to calculate the dose to the red bone marrow is reasonably accurate (paragraph 4.76);

d. and that the contribution to exposure from unknown sources or from undetected accidents does not add up to 40 times the total dose calculated to be received by the population from the known discharges over the last 30 years.

4.7 With these qualifications the Sellafield discharges, including those from the Windscale fire and known accidents, are predicted to have resulted in less than 0.1 additional deaths from leukaemia in Seascale between 1945–1980 in the under 20 year old population.

4.8 There have been approximately 1,220 children born in Seascale since 1950. 0·1 additional deaths from leukaemia in 1,200 children would represent a risk of 1 in 12,000 over a period in excess of 20 years or approximately a 1 in 240,000 risk per annum, ie a chance of about 4 in a million of dying from leukaemia before the age of 20 years from living in Seascale each year for under 20 year olds.

INTRODUCTION

4.9 The sources of radiation to which the general population of West Cumbria are exposed are:

a. natural background

b. medical diagnostic and medical therapeutic procedures

c. fall-out from atmospheric testing of nuclear weapons

d. miscellaneous other sources

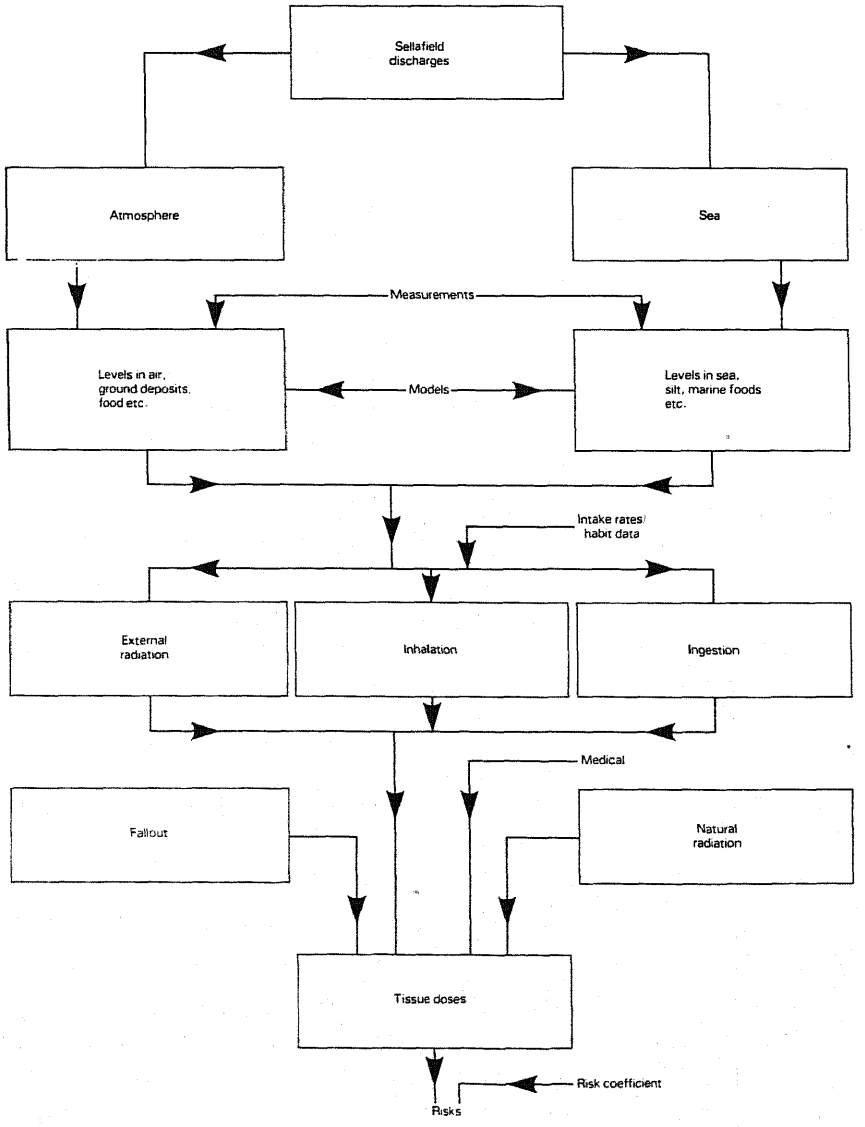
e. radioactive releases both to sea and to atmosphere from routine operations at nuclear sites in the country and as a consequence of accidents and incidents.

4.10 Those working at Sellafield or any other establishment where radioactive substances or ionising radiations are in the environment, or are used, may also be exposed as a consequence of their work.

4.11 There is no evidence that exposure from the first 4 causes is likely to be different in West Cumbria from in the rest of the United Kingdom, although there will be regional variations. However, because West Cumbria contains the Sellafield site, radiation exposure from the fifth source will differ from that in other parts of the United Kingdom.

4.12 Adults and children have rather different habits and consequently may have different exposures to radiation; much of the information generally available does not pay particular attention to childhood exposure. Since we are particularly interested in exposure in the under 25 age group, we asked NRPB to prepare a comprehensive review of radiation exposure in young people resident in Seascale, including *in utero* exposure, using the best available data and including exposure due to known accidents and to the Windscale fire in 1957. NRPB also critically reassessed possible routes of exposure as part of this study (NRPB R171, 1984). A diagram of their assessment procedure is shown in Figure 4.1.

Figure 4.1 Schematic diagram of assessment procedure



4.13 In this Chapter we shall consider the contribution to radiation dose from the 5 sources outlined above. We consider the low linear energy transfer (LET) (beta and gamma rays) and the high LET (alpha rays) component separately in each case, since the biological effect per unit absorbed dose differs for these 2 types of radiation by a variable factor depending on the rate at which the dose is received (see Annex to this Chapter). We consider the red bone marrow dose in particular, because this is the target organ for induction of leukaemia by radiation. Except where otherwise stated, doses given in this Chapter are quoted from the NRPB review (NRPB R171, 1984).

a. Background Radiation

4.14 Natural radiation pervades the whole environment, and it is helpful to consider the likely significance of any additional radiation exposure in this context. Radiation reaches the earth from outer space; the earth itself contains radioactive elements; and natural radioactivity is present in the food we eat and in some of the elements contained in our body.

4.15 Cosmic rays penetrate the atmosphere from space. The total dose from cosmic rays to all tissues of the body can be assessed as 300 μGy in a year at Seascale and this is almost all low LET radiation.

4.16 Terrestrial radionuclides include Potassium-40 and the radionuclides in the Uranium-238 and Thorium-232 series. All materials in the earth's crust contain these radionuclides and the population is continuously exposed externally to gamma radiation resulting from their decay, and internally to alpha, beta and gamma radiation from inhalation and ingestion routes.

4.17 Measurements of outdoor gamma ray dose rates have been made in West Cumbria. A mean of 42nGy per hour was obtained, which is only marginally above the national average. Gamma ray doses in dwellings in Seascale are not available, but 6 dwellings in the Cumbrian area have been monitored by NRPB and gave results very near to the national average of about 65 nGy per hour. Assuming average usage of indoors and outdoors, the average dose to Seascale residents can be assessed as 400 μGy per year from gamma rays from external terrestrial radionuclides.

4.18 Radon decay products in the atmosphere originate from the decay of Thorium-232 and Uranium-238. Radon is a gas and so can move through rocks, soils or building materials in which it is generated and be released from the surface. Out of doors, radon is soon dispersed in the atmosphere but indoors it can accumulate due to limited ventilation. Indoor concentrations vary widely depending on the ground the house stands on, the material the house is constructed of, and the degree of ventilation.

4.19 Radiation from radon decay products is predominantly high LET radiation and the dose is delivered almost entirely to the lung tissue. NRPB estimated that a dose of 420 μGy is received per year from this source.

4.20 Potassium-40 is the major source of internal low LET irradiation. This radionuclide is always present in natural Potassium. The average annual dose has been estimated as 270 μGy per year to red bone marrow. The other main contributors of dose from internal irradiation are Lead-210, Polonium-210 and Radium-226. These give about 2·3 μGy of high LET radiation to the red bone marrow per year (NRPB R171, 1984; Table 8.5.c).

Dose to red bone marrow from natural background radiation in 20 years for Seascale young people

4.21 In their report, NRPB calculate the doses of high and low LET radiation from natural backgound to red bone marrow for individuals in 7 cohorts of children born in Seascale at 5 yearly intervals from 1945–1975 and assumed to be living in Seascale since birth. An estimate of the *in utero* contribution is also included. Table 4.1 shows that the total dose to red bone marrow from natural background for the 1950 cohort up to 1970 is 47·5 μGy of high LET radiation and 20,000 μGy of low LET radiation. High LET radiation therefore contributes 0·2% of the total absorbed dose to red bone marrow from natural background.

Table 4.1 Radiation dose to red bone marrow from natural background from 1950–1970 for an individual in a cohort of those born in Seascale in 1950 and resident in Seascale until 1970.

Radionuclide[+]	High LET dose (μGy)	High LET dose equivalent (μSv*)	Low LET dose (μGy)	Low LET dose equivalent (μSv*)
Pb–210	29	580	18	18
Po–210	5·5	110	$4{\cdot}4 \times 10^{-6}$	$4{\cdot}4 \times 10^{-6}$
Ra–226	13	260	2·2	2·2
Gamma Emitters	—	—	$2{\cdot}0 \times 10^{4}$	$2{\cdot}0 \times 10^{4}$
Total	47·5 (0·2% of total)	950 (5% of total)	$2{\cdot}0 \times 10^{4}$ (99·8% of total)	$2{\cdot}0 \times 10^{4}$ (95% of total)

*Quality Factor=20 for high LET radiation
Quality Factor=1 for low LET radiation
For explanation of high and low LET radiation see Annex to Chapter 4) (page 84).
[+]See Table 4.11 for key for abbreviations for radionuclides (page 83)
Total dose to red bone marrow=$2{\cdot}1 \times 10^{4}$ μSv (21 mSv)

(From NRPB R 171, 1984; Table 8.5c)

b. Medical Irradiation

4.22 Medical irradiation includes doses from diagnostic X-rays and radioisotopes and radiotherapy with X- or gamma rays. For the average individual the largest artificial exposure is derived from these sources, and within this, diagnostic X-ray examinations are responsible for the major part of medical exposure. A large proportion of the population are not exposed to radiation from this source each year, and certain individuals may receive several times the average dose from this source. In a Swedish study an X-ray of lungs and heart was reported to give an average whole body dose of 0·57 mGy (57 mrad), a bone marrow dose of 0·54 mGy (54 mrad), and a thyroid dose of 0·24 mGy (24 mrad). A retrograde pyelogram (involving screening over a period of time rather than a single exposure) is estimated as giving 10 mGy (1,000 mrad) whole body dose (UNSCEAR, 1978) which is twice the ICRP recommended limit for annual exposure to the public from sources other than background and medical sources. These doses are justifiable because the potential benefit of reaching a correct diagnosis greatly outweighs the risk from the radiation exposure.

4.23 There are no data available on frequency of radiological examinations in West Cumbria, but equally there are no reasons to suppose an unusual pattern in the area, and the 1977 survey of diagnostic radiology practices in Great Britain found the number of X-ray examinations per head of population in the Nothern Regional Health Authority to be within 10 per cent of that for Britain as a whole.

4.24 Annual mean red bone marrow doses from diagnostic radiology practices in the UK were estimated in 1957/8 by a Committee under the chairmanship of Lord Adrian (1966) and a new study is currently underway. The NRPB report calculated the average radiation dose up to 1970 from medical exposure for individuals born in 1950 as $3{\cdot}9 \times 10^3$ μGy. This will all be from low LET radiation and includes a component for foetal exposure (NRPB R171, 1984; Table 8.4).

c. Nuclear weapon fallout

4.25 This has contributed to background exposure since the late 1940's. The periods of most intensive atmospheric testing were 1955–58 and 1961–62. The main constituents of nuclear fallout are fission products such as Strontium-90, Caesium-137, Cerium-144, Strontium-89, Ruthenium-106, Zirconium-95 and Iodine-131. Those components of fallout which are particulate tend to deposit in any region in proportion to the rainfall in the area.

4.26 The external gamma dose from ground deposited material from fallout is mainly due to Caesium-137 and Zirconium-95. The annual absorbed dose rate in air at 1 metre above ground has been measured at Chilton in Oxfordshire since 1951. The average annual rainfall in the Sellafield area is about twice that at Chilton and the dose rates from this source can be estimated from the Chilton figures by scaling for this factor. Allowance also has to be made for shielding by buildings and for time spent indoors. NRPB calculate a total dose of 420 μGy red bone marrow from this source for a 20 year old living since birth in 1950 in Seascale (NRPB R171, 1984; Table 8.3c).

4.27 The concentrations of radionuclides in milk and other foodstuffs in the UK have been measured by the Agricultural Research Council Laboratories at Wantage, Oxfordshire since 1958, and by NRPB since 1978. The concentrations of the more important radionuclides in air and rain have been measured since 1954 by the Atomic Energy Research Establishment (AERE) at Harwell, and since 1975 by NRPB.

4.28 Strontium-90 tends to become fixed in soil and very little reaches drinking water supplies. The main dietary sources are dairy produce, flour and cereals. Milk can be used as an indicator of total dietary intake of Strontium-90.

4.29 The major exposure pathway for Caesium-137 is through diet, and milk is a good indicator of dietary levels. Caesium-137 levels in milk have been measured since 1961.

4.30 Iodine-131 has a half-life of only 8 days and therefore only its concentration in milk is important. It has been assayed in milk since 1961, but levels have been below the limit of detection except for in 1961–62 and 1976–77.

4.31 Plutonium-239, -240, and -238 in fallout have been measured by AERE, Harwell since 1961 and NRPB since 1975. There appears to be little variation with rainfall.

Summary of contribution of Fallout to Background Radiation

4.32 Table 4.2 summarises the red bone marrow dose calculated by NRPB for a 20 year-old resident in Seascale born in 1950 using best available estimates. 1.7 μGy of high LET and 2,200 μGy of low LET radiation is received by an individual by the age of 20 from fallout.

Table 4.2 Radiation dose to red bone marrow from nuclear fallout from 1950–1970 for an individual in a cohort of those born in Seascale in 1950 and resident in Seascale until 1970.

Radionuclide[+]	High LET dose (μGy)	High LET dose equivalent (μSv*)	Low LET dose (μGy)	Low LET dose equivalent (μSv*)
Sr-90			$7{\cdot}3 \times 10^{2}$	$7{\cdot}3 \times 10^{2}$
Ru-106			1·9	1·9
Cs-137			$6{\cdot}7 \times 10^{2}$	$6{\cdot}7 \times 10^{2}$
Ce-144			34	34
Pu-238	$1{\cdot}7 \times 10^{-1}$	3·4	$3{\cdot}5 \times 10^{-4}$	$3{\cdot}5 \times 10^{-4}$
Pu-239	1·6	32	$2{\cdot}2 \times 10^{-3}$	$2{\cdot}2 \times 10^{-3}$
I-131			$1{\cdot}7 \times 10^{-1}$	$1{\cdot}7 \times 10^{-1}$
Sr-89			$2{\cdot}4 \times 10^{2}$	$2{\cdot}4 \times 10^{2}$
C-14			71	71
H-3			6·7	6·7
External			$4{\cdot}2 \times 10^{2}$	$4{\cdot}2 \times 10^{2}$
Total	1·7 (0·1% of total)	35·4 (2% of total)	$2{\cdot}2 \times 10^{3}$ (99·9% of total)	$2{\cdot}2 \times 10^{3}$ (98% of total)

Total Dose to red bone marrow=$2{\cdot}2 \times 10^{3}$ μSv=2·2 mSv

*Quality Factor for High LET radiation=20
Quality Factor for Low LET radiation=1
For definition of High and Low LET radiation see Annex to Chapter 4
[+]See Table 4.11 for key to abbreviations for radionuclides (page 83)

(from NRPB R171, 1984; Table 8.3c)

d. Miscellaneous other sources

4.33 These include such things as the luminous dials of watches painted with radium. Their contribution to red bone marrow doses is insignificant.

SUMMARY OF RADIATION EXPOSURE EXCLUDING THAT FROM SELLAFIELD DISCHARGES

4.34 Radiation exposure of the population in Seascale and adjacent areas from sources apart from nuclear site discharges is likely to be similar to that in the rest of the country. Although there are deficiencies in the data for this part of the country, none of the available evidence suggests that the population is exposed to unusually high levels of radiation from the above sources.

4.35 The total red bone marrow dose to individuals in the 1950 cohort living in Seascale from the above sources is estimated by NRPB to be 48·7 μGy from high LET radiation and 26,100 μGy from low LET radiation (Table 4.3). Therefore 99·8% of the absorbed dose to red bone marrow from the above sources derives from low LET radiation and 0·2% from high LET radiation.

Table 4.3 Radiation dose to red bone marrow from all background sources from 1950–1970 for an individual in a cohort of those born in Seascale in 1950 and resident in Seascale until 1970.

Source	High LET dose (μGy)	High LET dose equivalent (μSv*)	Low LET dose (μGy)	Low LET dose equivalent (μSv*)
Natural Background	47	950	20×10^{3}	20×10^{3}
Nuclear Fallout	1·7	35·4	$2{\cdot}2 \times 10^{3}$	$2{\cdot}2 \times 10^{3}$
Medical Radiation	—	—	$3{\cdot}9 \times 10^{3}$	$3{\cdot}9 \times 10^{3}$
Total	48·7 (0·2% of total)	985·4 (4% of total)	$26{\cdot}1 \times 10^{3}$ (99·8% of total)	$26{\cdot}1 \times 10^{3}$ (96·0% of total)

Total radiation from background sources=$27{\cdot}085 \times 10^{3}$ μSv
=27 mSv

*Quality Factor=20 for High LET radiation
Quality Factor=1 for Low LET radiation
(See Annex to Chapter 4 for explanation of high and low LET radiation)

Risk estimates from population exposure to radiation

4.36 The main late somatic effect of radiation in man is cancer. Usually no clinical distinction can be made between cancers induced by radiation and those occuring from other causes. There are considerable uncertainties regarding the radiation doses to human populations in which excess leukaemia rates have been observed subsequent to radiation exposure.

Risk of leukaemia following radiation of the parent prior to conception

4.37 The incidence of leukaemia in children of Japanese survivors conceived after the atom bombs were dropped has not demonstrated an excess risk of leukaemia (see NRPB R171, 1984; Tables 7.4 and 7.5), whether one or both parents were exposed in either city. These data would suggest that the risk of leukaemia arising in children from gonadal irradiation of the parents is small.

4.38 At present there is no convincing evidence that establishes such a mechanism for cancer induction in man although only limited data is available.

Risks of leukaemia following irradiation in utero

4.39 Risk estimates by UNSCEAR are based on data from Stewart and Kneale (1970a, 1970b) and others, (NRPB R171, 1984; Chapter 7 paragraphs 7.2.3 and 7.3.7). The UNSCEAR estimate is $2{\cdot}3\times10^{-3}$ cancer deaths induced/year/gray of radiation exposure, for doses to the foetus in the range of 0·002–0·2 Gy; the cancers occurring over a 10 year period. Leukaemias would be expected to contribute about half of the cases. Monson and MacMahon (1984) in their study of children in the United States receiving pre-natal diagnostic X-rays, demonstrated an excess incidence of cancers in the 0–5 years from birth; a declining incidence of excess cancer from 6–9 years from birth and no excess of cancers after 9 years. The tot risk of developing a fatal induced malignancy from *in utero* exposure to lo LET radiation may therefore be in the region of $2{\cdot}0–2{\cdot}5\times10^{-2}$/Gy exposure to the foetus with a risk of death from developing leukaemia o $1{\cdot}0–1{\cdot}25\times10^{-2}$/Gy of exposure to the foetus. For their report NRPB assumed a total risk of death from leukaemia of $1{\cdot}25\times10^{-2}$/Gy from *in utero* irradiation, which is at the upper end of the range of values recommended by UNSCEAR (1972), and assumed that the deaths would be expressed within 9 years of birth with no latent period: 36% would appear in the first 3 years, 40% in the next 3 years and the remainder in the last 3 years. These figures apply to low LET radiation. NRPB used a relative biological effectiveness (RBE) factor of 20 to calculate risks from high LET radiation, (See Annex to this Chapter).

Risk of leukaemia in children up to age 10 years

4.40 Beebe et al (1978) reported that the incidence of leukaemia in the survivors under age 10 at the time the bombs were dropped on Hiroshima and Nagasaki was about 50% greater than that in the rest of the exposed population. The Hiroshima and Nagasaki data were not collected until 5 years after the bombs were dropped, and therefore cases dying during these first 5 years may not be included in the study. In their calculations NRPB have assumed that the period of risk is 15 years with half the cases occurring in the first five years.

Leukaemia in young persons and adults

4.41 Based on data from ankylosing spondylitis patients (Smith and Doll, 1982) and the incomplete Hiroshima and Nagasaki data (Beebe et al, 1978) NPRB assumed that the total risk of leukaemia induced by exposure to low LET radiation is $3{\cdot}5\times10^{-3}$/Gy with 50% of cases appearing in the first 7 years, with no latent period, 33% in the next 7 years and the remainder in a final 7 year period.

4.42 The only evidence covering the entire potential induction period on leukaemia induction by high LET radiation alone is from Thorotrast used as a contrast medium in diagnostic radiology in the past. Data on the induction of lung and bone cancer in animals and on bone cancer in man suggest that an RBE of 20 is reasonable for doses of about 0·1 Gy (low LET) upwards. The probable increase in the RBE for high LET radiation at low doses and low dose rates is likely to arise not because the risks of high LET radiation are greater, but because the risks of low LET radiation, whatever their value, are smaller (see Annex to this Chapter).

4.43 In summary, for calculating the risks from natural background radiation, medical radiation and Sellafield discharges, NRPB used a risk factor for deaths from leukaemia by radiation of $1{\cdot}25 \times 10^{-2}$/Gy for irradiation *in utero*; 5×10^{-3}/Gy at ages 0–9 years, and $3{\cdot}5 \times 10^{-3}$/Gy for ages 10 years and over for low LET exposure (Table 4.4). They used a relative biological effectiveness factor of 20 for calculating effects from high LET radiation.

Table 4.4 Risk estimates* for radiation-induced leukaemia

Age (in years)	Risk Estimate* (Low LET radiation)	Source
In Utero	$1{\cdot}25 \times 10^{-2}$/gray	Upper limit of UNSCEAR
0–10	5×10^{-3}/gray	NRPB
10+	$3{\cdot}5 \times 10^{-3}$/gray	NRPB
in utero + 0–20	$2{\cdot}28 \times 10^{-2}$/gray	Comparison with background

*Number of radiation-induced leukaemias expected per gray of radiation exposure

Risk Factor Limits

4.44 All of the above estimates can be criticised on the grounds that they are based on acute exposure rather than chronic exposure to radiation, and on dose values concerning which there is at least some uncertainty. The upper limit for the risk factor for death from leukaemia in those up to the age of 20 can be found if one postulates that all deaths from childhood leukaemia in England and Wales up to the age of 20 years are caused by the red bone marrow dose from background radiation either *in utero* or post-natally. This is an unlikely "worst-case" postulate, Stewart and Kneale calculated that 70% of childhood cancer was the greatest proportion likely to be due to natural background, extrapolating from their work on diagnostic X-ray exposure *in utero*, (Stewart and Kneale, 1983). The advantage of this method is that the upper limit risk factor thus obtained will apply to doses and dose rates that are of similar size to the doses received from background radiation and of similar size to the doses calculated as received from the discharges from the Sellafield site.

4.45 NRPB have calculated the mortality from leukaemia expected to occur during the first 20 years, in any cohort of 175 children born in England and Wales in 1950–55 and therefore comparable to the Seascale '1950 cohort'. Approximately 0·1 cases of leukaemia would be expected (NRPB R171, 1984; Table A1). 0·5 cases would be expected from 7 cohorts (1,225 children) starting in 1945 in five year periods and calculating the risk until the age of 20 or until 1980, whichever occurs first, again to form a group comparable to the 7 Seascale cohorts. Using the postulate that all childhood leukaemias in England and Wales are caused by background radiation and the estimate of the dose received from all background radiation in Table 4.3 an estimate of a risk factor of approximately 2×10^{-2}/Gy for the induction of leukaemia by radiation can be obtained. This is about 4–6 times the risk estimate NRPB

used for exposure to radiation in childhood, and slightly less than twice the risk estimate NRPB used for exposure *in utero* (Table 4.4), in their review (NRPB R171, 1984; Chapter 7). It is therefore about 5 times more conservative over the 20 year period than the NRPB risk estimate of leukaemia deaths from radiation.

4.46 Seascale young people are exposed to additional radiation due to the discharges of radioactivity from the Sellafield site, both planned and accidental. The NRPB have reassessed the doses received by the young people of Seascale from these sources in Chapters 4 and 8 of their report, (NRPB R171, 1984). The doses to the red bone marrow from routine and accidental Sellafield discharges are shown in Table 4.5 and the doses to red bone marrow from the Windscale fire in Table 4.6, the way that these dose estimates are obtained is explained in detail in paragraphs 4.49–4.62. The red bone marrow dose from the Sellafield discharges for individuals in the 1950–1970 cohort is calculated to be 3·7 μGy high LET and 2,600 μGy low LET radiation, while that from the Windscale fire is 13·9 μGy high LET and 560 μGy low LET radiation. The total dose equivalent (allowing for the differing biological effectiveness of the two types of radiation) to the red bone marrow from Sellafield activities (Tables 4.5 and 4.6) is therefore 2·7 + 0·8=3·5 mSv. This is 13% of the dose equivalent from background sources.

Table 4.5 Radiation dose to red bone marrow from Sellafield discharges and accidental releases (excluding Windscale fire) from 1950–1970 for an individual in a cohort of those born in Seascale in 1950 and resident in Seascale until 1970.

Radionuclide[+]	High LET dose (μGy)	High LET dose equivalent (μSv*)	Low LET dose (μGy)	Low LET dose equivalent (μSv*)
Sr- 90			$3{\cdot}2 \times 10^{2}$	$3{\cdot}2 \times 10^{2}$
Zr- 95			1·9	1·9
Nb- 95			$4{\cdot}9 \times 10^{1}$	$4{\cdot}9 \times 10^{1}$
Ru-106			$1{\cdot}4 \times 10^{2}$	$1{\cdot}4 \times 10^{2}$
Cs-134			$1{\cdot}4 \times 10^{2}$	$1{\cdot}4 \times 10^{2}$
Cs-137			$3{\cdot}2 \times 10^{2}$	$3{\cdot}2 \times 10^{2}$
Ce-144			$4{\cdot}5 \times 10^{-1}$	$4{\cdot}5 \times 10^{-1}$
Pu-238	0·0	0·0	0·0	0·0
Pu-239	2·7	54	$3{\cdot}8 \times 10^{-3}$	$3{\cdot}8 \times 10^{-3}$
Pu-241	$7{\cdot}8 \times 10^{-2}$	1·56	$2{\cdot}5 \times 10^{-2}$	$2{\cdot}5 \times 10^{-2}$
Am-241	$9{\cdot}1 \times 10^{-1}$	18·2	$1{\cdot}5 \times 10^{-2}$	$1{\cdot}5 \times 10^{-2}$
I-131			$5{\cdot}6 \times 10^{-1}$	$5{\cdot}6 \times 10^{-1}$
I-129			$5{\cdot}0 \times 10^{-3}$	$5{\cdot}0 \times 10^{-3}$
S- 35			1·2	1·2
External			$1{\cdot}7 \times 10^{3}$	$1{\cdot}7 \times 10^{3}$
Total	3·7 (0·1% of total)	73·76 (3% of total)	$2{\cdot}6 \times 10^{3}$ (99·9% of total)	$2{\cdot}6 \times 10^{3}$ (97% of total)

Total dose from Sellafield discharges=2·7 mSv

*Quality factor for high LET radiation=20
Quality factor for low LET radiation=1

[+]See Table 4.11 for key to abbreviations for radionuclides (page 83)

(From NRPB R171, 1984; Table 8.1c)

Table 4.6 Radiation dose to red bone marrow from Windscale fire from 1950–1970 for an individual in a cohort of those born in Seascale in 1950 and resident in Seascale until 1970.

Radionuclide[+]	High LET dose (μGy)	High LET dose equivalent (μSv*)	Low LET dose (μGy)	Low LET dose equivalent (μSv*)
Ru-106			2·4	2·4
Cs-137			$1{\cdot}2 \times 10^{2}$	$1{\cdot}2 \times 10^{2}$
Ce-144			$1{\cdot}6 \times 10^{1}$	$1{\cdot}6 \times 10^{1}$
Pu-239	3·9	78	$5{\cdot}4 \times 10^{-3}$	$5{\cdot}4 \times 10^{-3}$
I-131			7·5	7·5
Po-210	10	200	$1{\cdot}0 \times 10^{-5}$	$1{\cdot}0 \times 10^{-5}$
Te-132			$4{\cdot}0 \times 10^{1}$	$4{\cdot}0 \times 10^{1}$
External			$3{\cdot}7 \times 10^{2}$	$3{\cdot}7 \times 10^{2}$
Total	13·9 (2·4% of total)	278 (33% of total)	$5{\cdot}6 \times 10^{2}$ (97·6% of total)	$5{\cdot}6 \times 10^{2}$ (67% of total)

Total dose to red bone marrow = 0·838 mSv

*Quality factor for high LET radiation = 20
Quality factor for low LET radiation = 1

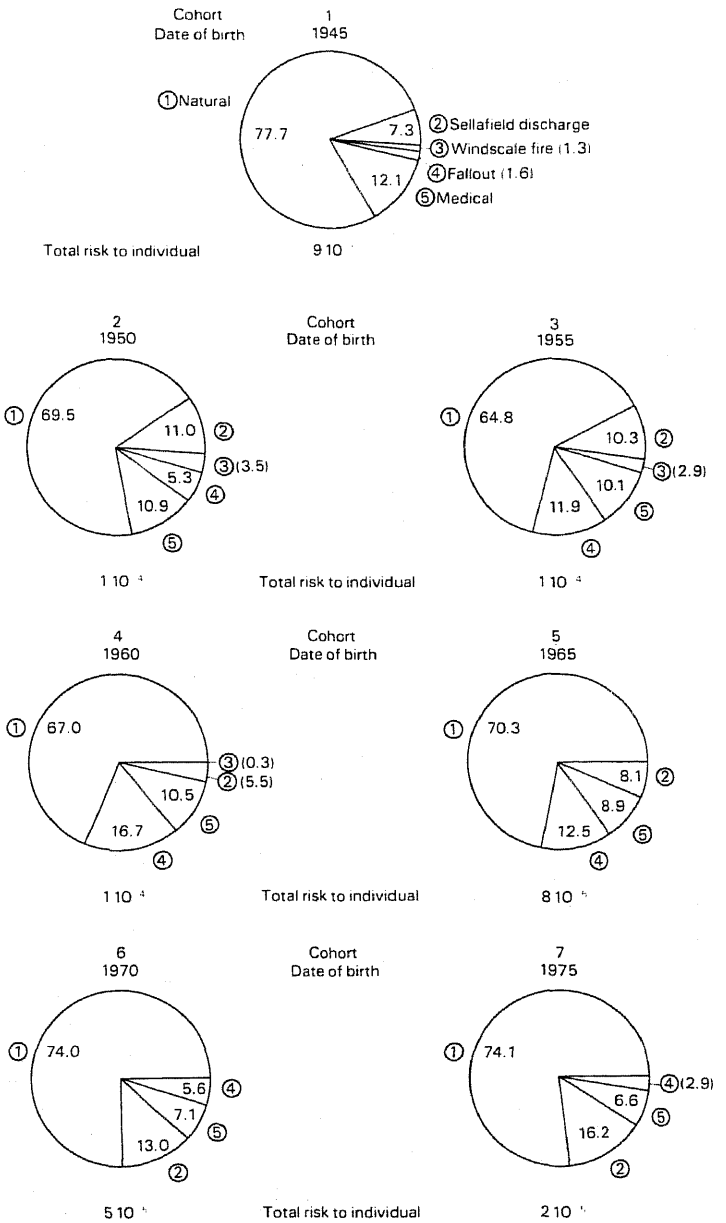
[+]See Table 4.11 for key to abbreviations for radionuclides (page 83)

(From NRPB R171, 1984; Table 8.2c)

4.47 It is generally assumed that the relationship between dose received and number of leukaemias or cancers induced is linear. However there is considerable evidence both from radiotherapy experience with patients and from animal and *in vitro* work that this assumption probably produces an over-estimate of the number of cases induced by radiation at low dose rates when low LET radiation is being considered, because repair of damaged DNA can occur to a greater extent at low dose rates. Nevertheless, if we assume a linear relationship, thus making a further 'worst-case' assumption, then the dose received by the 1950 cohort from the Sellafield discharges can be calculated to be expected to give rise to a maximum of 13% of 0·1 additional cases of leukaemia (see paragraph 4.45) or 0·013 cases. If one considers the entire Seascale population under 20 up to 1980 then the expected number of additional cases can be similarly calculated to be about $0{\cdot}013 \times 7 = 0{\cdot}091$ cases. (There are some simplifications in this calculation since the cohorts born after 1960 have not had 20 years exposure and therefore have a reduced risk of leukaemia. In addition the doses calculated as being received by the different cohorts varies (see Figure 4.2)).

4.48 Table 2.1 (page 13) lists 4 deaths under age 20 from leukaemia in Seascale since 1955 (cases 1, 3, 5 and 6). NRPB calculate that 0·5 deaths from leukaemia would be expected during this period (paragraph 4.45). If 3·5 mSv average exposure per person up to the age of 20 years is expected to give rise to 0·091 additional leukaemia deaths in a population of about 1,200 children, then for irradiation to cause the additional 3·5 deaths found in Seascale in the same number of children, 135 mSv or 39 times the calculated dose equivalent would have to have been received by every person 20 years old or less during their 20 years or less residence in Seascale since 1945 from all the discharges and accidents at Sellafield since the plant opened in 1952. *In summary, background radiation would be expected to cause 0·5 deaths from leukaemia; additional radiation exposure from the discharges would be expected to cause less than 0·1 deaths from leukaemia; in fact 4 deaths from leukaemia in under 20 year-olds were observed in Seascale during the period under consideration.*

Figure 4.2 Percentage contribution to risk of radiation-induced leukaemia to age 20 or 1980 (whichever is earlier) for each cohort



4.49 By calculating the expected number of cases of leukaemia from the maximum number that can be induced by natural background we avoid having to make any assumptions about risk factors for leukaemia mortality using high dose rate radiation since we are able to use background radiation as our standard and this is itself low dose-rate radiation.

4.50 It is very unlikely that the risk of dying from leukaemia due to the discharges is as high as has been calculated in paragraph 4.48 above. The largest risk factor for death from leukaemia used by UNSCEAR is about one half of the risk factor used above (see Table 4.4) and is only recommended for *in utero* exposure of the foetus; lower risk factors being recommended after birth. All the available evidence suggests that low dose rate low LET radiation is probably less effective than higher dose rate low LET radiation (paragraph 4.47). Finally, the assumption that the number of deaths expected in the 1950 cohort can simply be multiplied by 7 to give the number

of cases expected in the entire exposed population from 1945–1975 probably over-estimates the number of cases by a factor of 2. Taking all these factors into account there could be an additional safety factor of 10 involved and the actual additional dose required to produce the additional deaths from leukaemias at Seascale could in fact approach nearer to 400 times that calculated as being received by the young people.

4.51 We do need to consider carefully the assumptions made in arriving at our risk estimate to ensure that these assumptions do not significantly affect the calculation above (paragraphs 4.46–4.50). We shall do this in the following paragraphs.

4.52 High LET radiation is more biologically effective at low doses as compared with low LET radiation, probably because the cell is less able to repair high LET radiation (see Annex to this Chapter) and there are more uncertainties about its biological effects. Therefore if the contribution from high LET radiation were greater in the discharges than in background radiation this could be a source of error. In fact, background sources contribute 4% of the total biologically effective dose as high LET radiation (Table 4.3), an identical proportion to that contributed by the Sellafield discharges (Table 4.5). The high LET component from the Windscale fire is greater at 33% of the total (Table 4.6) and introduces a small amount of uncertainty, but the Windscale fire contributes less than 20% of the total dose from discharges to people in the 1950 cohort. This difference is unlikely to result in significant differences in the number of expected deaths calculated above.

Possible routes of exposure to the radioactive discharges

4.53 The routes of intake thought to give rise to the greatest dose to the population as a whole are:

Shore sand	—inhalation of suspended radionuclides in sand;
Seaspray	—inhalation of radionuclides associated with seaspray;
Fish	—ingestion of radionuclides;
Crustaceans	—ingestion of radionuclides;
Molluscs	—ingestion of radionuclides.

Less important routes from the routine discharges to sea, which apply to a few individuals with unusual habits only, or which lead to relatively small intakes for the population as a whole are:

Seawater	—inhalation of radionuclides during swimming;
	—inadvertant ingestion of radionuclides in water during swimming;
Shore, silt and sand	—inhalation of enhanced concentrations of radionuclides in air due to localised disturbances;
	—deliberate ingestion of silt or sand and associated radionuclides;
Seaweed	—ingestion of seaweed;
	—inadvertant ingestion or inhalation of material associated with seaweed;
Beach debris	—inadvertant ingestion or inhalation of material associated with beach debris.

Details of the assumptions and estimates made by NRPB in calculating the doses to red bone marrow are contained in the NRPB report, Chapter 4 and Chapter 9 (NRPB R171, 1984).

Atmospheric discharges

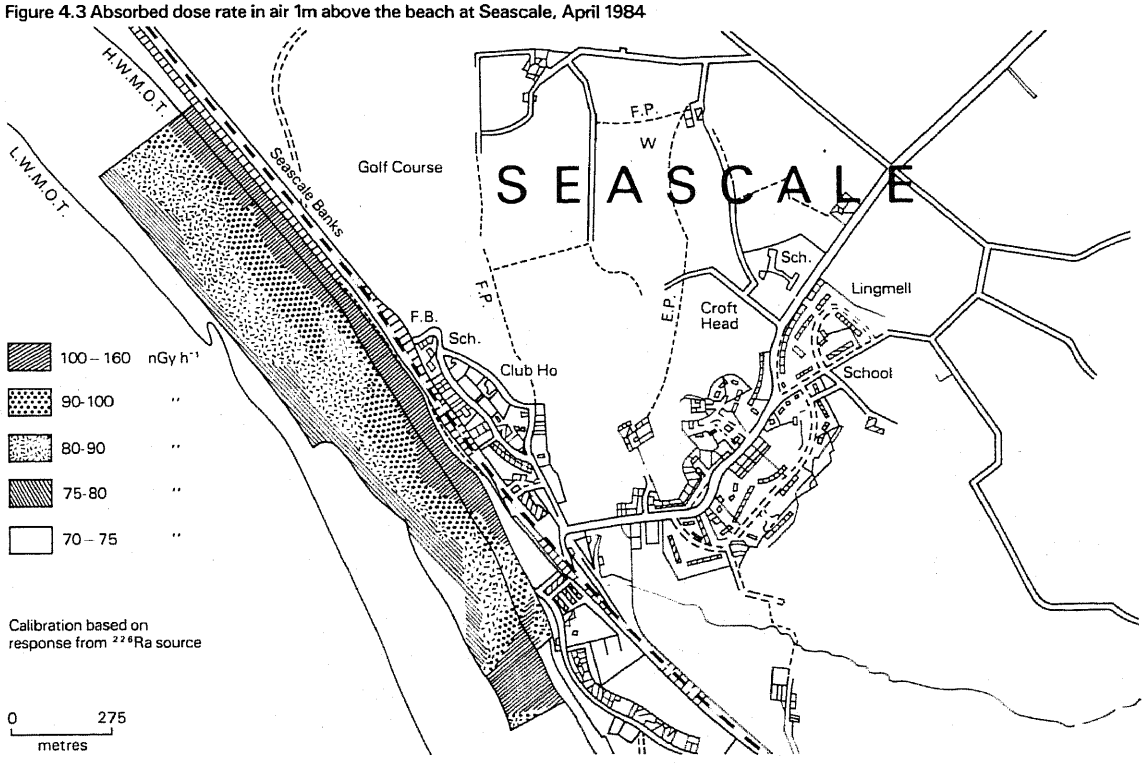
4.54 Atmospheric discharges are small in comparison to aqueous discharges (Figures 3.5–3.11, pages 47–53). Atmospheric discharges are dispersed and diluted in air as they travel downwind from the point of release, they are subsequently transferred through terrestrial food chains and inland water bodies such as reservoirs and rivers. Their contribution to marine levels of radioactivity is insignificant. Some monitoring of terrestrial food chains is carried out but this is not believed to be a significant pathway of exposure. For their dose estimations NRPB relied largely on models plus extrapolation from levels in milk which is subject to more intensive monitoring.

External doses

4.55 Radionuclides deposited on the ground and on the beaches will result in whole body absorbed doses from penetrating gamma radiation only. Beta and alpha rays are not sufficiently penetrating to contribute to this dose. Gamma ray doses have been measured at a number of locations in Cumbria by Cawse (NRPB R171, 1984), and the contribution of the Sellafield discharges to external doses from ground deposits is within geographical fluctuation of the natural gamma background radiation.

4.56 For their report NRPB did a more detailed gamma radiation survey of the beach at Seascale (Figure 4.3), which revealed that variation in levels across the beach is generally small and that the mean absorbed dose rate in air is 96 nGy/hr. Measurements were also undertaken at Drigg, and NRPB concluded that the gamma radiation dose at either beach does not vary significantly with location or activity on the beach.

Figure 4.3 Absorbed dose rate in air 1m above the beach at Seascale, April 1984



4.57 Doses to the population around the Sellafield site from the discharges of radiation into the sea and air are calculated from monitoring data on levels of the different radionuclides in the marine and terrestrial environments, carried out by BNFL, MAFF and the Department of the Environment. From this monitoring data predictions are made about the likely exposure of the population, based on a study of environmental pathways and on data from MAFF on local habits. The environmental monitoring programme has been modified over the years due to changes in the composition and magnitude of

liquid and atmospheric discharges and also due to changes in the habits of the population, making certain pathways more or less important as routes for population exposure. Since the 1970s other agencies have also monitored different aspects of the environment in West Cumbria (eg NRPB, UKAEA, Institute of Terrestrial Ecology). There is now available a considerable body of data on the exposure of the population around Sellafield resulting from on-site operations. It must also be pointed out, however, that although all monitoring information was made available to the Group from as far back as the start of operations in 1952, the quantity and quality of the monitoring data from the earlier years are necessarily less good than the more recent results. MAFF habit surveys for fish and shellfish consumption have included a particular consideration of children in the last few years. There are few measurements on crustacea before 1970 and detailed measurements on crustacea and molluscs, including actinide levels have only been carried out since 1977. The NRPB report details all these points, and considers how much uncertainty these unknown factors in earlier years introduce into the dose estimates (NRPB R171, 1984; Chapter 4).

4.58 NRPB in their report consider that their estimates of concentrations of radionuclides in marine foods are probably accurate to within a factor of about 5 in most cases, although they state that for some less important radionuclides in some foods the uncertainty may be as great as a factor of 10 (NRPB R171, 1984; Chapter 4).

Habit surveys and critical groups

4.59 MAFF conduct habit surveys to establish local food consumption patterns and routes of external exposure. Based on these surveys 'critical groups' are identified. These are small groups of people with an unusually high consumption of particular foods, or with lifestyles that involve unusually prolonged occupancy of the shoreline area. The doses received by these 'critical groups' is calculated to fall within the ICRP recommended limit of exposure for members of the public per annum (5 mSv). It should be emphasised that these 'critical groups' can consist of relatively few people. These members of 'critical groups' are important in enabling an assessment of the maximum dose received by any member of the population in the area to be made, but are not so relevant to any risk estimate since the majority of the population under consideration will receive doses considerably below those received by the 'critical groups' (generally below 10–20% of the 'critical group' dose). It is these average doses to the population that are most relevent to any risk estimate, and these average doses were used in the NRPB report in calculating doses to red bone marrow. NRPB consider the effects of the doses received by 'critical groups' in more detail in Chapter 9.3 of their review (NRPB R171, 1984). The only extreme behaviour that has a significant effect on doses received is excessive sea food consumption. NRPB calculate that a 10 year-old child in the 'critical group' for sea food consumption will receive a red bone marrow dose equivalent greater than the average dose equivalent by a factor of 30. However it should be stressed that the number of children receiving such an increased dose will be a very small proportion of the total child population, and would not significantly affect the risk estimate calculations above.

Transfer factors

4.60 Monitoring activities plus habit surveys result in estimates of consumption of radionuclides in food. These are converted into estimates of doses to the tissues, using metabolic and dosimetric models, mainly derived from animal studies.

4.61 At the present time the main internationally recognised source of information on metabolic and dosimetric models for use in estimating radiation doses resulting from the intake of radionuclides are the recommendations contained in ICRP Publication 30, 'Limits for Intakes of Radionuclides

by Workers'. The dosimetric models and metabolic data given in ICRP Publication 30 are intended for calculating Annual Limits of Intake (ALIs) for occupationally exposed adult workers, and are based on the behaviour in the body of chemical forms likely to be encountered in the workplace (mostly inorganic forms). There are difficulties in using these models for estimating doses to members of the public because of age-related variations in metabolic behaviour, organ size and separation and physiological parameters, as well as because of possible differences in the metabolic handling of radionuclides found in the environment compared to those in the workplace.

4.62 The NRPB have developed a methodology for the evaluation of doses to members of the public which takes account of changes in dose per unit intake with age as a result of growth of the body and body organs and for their separation, but metabolic behaviour is usually assumed to be the same as for the adult.

4.63 Some consideration has also been given to differences in metabolic transfer rates due to the physico-chemical forms of radionuclides which may be present in the environment, and revised values have recently been recommended for the gut transfer factor for the ingestion of organic forms of Plutonium associated with foodstuffs (0·05% transfer factor as opposed to the previously recommended 0·01% transfer factor). Further uncertainties are introduced here when young people are being considered. The gut wall is known to be more permeable to large molecules during the first few months of life prior to weaning, when maternal antibodies are absorbed from ingested milk. Animal feeding studies have confirmed that the neo-natal transfer factor for Plutonium species is around 100 times greater than that fc adults, although it declines to adult values quite soon after weaning. Ther are no human data on such transfer factors in neo-nates. The enhance values, which might be valid for infants on a milk diet in the first few weeks oi life were not used to calculate doses to children as they are weaned onto a solid food diet after a few months (NRPB R171, 1984; paragraph 6.4.2). The use of slightly higher values is considered by NRPB in paragraph 10.2 of their review.

4.64 Table 4.7 summarises the gut transfer factors used in the above calculations of red bone marrow dose by NRPB. From Table 4.5 the major internal

Table 4.7 Summary of estimates of gastro-intestinal absorption applicable to the ingestion of radionuclides by children

Element	% absorption		
	First Year[1]	From 1 year[2]	ICRP value
Plutonium	0·5	0·05 (0·01– 0·1)	0·01
Americium	0·5	0·05 (0·01– 0·1)	0·05
Cerium	5	0·03 (0·01– 0·1)	0·03
Zirconium	5	1 (0·1 –10)	0·2
Ruthenium	10	5 (1 –15)	5
Polonium	20	10 (5 –20)	10
Lead	40	20 (5 –60)	20
Radium	40	20 (10 –30)	20
Strontium	60	30 (10 –60)	30
Caesium	100	100	100
Sulphur	100	100	80
Iodine	100	100	100

Values given are best estimates of absorption with possible ranges in parentheses.

[1] Used by NRPB in assessment of changed parameters in dose assessment (NRPB R171, 1984; Chapter 10).

[2] Used in main NRPB assessment (NRPB R171, 1984; Chapter 8).

(From NRPB R171, 1984)

contribution to the red bone marrow dose comes from Strontium-90, Ruthenium-106, Caesium-134 and Caesium-137. Caesium is assumed to have 100% gut transfer factor; Strontium-90 is assumed to have a 60% gut transfer factor in the first year and a 30% gut transfer factor in subsequent years, while Ruthenium is assumed to have a gut transfer factor of 10% in the first year and 5% in subsequent years. If these last two and all other low LET emitters consumed are assumed to have 100% gut transfer factors then the average low LET dose equivalent contribution from Sellafield emissions is increased to about 7·6 mSv, ie approximately treble the estimated dose equivalent, if all of the intake is assumed to be by ingestion; (in fact, some is by inhalation, for which a 100% transfer factor will already have been assumed). For high LET radiation, if the gut transfer factors were 100 times greater than the estimates used by NRPB, then the high LET contribution to the red bone marrow dose would be 7·4 mSv and the total dose to the red bone marrow would be increased four-fold (to 10·1 mSv).

4.65 Metabolic factors for children are not well known but are unlikely to alter doses by more than a factor of one or two and may well reduce the dose below calculated values since the biological half-life of many compounds is shorter in children than in adults.

Human Monitoring

4.66 The best way to confirm dose estimates is by monitoring children and adults for radionuclides. While it is possible to detect Caesium-137, Caesium-134 and Ruthenium-106 fairly readily by whole body monitoring, it is much more difficult to detect the alpha emitters, Plutonium and Americium in this way, and we were unable to obtain any data on alpha emitter levels in children.

Whole body monitoring

4.67 The whole body monitor on-site at BNFL is used to measure occupational exposure of workers and also provides a free service for any members of the public requesting monitoring. Many of those monitored by BNFL had low levels of Caesium-137, most had levels below 20 nCi (4,000 nCi maintained in the body would give an annual dose equivalent to the ICRP recommended limit). Some of this Caesium-137 dose could be contributed by nuclear fallout as well as by the discharges from BNFL. Since the gut transfer factor for Caesium-137 is 100% this information does not contribute information on the accuracy of any gut transfer factors. The results are however compatible with predictions on Caesium-137 levels expected from whitefish consumption.

4.68 In the voluntary monitoring carried out by BNFL only one of the approximately 200 people monitored was under 16. Following discussions with NRPB, they monitored volunteers from the Seascale population with a portable whole body monitor, to get some measurement of doses received by children in Seascale from all sources. They monitored more than 100 young people. From Table 4.8 it can be seen that only 2 of 112 young persons under 26 had detectable levels of Caesium-137 in their body, and that these 2 had levels below 15 nCi (0·6 kBq). These were below the levels calculated from environmental monitoring and habit surveys as likely to occur. NRPB will shortly be publishing the results of this study in greater detail (NRPB R172, 1984).

Table 4.8 Results of whole body measurements of body content of Caesium-137 for different age ranges.

Age in years	No of persons	Caesium-137 content			
		Not detected	0·6 kBq (15 nCi)	0·6–1·5 kBq (16–40 nCi)	1·5–3·7 kBq (41–100 nCi)
0– 2	5	5	0	0	0
3– 7	22	22	0	0	0
8–14	41	40	1	0	0
15–25	44	43	1	0	0
26 and over	178	159	15	3	1

(NRPB R172, 1984)

4.69 Post mortem assessments of tissue levels would be a possible source of information on human exposure. The limited data made available to us by NRPB, did not suggest that levels of Plutonium in members of the public in Cumbria were significantly different from levels in members of the public in the rest of the UK, but the data available were very limited.

4.70 In conclusion, although there were deficiencies in the monitoring programme, especially in early years, and in spite of some uncertainties about gut transfer factors for actinides and Ruthenium and the absence of human monitoring data for actinides, it seems likely that any deviation from normal plant operation that had health consequences would be detected by MAFF's monitoring activities, and that the doses to the red bone marrow calculated by NRPB in their review are based on reasonable 'best-estimate' assumptions.

Accidental Releases

4.71 The data above includes any discharges and emissions due to acciden occurring on-site at BNFL and resulting in off-site consequences. BNF. provided the Group with details of 14 incidents (including the November 1983 incident) that had occurred at Sellafield and which had involved abnormal releases of radioactivity into the environment between 1952 and December 1983 (BNFL, 1983). Apart from the Windscale fire (see below) none of these accidents are believed to have resulted in significant exposure to the public.

The Windscale Fire

4.72 The accident at the Windscale No 1 pile in October 1957 resulted in significant quantities of radioactive material being released into the atmosphere. During and after the fire various environmental measurements were made, including some measurements at Seascale. Levels of the main radionuclides in air at Seascale can be estimated from these data. Restrictions on the distribution of milk were imposed and reduced the potential population exposure as a consequence of the fire significantly. The milk from Seascale comes from a large area, but not generally from those farms closest to the Sellafield site (NRPB R171, 1984). In their calculations NRPB assumed 40% of milk consumed in Seascale was locally produced. Doses to individuals in the 1950 cohort from the Windscale fire are listed in Table 4.6. The high LET component of the dose from the fire is about 33% of the total dose equivalent.

The November 1983 Incident

4.73 In November 1983 there was an unplanned release of radionuclides (mainly Ruthenium-106) plus solvent and 'interfacial crud' (precipitated material between the organic and aqueous layers of liquid waste from the Sellafield site), which resulted in the beach between St Bees and Eskmeals being contaminated with unusual quantities of Ruthenium-106. In addition there was a small and transient elevation in Ruthenium-106 levels in mussels (MAFF Report, 1983) as a result of this release.

4.74 The consequences with regard to exposure of the public from this incident are believed to be small, and to relate mainly to the risk of a skin dose from skin contact with abnormally contaminated debris picked up from the beach and held over a significant period of time. It was this concern that led to the advice to the public not to frequent the beaches unnecessarily, which has now been revised. In the context of our investigation this hazard is not relevant since it is not believed to have resulted in a significant bone marrow dose likely to affect leukaemia incidence rates. There was evidence that a number of people on the beach at the time of the unplanned release may have ingested small amounts of Ruthenium-106; however the doses detected by whole body monitoring were at the limit of sensitivity of the machine.

4.75 There remain questions of concern with regard to this incident, especially whether similar occurrences could have taken place in the past and gone undetected. We questioned all relevant government departments and BNFL closely on this, and they told us that it was probable that such an incident would have been detected in the past. However, the incident did serve to underline several deficiencies in the on-site operation of BNFL most of which we believe have now been rectified. It also demonstrated that there can be even quite a large release of radioactivity from the site with small effects on the doses received by the adjacent population. The more intensive monitoring of the beaches precipitated by this incident did provide additional information on population exposure from the beaches. NRPB consider this route in their report.

Bone Marrow Model

4.76 Another possible source of error is the model used to calculate the dose to the red bone marrow. The assumptions behind the model are discusssed in NRPB R171, 1984; Appendix B. The model is not entirely satisfactory, in that it is one recommended for adults. There are problems with red bone marrow dose estimations for the alpha emitters because bone growth will distance the surface-seeking radionuclide from the active marrow and so reduce the red bone marrow dose.

SUMMARY OF RADIATION EXPOSURE OF THE YOUNG PEOPLE RESIDENT IN SEASCALE

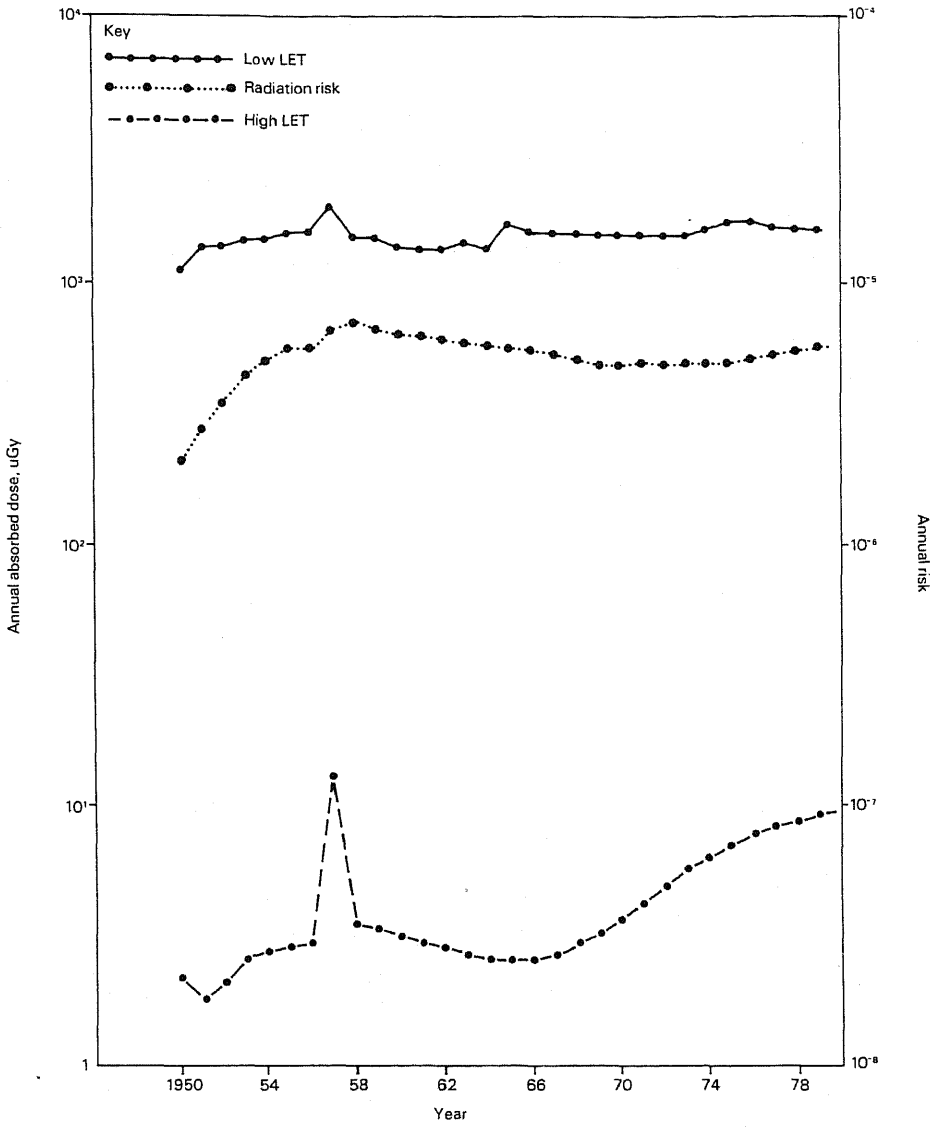
4.77 Figure 4.4 from the NRPB review (NRPB R171, 1984; Figure 8.1) shows the annual absorbed radiation dose to the red bone marrow for the 1950 cohort discussed in paragraphs 4.21–4.52 up to 1980. Using their three risk estimates for leukaemia induction at different times in childhood (Table 4.4), NRPB have calculated the percentage contribution to the risk of radiation-induced leukaemia up to the age 20 or up to 1980 (whichever is the earlier) for the 7 cohorts born between 1945–1975 (Figure 4.2). For the 1950 cohort, contribution from the Sellafield discharges to the total radiation risk is 11%, with a further 3·5% contributed by the Windscale fire.

4.78 It should be noted that the contribution to the absorbed dose to red bone marrow and hence to leukaemia risk from the Sellafield discharges has increased for more recent cohorts; 16·2% of the total risk in the 1975 cohort was due to Sellafield discharges. The levels of discharges have reduced markedly in recent years and are expected to reduce further and this means the average percentage contribution to the risk for these cohorts over the full 20 years will be correspondingly less.

Risks for other cancers

4.79 These are dealt with in detail in NRPB Report (NRPB R171, 1984). Table 4.9 summarises these risks for 5 other sites as well as for red bone marrow, combining the results for all 7 cohorts. The contribution from the

Figure 4.4 Annual absorbed dose to red bone marrow and risk of radiation-induced leukaemia for an individual born in 1950



Sellafield discharges and the Windscale fire combined is less than 15% of the total risk of radiation-induced cancer in all cases except that of the dose to the thyroid from the Windscale fire (53·9%) and the dose to the lower intestine from the discharges (24·3%).

Table 4.9 Predicted number of cases of radiation-induced leukaemia or other fatal cancers for all persons in Seascale up to age 20 or up to 1980 (for 1965 cohort and later cohorts) for all cohorts combined.

Tissue	Red bone marrow	Bone surfaces	Lung	Lower Large intestine	Liver	Thyroid
Predicted numbers of cases of radiation-induced leukaemia or fatal cancer from all sources[a]	1×10^{-1}	7×10^{-3}	1×10^{-1}	1×10^{-2}	1×10^{-2}	1×10^{-2}
	% contribution from sources					
Sellafield discharge	9·1	10·1	1·1	24·3	8·0	13·8
Windscale fire	1·6	2·3	5·3	2·2	3·9	53·9
Fallout	9·2	10·5	0·9	12·5	5·8	4·8
Medical	10·1	6·9	0·9	7·6	8·8	1·7
Natural background	70·1	70·2	91·7	53·4	73·5	25·8

[a] Assuming 175 persons in each of 7 cohorts born from 1945 to 1975 at 5 year intervals.

Conclusion

4.80 The Group has considered the likely dose of (see Table 4.10) and possible effects from gamma radiation (low LET) and alpha radiation (high LET) to the red bone marrow of children in Seascale. The NRPB and other bodies at our request have provided much data and carried out measurements and preliminary analyses and evaluations. We have had access to existing unpublished data collected over many years by the various bodies charged with monitoring radioactivity in the environment. Three full reports from NRPB, requested by us, will shortly be published as NRPB documents.

Table 4.10 Summary of contribution of different sources of radiation up to 1970 to exposure for a Seascale resident born in 1950 in Seascale.

Source	High LET		Low LET	
	μGy	% of total high LET	μGy	% of total low LET
Natural Background	47	71	20×10^3	68
Fallout	1·7	3	$2{\cdot}2 \times 10^3$	8
Medical Radiation	—	0	39×10^2	13
Sellafield Discharges	3·7	5	$2{\cdot}6 \times 10^3$	9
Windscale Fire	13·9	21	$5{\cdot}6 \times 10^2$	2
Total	66·3	100	29×10^3	100

High LET radiation forms 0·2% of the total dose from all sources of background radiation or 4·5% of the biologically effective dose using an RBE of 20.

4.81 The question we asked was *not* whether the absorbed doses of radiation from Sellafield discharges to Seascale children were and are within the recommendations of the relevant international committees. Rather we looked at the extent to which we believed it probable that radiation from the Sellafield site could be the cause of the increased incidence of leukaemia cases at Seascale. We therefore paid particular attention to comparing the doses received from background to those from the Sellafield discharges.

4.82 The dose from beta and gamma radiation from Sellafield discharges to Seascale children from ingested Caesium-137 in 1984 has been determined on a self-selected sample from direct measurement by NRPB. The results agree with those inferred from the MAFF studies of the pathways by which radioactive isotopes emitting gamma radiation are taken in by these children. The results show that it is very unlikely that any child currently receives more additional absorbed low LET radiation doses from ingestion than they already receive from the natural background. If any do, they will be exceptional, that is members of a 'critical group', and the doses they receive will still be comparable to those from background.

4.83 Background radiation in the UK varies from one area to another. So far as we know this variation is not reflected in the incidence of childhood leukaemia. The absorbed doses from gamma radiation that children receive from background will cause only a fraction of the normal incidence of childhood leukaemia. The investigations made of leukaemia after gamma radiation from accidental, military, or medical exposure have been analysed over many years to give estimates of risk which are used in recommending limits of radiation dose to radiation workers and to the public. The use of these factors with the measured and inferred gamma radiation absorbed dose from background gives an expected incidence of leukaemia of approximately one-fifth of normal. These factors are derived from high doses and if the risk factors for the low dose rates and low doses at Seascale are lower then the number of leukaemias caused by radiation would be less.

4.84 The situation for absorbed doses from alpha radiation is different from that for gamma radiation. Only about 0·2% of the absorbed dose from natural background radiation is alpha radiation or similar. However this proportion is similar to that estimated to have been received from the Sellafield discharges to sea by most Seascale children, although a few children who are major consumers of local shellfish may receive higher doses. Background radiation therefore provides a check on this situation also. However, the quantity of radioactive isotopes emitting alpha radiation in the children cannot be directly measured, but must be inferred from environmental and pathway studies. Such studies have been carried out for several years and more are being undertaken, but data on children and actinide exposure in the early years at the site is sparse and we shall never know for certain the levels of actinides in children in the area in earlier years.

4.85 Remote possibilities are that:

a. there is an unusual concentration of unusually susceptible children in the Seascale area;

b. there have been undetected discharges that have given rise to doses to the public greatly different to those believed to have occurred;

c. ingestion, inhalation and/or absorption of high LET emitters has been grossly under-estimated;

d. the model used to calculate red bone marrow doses is highly inaccurate.

4.86 Absorbed dose from alpha radiation in low doses at low dose rates has a much greater biological effect than the same dose of gamma radiation at low dose rate. The extent to which alpha radiation may cause more leukaemia in children than gamma radiation for the same dose cannot be found directly from any existing human evidence. Guidance can be obtained from other radiation-induced human cancers, from radiation-induced human adult leukaemia, and from the results of many animal experiments. This guidance is the basis of the recommendations on limits of radiation dose. Despite the uncertainties in these values we regard the relationship between the doses inferred for Seascale children and the doses from background radiation as an important check.

4.87 It has been assumed in our calculations that all deaths from leukaemia are due to the background radiation dose to the red bone marrow to provide 'worst-case' assumptions.

4.88 If all the assumptions are correct, these calculations have demonstrated that at most less than 0·1 deaths from leukaemia would be expected from the discharges (accidental and planned) from Sellafield to the under 20 year-old population of Seascale born between 1945–1975, giving a maximum risk of death from leukaemia of about 4 in a million young people per annum. This is approximately 1/40 of the additional number of deaths found at Seascale. To attribute these additional deaths from leukaemia to radiation it would require that the total discharges from Sellafield site had in fact been at least 40 times greater than reported and that monitoring and extrapolation of doses to the public were in error by a similar factor.

RECOMMENDATIONS

4.89 During consideration of the above data, we did find several areas where we felt that there could be improvements in the methods used to assess population exposure and in the controls placed by government upon industry. We therefore make the following recommendations:—

4.90 The chain of calculations leading to the assessed population dose is based on many assumptions and estimates. These are almost invariably maximising assumptions, however when a toxic agent is being considered, there is no substitute for direct measurement of that material in the exposed population.

4.91 Suprisingly there are few data on body levels of radionuclides in local people who are not workers at BNFL (at the start of our investigation only one measurement in a local child was available). The majority of those measurements that were available initially were made at the request of members of the public by BNFL (on a confidential basis) and not reported to authorising departments. We were told that the reason for the absence of human monitoring data on the general public was that human data were technically difficult to obtain, especially for the actinides. However, we were able to commission whole body monitoring of the residents in Seascale from NRPB once we pointed out the need for this information, and we felt the lack of data reflected, at least in part, a lack of appreciation of the value of such measurements. We recommend that more human monitoring data should be obtained, both locally in the area around the Sellafield site, and nationally and especially on children.

4.92 We were surprised at the lack of health input into this area, and the lack of co-ordination in the assessment of the overall impact of the discharges on the population. Each organisation we spoke to had considerable expertise in their particular area of environmental monitoring, but we were unable to identify any organisation that had the responsibility for assessing all of the information available and deciding on the overall implication of the discharges with regard to the health of the community. We recommend that there should be such a co-ordinating body, with a strong input by the DHSS and NRPB, that is able to ensure that more consideration is given to the adequacy of the data provided for dose assessment both in quality and quantity and to the need for research to improve the accuracy of dose assessment.

4.93 The authorisation of radioactive discharges appeared to us to be in too general terms; it had not been revised substantially since 1971 and did not include certain radionuclides discharged in considerable quantity. There was an incident in November 1983 which resulted in the beaches being contaminated to such an extent that the public were for a time advised not to use them unnecessarily. This was due to the release of solvent and quantities of radionuclides which fell within the authorisation; even if the public health consequences of the November incident were probably extremely small, the economic and social consequences to the community were much greater.

4.94 We therefore recommend that the Sellafield Authorisation should be revised and that tighter limits should be placed on the discharges of solvents and particulates, and that there should be limits on discharges over periods much shorter than three months.

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Table 4.11 Abbreviations used for Radionuclides in Tables

Am	Americium
Cs	Caesium
C	Carbon
Ce	Cerium
I	Iodine
Pb	Lead
Nb	Niobium
Pu	Plutonium
Po	Polonium
Ra	Radium
Ru	Ruthenium
Sr	Strontium
S	Sulphur
Te	Tellurium
H-3	Tritium
Zr	Zirconium

ANNEX TO CHAPTER 4

RADIATION AND ITS BIOLOGICAL EFFECTS

A.4.1 Radiation is the transfer of energy through space or some other accommodating medium. One commonly experienced form of radiant energy is the heat from a fire, in which the energy from combustion of fuel is dissipated as warmth to those sitting in front of the fire without the temperature of the intervening air being significantly elevated. Ionising radiation is produced when one or more of the protons, neutrons and electrons, which make up the atoms of all elements, are released from an unstable mother element or radionuclide. We will not deal further with neutrons here since they are not relevant to the discharges from Sellafield. Electrons and protons are charged particles (electrons carry a negative charge, protons carry a positive charge), they are expelled from the mother atom at speed and travel through the atmosphere. Some of their kinetic energy is dissipated as they travel by the induction of charges on molecules in the medium they are travelling through. This is called 'ionisation'. Because these types of radiation are particulate they are not able to travel far before being stopped by collision with an atom of the medium they are passing through. Their energy may then be deposited in the material as a mixture of heat, ionisation and X-rays. When particles are emitted from such an unstable element or radionuclide, additional energy may be released in a non-particulate form, called gamma rays.

High and Low Linear Energy Transfer (LET) Radiation

A.4.2 Ionising radiation is recognised to be a carcinogen or cancer-causing agent, which acts by damaging the DNA in the chromosomes of the target cell. Damage due to low LET radiation may be repaired and more repair can occur when radiation is delivered at low dose rates than at high dose rates. This reduces cell killing due to low LET radiation at low dose rates. High LET radiation damage is less able to be repaired, and therefore for high LET radiation the biological effect per unit dose is relatively constant, irrespective of the dose rate.

A.4.3 Because X-rays and gamma rays were first used therapeutically and diagnostically the biological effect per unit dose for these low LET radiations was taken as the standard, and other ionising radiations are compared to X-rays. This means that the Relative Biological Effectiveness (RBE) of alpha rays and other high LET rays (as compared to gamma rays) increases as the dose rate decreases, and that at the very low dose rates relevant to background radiation, alpha rays may be between 20–50 times more biologically effective than gamma rays per unit dose. This is because X-rays and gamma rays become less biologically effective at low doses rather than because alpha rays become more biologically effective at low doses.

A.4.4 *Alpha rays (or particles):* These are helium atoms without their 2 outer electrons. They therefore carry a net positive charge and since they consist of 2 neutrons and 2 protons, have a mass of 4.

A.4.5 *Beta rays (or particles):* These are high energy electrons and are therefore negatively charged. They have a much smaller mass than alpha rays. If beta rays are stopped suddenly then their kinetic energy is converted to heat and electromagnetic radiation (X-rays).

A.4.6 *X-rays:* If a beam of high speed electrons (accelerated in magnetic fields produced from currents of hundreds of millions of volts), is suddenly arrested by interposing a dense material (eg tungsten) in its path, then some of the kinetic energy will be emitted as heat, but the rest will be emitted as short wave radiation of the same type as gamma rays, but with a continuous instead of discontinuous energy spectrum.

A.4.7 *Gamma rays:* These are a form of electromagnetic radiation, as are light and radio waves. The wavelength of gamma rays, however, is much shorter than that of light. Gamma rays can also be emitted by radionuclides in association with the release of particulate radiation.

A.4.8 Gamma rays and X-rays are the same form of radiation, but gamma rays are emitted by a radionuclide and have a single or discontinuous energy spectrum, whereas X-rays are produced by collisions of high speed electrons with other particles and produce a continuous energy spectrum (see A.4.6 above).

A.4.9 Radioactive decay in any given quantity of a radioactive element occurs at a constant rate, yet no one can tell at what time any particular atom will decay. What is certain is the period over which half of the material will have decayed, called the half-life ($T_{\frac{1}{2}}$). For example, if one starts with a gram of Radium-226, one will have half a gram of Radium in 1,600 years, a quarter of a gram of Radium in 3,200, (2 × 1,600), years and an eighth of a gram of Radium in 4,800, (3 × 1,600), years. The Radium will be decaying to it 'daughter products', ie other elements of lower atomic mass, many of whicl are also radioactive.

A.4.10 Each type of radiation emitted by radioactive materials interacts with other matter in important yet distinct ways. Alpha particles carry a charge of + 2 units. When an alpha particle passes near another atom, the electrons in its orbital shells are attracted to the alpha particle by virtue of their own negative charge. Some electrons are merely excited by the event, ie they move from a lower to a higher energy state while remaining in orbit round the nucleus. Many other atoms may lose their electrons entirely so that the atom is left ionised temporarily until it can recapture free electrons.

A.4.11 During this period of ionisation the atom may combine with other atoms in ways not usually possible giving rise to new, and possibly biologically active compounds. If the ionisation event takes place near the chromosomes in the cell, the reaction can result in the chromosomes being damaged, giving rise to mutations and impaired transfer of genetic information to daughter cells. These effects form the basis of the biologically adverse effects of ionising radiation. The ionisation of atoms in the path of the alpha particle results in the particle being slowed down in its path, and eventually the particle will stop.

A.4.12 Because of the density of the particle and its 2 positive charges, alpha particles have a very short range in biological material, of the order of a few micrometres. However they cause very dense ionisation over their path. They are called high linear energy transfer radiation particles (high LET particles).

A.4.13 Beta particles have far less mass and a single negative charge and therefore have a relatively low LET factor. Their biological effect is mediated via collisions with other electrons and nuclei to cause ionisation and greater chemical reactivity. As they are slowed down thay emit a small amount of X-rays.

A.4.14 Gamma (or X-) rays also have a low LET factor. They have no electric charge and no mass, however they can act like quantum particles in the same way as light does, and 'collide' with an electron, imparting kinetic energy to it and creating the equivalent of a beta particle. If no electron is encountered the gamma ray passes unchanged through the material. They are 'penetrating' radiation therefore and can pass completely through the body (as a proportion do when an X-ray film is made).

CHAPTER 5

RISK ASSESSMENT

5.1 In considering the assessment of risk, it is important to distinguish between *actual risk* during normal operation of the plant; *potential risk* should something go wrong; and *perceived risk*, which is not necessarily a true reflection of actual risk, and may be loosely equated with 'concern'. In Chapter 4 we have given some evidence that the *actual risk* of the Sellafield operation is comparatively low, provided that there are neither exceptional exposures, nor unusual susceptibility in particular individuals or groups, and that dose estimations are correct. The *potential risk*, given the scale of the Sellafield operation, must be greater. In this Chapter, we particularly examine the relationship between *actual* and *perceived risk*, which must be a factor in determining the degree of public concern.

5.2 In our daily lives we are all subjected to the risk of physical, microbiological, and chemical harm from the environment. Many such risks, although perceived originally as an inescapable part of life, have been substantially reduced, or even eliminated by modern science and technology. In the United Kingdom it would be reasonable to say that a substantial reduction in the risks from the environment affecting everyday life occurred during the past century, and that on average people are living longer because of these improvements.

5.3 As the number and severity of hazards in the environment has decreased, concern about the remaining risks, rather strangely, has increased.

5.4 Perhaps our perception of risks has been changed because any modern hazards (eg chemical and radioactive) are more difficult to understand and to assess than those of the past. Often they can be detected only by using complex equipment, and they produce chronic and delayed rather than acute and immediate effects. This has resulted in increasing public unease about these more subtle hazards in the environment, and if not properly controlled, the impact they may be having on people.

5.5 No one can completely eliminate all risk of harm, nor would it even be desirable for any person or government to try to do this in all cases. Few people would support a move to ban motor vehicles, yet 6,000 people are killed on the road each year (Central Statistical Office, 1984). Where the benefits are substantial and the risk to any single individual is comparatively small, the risk is generally accepted in practice, although where blame is proven damages and punishments may be imposed by society.

5.6 An important concept in controlling exposure to hazards is that of maintaining individual liberty. Since we do not all perceive the same risk as equally acceptable, it is normally conceded that any one individual may choose to expose himself to quite serious risks voluntarily, eg a mountaineer may accept the risk of death or serious injury while climbing, and it has been calculated that being President of the United States carries a 2% per annum

risk of assassination, yet there continue to be candidates for election. There can be considerable opposition to the imposition of safeguards, as was the case with the introduction of legislation to ensure compulsory wearing of seat-belts.

5.7 When people are exposed to hazards without their knowledge or consent, and where there is little or no directly perceived benefit to those exposed to the risk, public expectations are greater, and people may talk of making things 'absolutely safe'. The development of cancer following unwitting and involuntary exposure to environmental carcinogens is a case in point. Apprehension is particularly strong where radioactivity is concerned, because of the military applications of atomic energy.

5.8 It is argued by some environmental groups that the nuclear energy industry should be closed down, and that we do not need nuclear power. Others point out that the present energy supply of the country depends on a certain proportion of the energy produced being derived from nuclear power stations which at present depend upon Sellafield for their continued functioning (Chapter 3).

5.9 We would suggest that the question to be considered is whether the discharges from the Sellafield site pose a greater hazard than other imposed, hidden, low exposures to long term hazards normally accepted by the public. In order to consider this question, it is necessary to find out what risks are generally found to be acceptable by members of the public.

5.10 The levels of fatal accidents averaged over broad areas of industry traditionally considered dangerous (quarries, mines, railways and the construction industry) are mainly between 1 and 3 in 10,000 annually, while in the manufacturing industry as a whole the level approaches 3 in 100,000. All these risks could be said to be freely entered into, although the additional incentive or benefit of financial reward has also to be considered (Royal Society, 1983). These risks are accepted by the occupationally exposed; the public will generally require a larger margin of safety.

5.11 A Working Party of the Royal Society estimated that most people are prepared to accept a risk of one chance in a million of dying in any one year from an environmental hazard, and would be reluctant to spend money or time on reducing such a risk further (Royal Society, 1983). As we considered in Chapter 3, this is of the same order as the average risk to populations from the discharges from Sellafield, even when they contain 'critical groups' (which represent small, highly exposed subgroups of the population) where exposure is below the ICRP recommended limit of 5 mSv per year.

5.12 From a decision on the accceptable level of risk, to a decision on the acceptable level of radionuclides in the environment, two extrapolations are necessary. First the radiation dose to people that would give rise to the acceptable level of risk must be determined, and then the level of radionuclides in the environment that will result in that dose being received by individuals in the population must be calculated. Monitoring can then take place to ensure that these levels in the environment are not exceeded.

5.13 In Chapters 3 and 4 we dealt with the problems of assessing population exposure from environmental measurements of radiation and in Chapter 4 we considered the evidence for deciding on the permitted doses to members of the public. There are problems with both of these extrapolations. There are areas of uncertainty surrounding the relative biological effectiveness of very densely ionising radiation such as that from Plutonium and Americium, when exposures occur continually at very low dose rates. There is no evidence from human exposures for the leukaemogenic dose to young people

from chronic exposure to such radionuclides, all presently available evidence having been collected from acute exposures and most frequently from exposures to gamma rays.

5.14 The absence of human measurements in this area of risk assessment is not peculiar to the field of radiation protection, it is a problem encountered throughout the field of toxicology, where animal data is frequently all that is available for decision making. It adds a degree of uncertainty to the calculations.

5.15 In assessing the likelihood of potentially hazardous levels of radioactivity arising from the Sellafield operation, it is important to distinguish between the normal operation of the plant, and the effect of incidents such as that which took place last November. Since discharge of radioactive material is an intrinsic part of the operation, there must be some increase of radioactivity over the local background; similar local increases can occur in other ways, such as from the natural emissions from rocks and building materials, or the emissions generated in the combustion of fossil fuels (Corbett, 1983). Since the existence of any threshold for the carcinogenic effect of radiation is unproven, and may even be unprovable, the 'no risk' hypothesis is inadmissible; but extensive monitoring has indicated that the increased radioactivity in the general environment is of an order which is accepted in other situations. The occurrence of incidents introduces a new order of unpredictability, with the possibility of local hazards arising from abnormal discharges of radioactive material in concentrated form. Future effort on the normal operation of the plant, as is indeed already planned, should take the form of diminishing discharges still further, and aim to prevent further incidents.

5.16 The doses to the public living in the area around Sellafield are not in excess of the ICRP recommended limits (Chapter 4), and using the most conservative estimates, the risk to the under 20 year-old population with regard to death from leukaemia has been calculated to be of the order of 4 in a million, after making certain assumptions. As described in Chapter 4 this order of risk would be expected to give rise to less than 0·1 additional deaths from leukaemia before the age of 20 in the approximately 1,200 children born in Seascale between 1945 and 1975.

5.17 However, there is epidemiological evidence which indicates that the incidence of leukaemia is above this and above average both in the village of Seascale and in the rural district in which that village lies. It is in the nature of an average that a proportion of its components will fall above it; so it becomes a matter of judgement at what level a raised incidence of leukaemia becomes significant. To put the matter in general terms, the incidence of leukaemia in Seascale is unusual, but not unique; and we acknowledge that those who have drawn attention to it may have performed something of a public service. However, the suggestion that in the neighbourhood of Sellafield there is a causal relationship between an increased level of radioactivity and an above-average experience of leukaemia, while it is possible, is by no means proven. The causes of leukaemia are not fully established, even though radiation is one acknowledged factor; and the risk estimates calculated in Chapter 4 suggest that the doses received by the population are insufficient to account for the additional cases of leukaemia in the area. On the other hand, the proposition cannot be completely discounted, and it is difficult to see what scientific evidence would suffice to do so. The risk estimate we have calculated, if based on accurate assumptions about the dose received, is

comparable to other risks to members of the public of everyday life normally accepted as reasonable by members of the public for human activities conveying some measure of benefit on society, such as other methods for the generation of energy or methods used for the production of food.

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CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Our group was set up following a programme produced by YTV, and shown on the national network on Tuesday 1 November 1983. The programme alleged that there had been an excess of young people with leukaemia and other cancers in the neighbourhood of the Windscale plant for reprocessing nuclear fuel situated on BNFL's Sellafield site. The whole programme aroused considerable local and national concern.

6.2 The hypothesis in the television programme that the proximity of Sellafield to the village of Seascale could be a factor in producing cases of childhood leukaemia is not one which can be categorically dismissed, nor on the other hand is it easy to prove.

6.3 In the course of our inquiries we were made aware of what were considered by local doctors and others to be additional unusual concentrations of people with leukaemia, other tumours and Down's Syndrome. The mortality and cancer registry statistics which we examined in Chapter 2 included some material concerning older age groups and other cancers and did not support the suggestion that there was any unusual incidence of cancer in people aged over 24 or in other areas of West Cumbria. Down's Syndrome falls outside our terms of reference and for this reason we have not examined in detail the evidence relating to the incidence of Down's Syndrome in Maryport. We do however, believe that this matter might be investigated further by detailed studies of maternal age-specific rates of the incidence of congenital disease in the population of the area.

6.4 The number of children who have developed leukaemia in a 30 year period in Seascale was less than 10. This is a relatively small number of cases. Because of uncertainty about the size of the population from which they are drawn the true incidence of leukaemia cannot be determined precisely. The fact that the final estimate of health risk has to be based on data which include those used to raise the hypothesis makes assessment of the significance of the observed incidence of leukaemia difficult. However, taking West Cumbria as a whole, mortality from childhood cancer is near to the national average, particularly for cancers other than leukaemia, but this does not exclude local pockets of high incidence.

6.5 In the Northern Children's Cancer Registry region, which contains 765 wards, Seascale had the third highest 'lymphoid malignancy' rate during 1968–82 in children under fifteen years of age in one study (this excess being entirely due to an increased incidence of leukaemia). Also, Millom Rural District (which includes Seascale) had the second highest rate among 152 comparable-sized Rural Districts in England and Wales, ranked according to mortality from leukaemia among people under the age of 25 during 1968–78. Mortality rates for other diseases in the local population, either of children or adults, are not unusual. In particular the overall mortality rate for young people under 25 in Millom Rural District is within normal limits (Chapter 2).

6.6 The Sellafield site contains a nuclear operation which is unique in the United Kingdom in terms of scale and complexity. The Windscale plant reprocesses not only the radioactive materials which are generated locally from the Calder Hall power station, but also materials brought from other nuclear power stations in the UK and imported from Italy and Japan (the imported material representing around 10% of the total material handled). The radioactive materials introduced into the plant contain a complex mixture of radioactive and non-radioactive chemicals. In order to reprocess this material and separate out the isotopes of value, large scale physico-chemical operations have to be undertaken. The unwanted radioactive materials (gaseous, liquid and solid) then have to be converted into a form suitable for either safe storage or planned disposal (Chapter 3).

6.7 While there is ample evidence of a real and sophisticated concern with the safe operation of the plant, which after all must be a major concern of those who work there, it has to be said that some of the plant was installed many years ago.

6.8 In any complex system there resides the possibility of human error. This was exemplified by the incident in November 1983 shortly after we started our inquiries. Even without such error, the possibility of accident remains, as in the 1957 fire. However, the risks to the public of the Sellafield operation should not be judged against the standard of 'total or absolute safety', which is quite unattainable in any human activity. A more realistic standard of comparison would be to the overall risks to the public from public transport or from deriving energy from coal or oil. The fact that no operation can be made absolutely safe does not conflict with the desirability, indeed the necessity, of making it as safe as is practicable.

6.9 Population exposure to radiation is at present inferred from environmental measurements of radionuclides in air, soil and food. This can only accurately reflect actual exposure if all possible routes from the environment to man are considered and if transfer factors used to calculate doses from environmental levels of radiation are known with certainty (Chapter 4).

6.10 It is impossible to establish for certain the situation with regard to environmental levels of radiation around Sellafield twenty or thirty years ago, and we shall never know the actual doses received by those children subsequently contracting leukaemia. In addition one cannot completely exclude the possibility of unplanned discharges which were not detected by the monitoring programmes and yet delivered a significant dose to humans via an unsuspected route.

6.11 Subject to the uncertainties described above, the NRPB provided us with a 'best estimate' of the average radiation dose to the red bone marrow received by a model population of the young people in Seascale. We then made a 'worst-case' assumption that leukaemia in under 20 year-olds in England and Wales is entirely due to the dose of background radiation received by the red bone marrow, and on this basis we estimated the risk from low dose rate radiation exposure. Using this risk estimate and a simple relationship between dose and effect, we were able to calculate the number of additional deaths from leukaemia in under 20 year-olds in Seascale that might be attributable to the additional dose their red bone marrow received from the discharges from the Sellafield site up to 1980. The number of deaths from leukaemia thus calculated is not sufficient to account for the deaths actually observed in Seascale, being around 20% of the number expected from background radiation (Chapter 4, paragraph 4.45).

6.12 These calculations do not support the view that the radiation released from Sellafield was responsible for the observed incidence of leukaemia in Seascale and its neighbourhood. However, it is important to stress the unavoidable uncertainties on dose in this situation, and the model we have used does not exclude other possibilities.

6.13 We have found no evidence of any general risk to health for children or adults living near Sellafield when compared to the rest of Cumbria, and we can give a qualified reassurance to the people who are concerned about a possible health hazard in the neighbourhood of Sellafield. However there are uncertainties concerning the operation of the plant, which were highlighted in the Nuclear Installations Inspectorate report of the November 1983 incident, and also problems attendant on the functioning of a plant, part of which has been long in service. There are further questions concerning the adequacy of the controls over present permitted levels for discharges; the quantitative assessment of apparent excesses of cancer; and possible genetic risks. During our investigations we also found some evidence of lack of co-ordination between the various agencies with an interest in this industry and considering its impact on the health of the community (Chapter 4).

RECOMMENDATIONS

6.14 In the interests of enhancing public safety, we believe that these matters should be addressed, and we therefore make the following recommendations. Our terms of reference relate mainly to epidemiological aspects of the problem, but we could not avoid the consideration of other matters during the investigation, in some of which we are unable to claim any special expertise.

I. Epidemiological (Chapter 2)

Recommendation 1

A study should be carried out on the records of those cases of leukaemia and lymphoma which have been diagnosed among young people up to the age of 25, resident in West Cumbria. These cases should be compared with suitable controls in respect of factors that could be relevant to the development of leukaemia and lymphoma.

Recommendation 2

A study should be carried out of the records on all children born since 1950 to mothers resident in Seascale at the time of birth. Its main purpose would be to examine cancer incidence and mortality among those children, including cases which might have occurred after moving from Seascale.

Recommendation 3

A study should be considered of the records of school children who have attended schools in the area.

Recommendation 4

The Northern Children's Cancer Registry should be asked to re-analyse their data using 1961, 1971 and 1981 population Census data where appropriate. Also stratification for age at diagnosis, and grouping by electoral ward at birth (as well as at diagnosis) should be undertaken, to determine the contribution these factors make to the incidence of leukaemia at Seascale.

Recommendation 5

We were impressed by the amount of data made available to us, and feel that encouragement should be given to an organisation such as OPCS or MRC to co-ordinate centrally the monitoring of small area statistics around major installations producing discharges that might present a carcinogenic or mutagenic hazard to the public. In this way early warning of any untoward health effect could be obtained.

II. Health Implications of Radioactive Discharges (Chapter 4)

Recommendation 6

More attention should be concentrated on measuring doses of radiation actually received by members of the public in West Cumbria and in other relevant areas, including control areas using whole body monitors, cytogenetic techniques and measurements of urinary and faecal radionuclides as appropriate and feasible. Much of such work is best carried out at a local level, but the ultimate responsibility for seeing that this type of monitoring is carried out should lie with the Health Departments so that it may be systematically and properly co-ordinated throughout the United Kingdom.

Recommendation 7

More work should be carried out on:

a. the gut transfer factors at present used, especially for children, with special attention being paid to radionuclides where this factor is believed to be low, and to organic forms of radionuclides;

b. the metabolic differences between adults and children with a view to improving the models used;

c. studies on children's habits in relation to the possibility that unknown critical pathways exist which are peculiar to children;

d. comparisons of the biological effects of low dose rate irradiation from alpha emitters with the biological effects from beta and gamma emitters both *in vitro* and *in vivo*.

Recommendation 8

Where discharge authorisations are considered particular attention should be paid to the upper limit placed on discharges over short periods of time; to the removal of solvent from discharges; the adequacy of filter systems to remove particulate material and to the limits imposed on specific radionuclides.

Recommendation 9

There should be a critical review of the necessity for discharges of alpha as well as beta/gamma emitters in discharges from BNFL Sellafield site to be significantly in excess of those from similar plant in other countries.

III. Regulatory Mechanisms (Chapter 4)

Recommendation 10

The controls imposed upon BNFL by government, and the ways in which these are reviewed should be revised so that:

a. reviews of the authorisations take place more frequently;

b. greater emphasis is placed on the collection and consideration of relevant epidemiological data and any other human data relevant to the possible health consequences of discharges;

c. there is formal consultation by the authorising department with Health Departments and NRPB on the possible health consequences of discharges;

d. the responsibility for monitoring and for interpretation of the results of monitoring this potentially serious environmental pollutant should be more clearly defined by government; these results of monitoring need to be considered in their entirety on a regular basis by a designated body *with significant health representation,* thus enabling decisions on action with regard to the control of permitted discharges to take account of all relevant factors.

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GLOSSARY

The terms below are to help the reader understand the text; they are not formal scientific definitions.

ACTINIDES
The group of fifteen elements with atomic numbers 89–103 which includes Uranium and Plutonium.

ADVANCED GAS COOLED REACTORS (AGR)
Nuclear reactors operating at high temperatures (over 1000°C), cooled by gas and utilising enriched Uranium oxide fuel.

ALARA (As Low As Reasonably Achievable)
The internationally accepted concept that the effects of radiation and levels of exposure of workers and members of the public should be kept as low as possible "with due regard to economic and social factors".

ALPHA EMITTER (α)
A radionuclide which emits alpha particles.

ALPHA PARTICLES/ALPHA RADIATION
A particle emitted during the radioactive decay of some radionuclides; it consists of two protons and two neutrons and has a net charge of +2. It is a high linear energy transfer radiation.

BECQUEREL (Bq)
The Standard International (SI) Unit for the number of radioactive disintegrations taking place per second in a material.
1Bq = 1 radioactive disintegration per second.
1Bq = 27×10^{-12} curies.

BETA EMITTER (β)
A radionuclide which emits beta particles.

BETA PARTICLES/BETA RADIATION
A particle emitted during the radioactive decay of some radionuclides. It has a mass and charge equal to that of an electron, (−1). It is a low linear energy transfer radiation.

CLADDING
The covering on nuclear fuel. Designed to resist physical and chemical effects thus preventing corrosion of the fuel and escape of products of the reaction.

COLLECTIVE DOSE COMMITMENT
Sum of the doses to all individuals in a population.

COMMITTED DOSE EQUIVALENT
The dose equivalent to the tissues resulting from a radionuclide that has been incorporated into the body will be spread out in time and will be delivered gradually as the radionuclide decays. The total dose equivalent to a tissue during the period of 50 years following the incorporation of a quantity of radionuclide into the body is known as the committed dose equivalent arising at the time of incorporation (measured in sieverts or rems).

COOLING PONDS
Areas of the Sellafield site where newly arrived fuel rods are stored under water to allow the decay of volatile, short half-life isotopes. The rods produce considerable heat which is removed by a flow of cooling-water through the ponds.

COSMIC RAYS
High energy extra-terrestrial ionising radiation. Mostly absorbed by the earth's atmosphere.

CURIE (Ci)
The old unit of radioactive disintegration. $1Ci = 3{\cdot}7 \times 10^{10}$ disintegrations per second ($27Ci = 10^{12}Bq$).

DECANNING
The first process in the cycle of nuclear fuel reprocessing in which the casing (cladding) is separated from the fuel.

DECAY
The process by which radionuclides change from one atom to another emitting ionising radiation as they do so.

DISCHARGES
The release of liquid effluent from an industrial site.

DOSE EQUIVALENT
The quantity obtained by multiplying the absorbed dose by a modifying factor, the Quality Factor (QF) (measured in sieverts or rems).

EMISSION
The release of gaseous effluent from an industrial plant. Filters or scrubbers are employed to clean the effluent before its release to the atmosphere.

FAST BREEDER REACTOR
A type of nuclear power reactor which produces more fissionable material than it consumes.

GAMMA RAYS (γ)
Photons emitted from the nucleus of a radionuclide during radioactive decay.

GAS COOLED REACTOR (GCR)
A nuclear reactor which uses gas, usually carbon dioxide, to cool the pile. In Britain these reactors use "magnox" fuel.

GRAY (Gy)

The S.I. unit of absorbed dose.
1 gray = 1 joule of energy absorbed per kilogram of tissue.
1 gray = 100 rad.

HALF-LIFE ($T_{\frac{1}{2}}$)

The time for the activity of a radionuclide to decay to half its original value.

HEPA

High efficiency particle absorbers. A type of filter which removes particles from the gas passing through it.

ICRP

International Commission on Radiological Protection. Consists of experts in radiology, genetics, physics, medicine and radiological protection from a number of countries. Established in 1928, it meets regularly to consider the results of research on the effects of radiation, and publishes recommendations on acceptable dose limits for man.

IN VITRO

Studies carried out on material from an animal under artificially controlled conditions in the laboratory.

IN VIVO

Studies carried out in the intact animal.

ISOTOPES

Forms of an element having the same atomic number (number of protons) but different atomic mass (number of neutrons + protons).

LINEAR ENERGY TRANSFER (LET)

A measure of the density of energy deposition in the track of ionising radiation.

MAGNOX

A type of nuclear fuel which is encased in a Magnesium alloy. It is also the name given to the gas cooled reactors using the fuel.

OPCS

The Office of Population Censuses and Surveys. A British government body which collates and publishes data on disease, mortality and population effects in England and Wales.

OXIDE FUEL

Nuclear fuel consisting of pellets of Uranium oxide. Used in Advanced Gas Cooled Reactors and Water Cooled Reactors.

PILE

The name given to the part of a nuclear reactor which contains the fuel and their moderating systems.

PRESSURISED WATER REACTOR (PWR)

A type of nuclear power plant which has a pile cooled by water kept under pressure.