Investigation of the Possible Increased Incidence of Cancer in West Cumbria

Report of the Independent Advisory Group

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INTRODUCTION

1.1 Sir Douglas Black was asked by the Minister of Health if he would head an independent inquiry into the possible increased incidence of cancer in the area adjacent to the Sellafield site following the Yorkshire Television (YTV) programme—"Windscale—the Nuclear Laundry"—shown on ITV on 1 November 1983. He asked a group of six experts in relevant fields to assist him (listed in Appendix I). The Department of Health and Social Security (DHSS) provided the Secretariat for the Inquiry. Observers from the Welsh Office and from the Scottish Home and Health Department (SHHD) were also present at the meetings.

1.2 The *terms of reference* for the Inquiry were:—

To look into the recently published claims of an increased incidence of cancer in the vicinity of the Sellafield site:—

1. examine the evidence concerning the alleged cluster of cancer cases in the village of Seascale;
2. consider the need for further research;
3. and make recommendations.

1.3 The Group was asked to act as speedily as was consistent with a rigorous investigation of the situation.

1.4. The Group first met on 22 November 1983. We decided that, while the area of greatest importance in our investigation was that immediately adjacent to Sellafield, we needed to put our investigations in the context of the incidence of cancer in the rest of Cumbria, and in England and Wales. We therefore encouraged the early completion of analyses of cancer incidence and mortality studies in England and Wales in general and in Cumbria in particular.

1.5 At the same time questions were being asked in Scotland about possible adverse effects of the discharges from Sellafield on the health of the population in South West Scotland. As there seemed to be some evidence that there were certain coastal areas with a raised incidence of leukaemia, the SHHD commissioned their own investigations and some of their results have been incorporated into this report. We thank the SHHD for permission to do this.

1.6 Our task was threefold:—

a. establishing the incidence of cancer in the area adjacent to Sellafield, and comparing it with the incidence of cancer in other areas in the United Kingdom and in Cumbria;

b. considering the available data on radiation exposure in the area adjacent to Sellafield and the evidence relating radiation exposure to cancer, thus assessing the likelihood that any radiation exposure could have caused any increased incidence of cancer detected in the area;

c. assessing other possible significant factors.

1.7 We took oral evidence from a number of people and representatives of Government Departments and other interested organisations (listed in Appendix II). Many of these also submitted written reports or suggested additional material that we should consider. We wish to thank the National Radiological Protection Board (NRPB) for the three reports they prepared at our request and British Nuclear Fuels plc (BNFL) for answering many queries throughout the period of the Inquiry.

1.8 Many others besides those listed in Appendix II suggested possible lines of research, or submitted written evidence, including details of individual case histories. We would like to thank these people for their submissions which were all carefully considered. The limitations imposed by space and sometimes by confidentiality do not permit us to list all these sources, but some are referred to in the text.

1.9 The Advisory Group visited Cumbria in January 1984 when we saw the Sellafield site and spoke to local medical staff and to Seascale's general practitioners. Subsequently there were several visits to the area by individual members and by the Secretariat for consultation on particular questions raised as work progressed. We are most grateful to Dr J D Terrell, District Medical Officer of West Cumbria Health Authority, and his staff for their assistance which facilitated our analysis of the available scientific data.

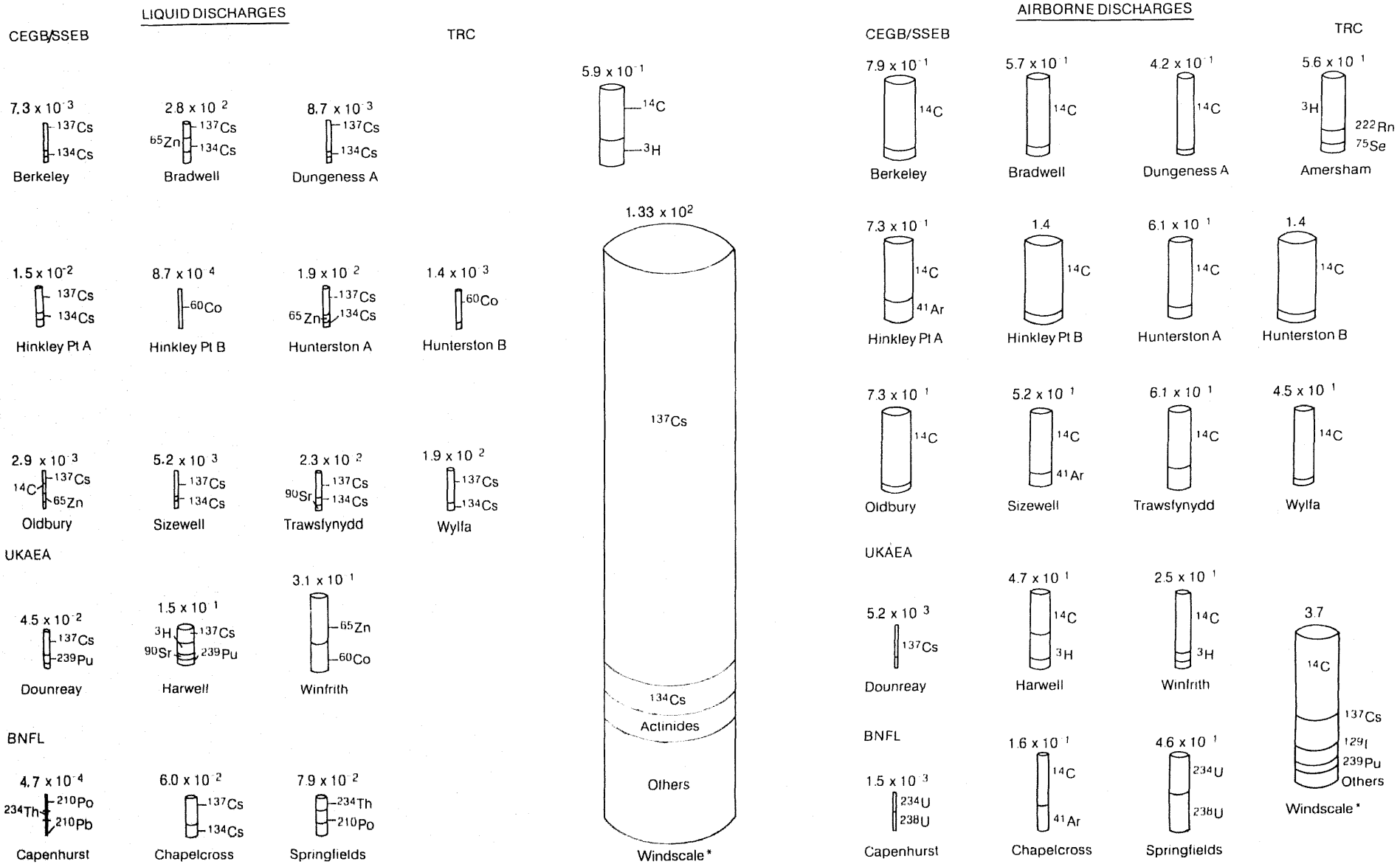
1.10 The Sellafield site includes a reprocessing plant for spent nuclear fuel. For that reason the airborne and liquid discharges are different in composition and quantity from those from other nuclear establishments in the United Kingdom. These discharges result in collective dose commitments to the public considerably greater than those from any other nuclear establishment in the United Kingdom (Figure 1.1).

1.11 In November 1983 an incident at the Sellafield site resulted in the release to sea of a quantity of liquid waste containing some solvent and a large quantity of the radionuclide Ruthenium-106, which emits beta rays and gamma rays. The discharge resulted in the appearance on the beaches of objects sufficiently contaminated with Ruthenium-106 that the Radiochemical Inspectorate of the Department of the Environment gave advice, endorsed by NRPB, that the public should avoid unnecessary use of the beaches. This incident was the subject of inquiries by the Nuclear Installation Inspectorate and the Department of the Environment, and of reports from NRPB and the Ministry of Agriculture, Fisheries and Food (MAFF).

1.12 We took the view that the incident itself fell outside the terms of reference of our Inquiry but that any insights the incident and subsequent investigations provided into the previous radiation exposure of the local population were relevant.

1.13 This report includes the results of several as yet unpublished epidemiological studies. We are satisfied that the conclusions we draw from the work we have quoted are unlikely to be changed substantially by any subsequent re-analyses, and we thank these authors for allowing us to refer to their work prior to publication. Where we make suggestions in the report for further work on a study we are frequently referring to the authors' own suggestions for improving the power of their study, and do not imply any criticism of the quality of the authors' work.

Figure 1.1 Collective dose commitments from liquid and airborne discharges during 1978, man Sv



** Renamed Sellafield in 1981. Includes discharges from Calder Hall Power Station.*

Note: Reproduced from Clark M.J. and Kelly G.N., Nuclear Energy 1982, 21(4) 275 – 288. Published by Thomas Telford Ltd. The collective dose commitment from liquid discharges made by BNFL, Sellafield in 1982 was 73 man Sv allowing for subsequent changes in dosimetry and reduced discharge levels.

1.14 We have provided a Glossary of the technical terms that we could not avoid using, and underlined terms included in the Glossary the first time they appear in the text.

1.15 The Group met sixteen times in all and in addition there were several meetings of sub-groups to consider specific points in greater detail. The three reports which NRPB prepared following discussions with the Group give the scientific basis of much of the data in Chapter 4 for those who wish to assess the evidence on which we based our conclusions on radiation exposure in more detail.

1.16 Finally we would like to thank the DHSS for providing the Secretariat to assist us in our investigations. Our Secretaries have been helpful, courteous and efficient in supporting us through quite a complex investigation, and we are all most grateful to them. We should, of course, make it absolutely clear that the views expressed in this report are those of the Independent Advisory Group and not necessarily those of the Secretaries.

References

Clark M J and Kelly G N (1982) Radiation exposure of the UK population from routine discharges by civil nuclear installations. Nucl. Energy. *21*, 275–288.

Department of the Environment (1984) An incident leading to the contamination of the beaches near to the British Nuclear Fuels Ltd., Windscale and Calder Works, Sellafield, November 1983. A Report of Investigations into the circumstances by the Department of the Environment Radiochemical Inspectorate.

Health and Safety Executive (1984) The contamination of the beach incident at British Nuclear Fuels, Ltd., Sellafield, November 1983.

Ministry of Agriculture, Fisheries and Food (1983) Incident leading to contamination of beaches near British Nuclear Fuels, Ltd., Sellafield, November 1983. Monitoring and assessment of environmental consequences undertaken by Ministry of Agriculture, Fisheries and Food.

National Radiological Protection Board—M101 (1983) Analysis and radiological assessment of survey results and samples from the beaches around Sellafield. Webb, G A M and Fry, F A.

National Radiological Protection Board—M102 (1984) Assessment of survey results from the beaches around Sellafield. Webb, G A M and Fry, F A.

CHAPTER 2

EPIDEMIOLOGICAL EVIDENCE AND RECOMMENDATIONS

BACKGROUND

2.1 Our initial concern was to establish whether or not there was an increased incidence or cluster of cancer, particularly in young people, in the area around Sellafield. The word cluster, which has a technical meaning related to a concentration of cases in space and time, will not be used in this Chapter because we are concerned with an extended time period.

2.2 Mr Cutler, the producer of the YTV film, told us that his original intention had been to look at the effects of occupational exposure to radiation in the nuclear power industry, and that initially he had approached BNFL at Sellafield with this in mind. BNFL had already published preliminary epidemiological studies on their workers (Clough 1983) and they agreed to co-operate. However, the attention of the YTV team was drawn to a number of children with leukaemia in Seascale. This led them to change the direction of their investigation, and to concentrate on the general population living near Sellafield.

2.3 The YTV study was carried out in an epidemiologically unconventional manner, cases of childhood cancer being identified by talking to local inhabitants and to the parents of affected children. Local registers were searched for deaths of children and death certificates obtained to establish the cause of death.

2.4 By proceeding in this way the YTV team collected information for the years 1956–83 on 7 young people with leukaemia who were under 22 years old at diagnosis, and living in Seascale. Using Census data they estimated that there was approximately a 10-fold higher incidence of leukaemia among children under 10 years old in Seascale when compared to the national incidence figures; this statement is based on 5 cases (Cutler 1983a).

2.5 The YTV team identified 25 young people under 22 years old with cancer in Millom Rural District dying or diagnosed between 1954 and 1983, including the 7 children with leukaemia in Seascale. These included 6 other young people with leukaemia, 2 children with lymphoma in Seascale, 3 young men with testicular teratoma in Millom Town, 3 children with brain tumours (one from Seascale), 3 children with sarcomas (one from Seascale) and one child with a kidney tumour (Urquhart 1983).

2.6 The YTV team claimed that the above findings demonstrated "a significant high excess of cancer and particularly leukaemia in children under 18 years old in the 5 coastal parishes south of Windscale in the last 25 years, and in the absence of any other readily apparent cause, the *possibility* of a link with environmental radioactivity from Windscale's discharges must be seriously investigated" (Cutler 1983b).

2.7 In a later television programme in April 1984 the YTV team claimed that there was an excess of cancer deaths among persons aged from 15–24 years in Maryport, a town to the north of Sellafield. They also referred to a further child in Seascale recently diagnosed as having cancer.

2.8 YTV had perforce to use unconventional and unsystematic methods to ascertain their cases. One of our tasks was to check the validity of their results. This included preparing, from official records where possible, a list of young people resident in the area who, since 1950 have died from cancer or have been diagnosed as suffering from cancer.

2.9 An exaggeration of the problem might have arisen in the way that the above data were used because the age group reported was defined by the ages of the discovered cases (paragraph 2.4). This is exemplified also in the statement in paragraph 2.6 with the choice of the age of 18 years as the upper limit. A statistically sounder method is first to define the age range of interest (0–14 years of age is most commonly used for childhood cancer) and then to ascertain the number of cases which fall within this defined range.

2.10 Selection of specific geographical areas for study on the basis of cases of cancer discovered in them may also lead to an artificial result. This can be seen by considering what would happen if there were 4 cases of leukaemia diagnosed in a particular town. The 4 (or fewer) streets where the 4 cases lived would each have a 'high' incidence of leukaemia, while all the other streets would have a zero incidence. This result would be a true description of the incidence of leukaemia in the different streets of the town. However it might reflect, not an aetiological influence peculiar to those streets, but merely the fact that 4 cases of leukaemia cannot occur in more than 4 streets. Similarly, if parishes are selected for study because cases of cancer are known to have occurred there, it is not surprising if the incidence of cancer in those parishes is found to be unusually high. The same comments apply to similar selection of certain calendar years, disease categories and age ranges for study.

DETAILS OF THE INDEX CASES

2.11 Tables 2.1–2.4 include those cases of leukaemia and other forms of cancer known to us by 1st June 1984 in the under 25 year old population of Millom Rural District based on information from YTV, death certificate data and the preliminary findings from an intensive review of hospital records being carried out for us by the West Cumbria Health Authorities. All of the studies considered below have included some of these index cases, grouping them variously according to time, age, sex, area and disease classification. It should be emphasised that the cases shown in the Tables may well be an incomplete list.

Table 2.1 Cases of leukaemia resident in Seascale since 1955 and aged under 25 years at diagnosis‡

Case No	Year of Birth	Place of Birth*	Year of Diagnosis	Year of Death	Place of Death**	Sex	Diagnosis‡
Case 1	1947	Outside Millom Rural District	1955	1956	Seascale	F	Acute lymphatic leukaemia
Case 2	1957	Outside Millom Rural District	1968	Alive	—	M	Acute lymphocytic leukaemia
Case 3	1957	Seascale	1960	1960	Seascale	M	Acute myeloid leukaemia
Case 4	1958	Seascale	1978	1979	Seascale	M	Chronic myeloid leukaemia
Case 5	1964	Seascale	1968	1970	Seascale	M	Chronic lymphocytic leukaemia
Case 6	1968	Seascale	1971	1971	Seascale	F	Acute lymphoblastic leukaemia
Case 7	1974	Seascale	1979	Alive	—	F	Acute lymphoblastic leukaemia

*Residential address of mother at time of birth
**Residential address at time of death
‡As recorded by certifying doctor

Table 2.2 Cases of leukaemia in Millom Rural District since 1955 and aged under 25 years at diagnosis‡ excluding cases in Seascale

Case No	Year of Birth	Place of Birth*	Year of Diagnosis	Year of Death	Place of Death**	Sex	Diagnosis‡
Case 8	1946	Other Millom Rural District°	1963	1964	Other Millom Rural District°	F	Erythroleukaemia
Case 9	1952	Other Millom Rural District°	1971	1971	Other Millom Rural District°	M	Acute myeloid leukaemia
Case 10	1953	Outside Millom Rural District		1973	Other Millom Rural District°	F	Acute lymphoblastic leukaemia
Case 11	1957	Other Millom Rural District°	1973	1974	Other Millom Rural District°	F	Acute myeloblastic leukaemia
Case 12	1957	Other Millom Rural District°	1957	1968	Other Millom Rural District°	M	Acute myelomonoblastic leukaemia
Case 13	?1963		?1984		Other Millom Rural District°		Leukaemia
Case 28	1939	Other Millom Rural District°	1958			F	Acute myeloid leukaemia

*Residential address of mother at time of birth
**Residential address at time of death
‡As recorded by certifying doctor
°Other Millom Rural District means Millom Rural District except Seascale

Table 2.3 Cases of lymphoma resident in Millom Rural District under 25 years at Diagnosis‡

Case No	Year of Birth	Place of Birth*	Year of Diagnosis	Year of Death	Place of Death**	Sex	Diagnosis‡
Case 14	1952	Seascale	1955	1955	Outside Millom Rural District	F	Lympho-sarcoma
Case 15	1961	Other Millom Rural District°	1984	Alive	—	F	Histio-cytosis X
Case 16	1974	Outside Millom Rural District	1983	Alive	—	M	?Non Hodgkin's Lymphoma
Case 17	1982	Seascale	1983	Alive	—	F	Non Hodgkin's Lymphoma
Case 29	1956	Other Millom Rural District°	1975	Alive	—	M	Lymphocytic Leukaemia
Case 30	1961	Other Millom Rural District°	1980	Alive	—	M	Hodgkin's Disease
Case 31	1961	Other Millom Rural District°	1982	Alive	—	F	Hodgkin's Disease
Case 32		Other Millom Rural District°		1969		M	Hodgkin's Disease

*Residential address of mother at time of birth
**Residential address at time of death
‡As recorded by certifying doctor
°Other Millom Rural District means Millom Rural District except Seascale

Table 2.4 Cases of solid tumours resident in Millom Rural District under 25 years at diagnosis‡

Case No	Year of Birth	Place of Birth*	Year of Diagnosis	Year of Death	Place of Death**	Sex	Diagnosis‡
Case 18	1955			1973	Millom Town	M	Teratoma of Testes
Case 19	1960			1976	Millom Town	M	Teratoma of Testes
Case 20	1964		1981	Alive	Millom Town	M	Teratoma of Testes
Case 21	1969	Outside Millom Rural District	1981	Alive		F	Suprasellar Teratoma
Case 22	1948	Seascale		1954	Seascale	M	Neuroblastoma of Adrenal
Case 23	1948	Other Millom Rural District°	June 1965	Alive	—	M	Cerebellar Astrocytoma
Case 24	1969	Outside Millom Rural District		1973	Millom Rural District	F	Neuroblastoma of kidney
Case 25	1955	Seascale		1964	Other Millom Rural District°	F	Sarcoma
Case 26	1969	Seascale		1975	Seascale	F	Retroperitoneal sarcoma
Case 27	1966	Outside Millom Rural District	1978	1979	Other Millom Rural District°	M	Ewing's Sarcoma of rib

*Residential address of mother at time of birth
**Residential address at time of death
‡As recorded by the certifying doctor
°Other Millom Rural District means Millom Rural District outside Seascale

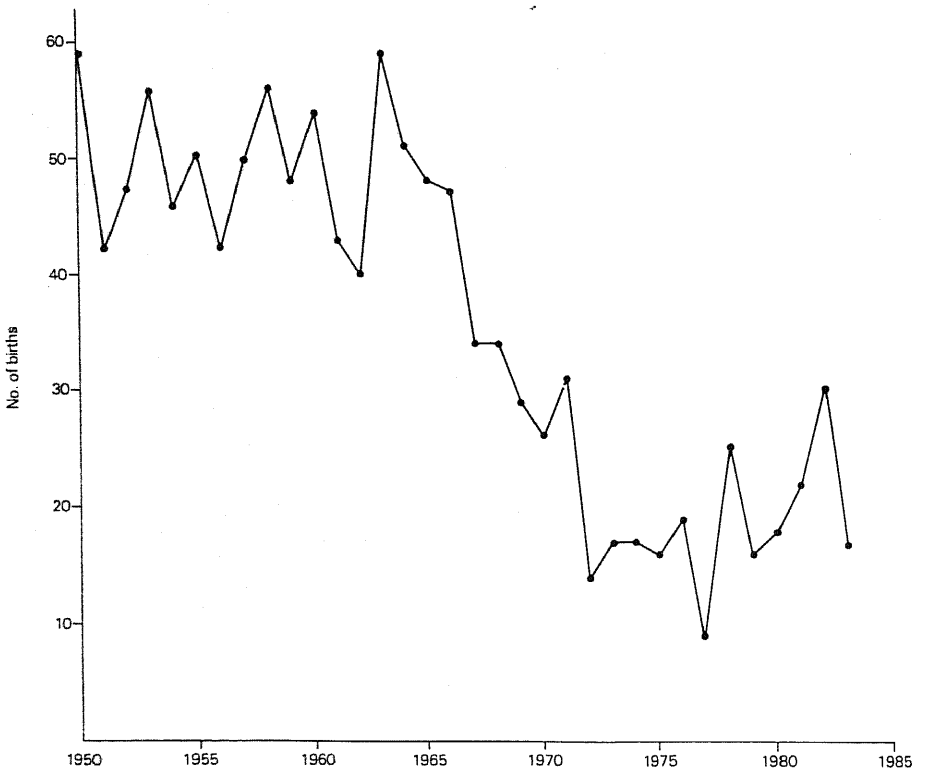
2.12 Seascale is not a typical West Cumbrian village. We were told that the Ministry of Supply and the United Kingdom Atomic Energy Authority (UKAEA) built much of the accommodation in the village to house its staff before and at the time that the Windscale Piles were under construction in 1952. We believe that BNFL continues to own a significant proportion of the houses. These are rented mainly to young graduates, who are a mobile population, possibly more likely to be working with radioactive material than the average BNFL employee.

2.13 We were also told that the population of Seascale was more mobile than that of many adjacent villages. This could affect the estimated incidence of cancer in various ways. For instance, the annual size of the population is not known accurately as Censuses are only undertaken every 10 years. This results in uncertainty about the numbers to be used in each age group to calculate rates or expected numbers of cases. Also, when considering the effect of a local environmental carcinogen on the incidence of malignant disease in such an area, the latent period between exposure and the development of malignancy can result in under-ascertainment due to emigration of cases. Such population movement is of particular importance when considering the incidence of cancers with long latent intervals between exposure and diagnosis, such as were found for solid tumours in those exposed following the dropping of atom bombs at Hiroshima and Nagasaki.

2.14 Figure 2.1 shows that the annual number of births in Seascale was highest from 1950–1965, at around 50 births per year. It fell subsequently to around 15 births per year in the early 1970's. More recently there has been a slight increase to around 20 births per year (Stevenson and Walker, 1984).

2.15 Figure 2.2 shows that of the 28 cases of childhood cancer considered, 4 were born in 1957 and 1 in 1958. However, only Case 3 was *in utero* in the area at the time of the Windscale fire in 1957; Case 4 was conceived around the time of the fire; and the birth of Case 2 was registered in Oxford. The other two cases (Numbers 11 and 12) were 5 months and 7 months old at the time of the fire. (Details of cases 29–32 were received too late to be included in this Table.)

Figure 2.1 Number of births/year in Seascale*



* M.D. Stevenson and B. Walker (SDB 442)

Figure 2.2a Year of diagnosis of cases in Tables 2.1—2.4

Key

° Born outside Cumbria
* Year of Death (year of diagnosis not available)
· Year unconfirmed

Cases 1—7 = Seascale Leukaemia
Cases 8—13 and 28 = Rest of Millom RD Leukaemia

Cases 14—17 = Millom RD lymphoma

Cases 18—27 = Millom RD solid tumour

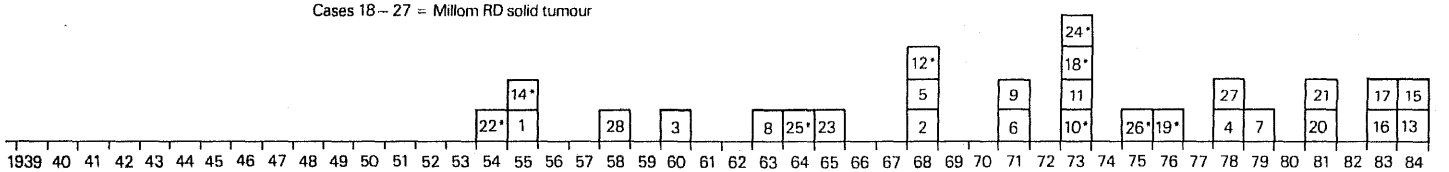
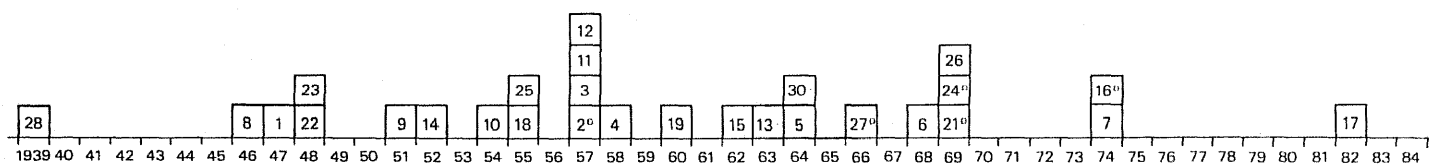


Figure 2.2b Year of birth of cases in Tables 2.1—2.4



2.16 *In utero* exposure to radiation via medical X-rays or nuclear medicine investigations was considered as a potential contributary cause. Of the 4 Seascale leukaemia cases for which the ante-natal notes have so far been traced, one had been exposed to diagnostic radiography during the last week of pregnancy (Case 6). One of the lymphomas (Case 14) had 4 X-ray exposures 3 weeks before birth. No details of X-ray exposure of the other 3 lymphomas have been obtained yet.

2.17 All of the fathers of the seven Seascale leukaemia cases, and three of the fathers of the five Seascale cases of other cancers worked at BNFL. These are not unexpected proportions given the predominance of BNFL employees resident in Seascale.

THE INCIDENCE OF CANCER IN CUMBRIA

2.18 Concern about patterns of cancer incidence and possible underlying causes is not a new phenomenon. Cumberland has been an area of interest to epidemiologists for many years, and a study of lung cancer in haematite miners in West Cumberland was reported as early as 1956 (Faulds and Stewart, 1956; Boyd et al, 1970). Studies on the incidence of cancer in Cumbria has been undertaken, and studies on cancer incidence around nuclear installations in the UK were in progress, before the YTV programme raised public interest. Table 2.5 gives summary details of some of the relevant studies which we have been able to examine.

Table 2.5 Summary of studies on the incidence of cancer in Cumbria

Study	Incidence Study	Death Rate Study	Period	Age Range in years	Diseases	Area
Tiplady	+	+	1951–77	All ages	All diseases	W Cumbria
Alderson, Ashwood and Cook-Mozafarri	+	–	1961–80	0–14 15–74	All cancers Selected Cancers All Leukaemias	Copeland District
	–	+	1959–80	0–14 15–74		
P Cook-Mozafarri	–	+	1969–78	0–24 25–44 45–64 65+	Leukaemia Radiation associated cancer Other cancer	Copeland District
Craft and Birch	+	–	1968–82	0–14	Cancer and acute lympho-blastic Leukaemia	Cumbria South Lakeland and Barrow
Urquhart Palmer and Cutler	–	+	1963–82	0–24	All Cancers Leukaemia	Seascale and coastal villages, Millom RD, Copeland,
	+	–	1968–83	0–14	All Cancers	
	–	+	1963–72 1973–82	15–24	All Cancers	Copeland Millom RD Allerdale Maryport
Palmer	–	+	1963–82	0–24	Leukaemia All Cancers	Five coastal parishes
Gardner and Winter	–	+	1968–78	All ages	All Causes All Cancers Leukaemia	Cumbria
	–	+	1959–67 1968–78	All ages 0–24	All Causes All Cancers Leukaemia	Millom RD Ennerdale RD Local Authority areas in Cumbria
Craft and Openshaw	+	–	1968–82	0–14	All Cancers All Lymphoid malignancies	Northern Children's Cancer Registry area
Gardner and Winter	–	+	1968–78	0–24	Leukaemia	152 Rural Districts

Key
+Included in study
–Not included in study

2.19 The Cumbria Area Health Authority published a report 'Leukaemia and other cancers in Cumbria' May, 1981 (Tiplady, 1981), which was later updated (Tiplady, 1983). Data on mortality from and registrations of leukaemia and other cancers for the period 1951–1980 were presented for Cumbria as a whole, and for East, West and South-West Cumbria Districts.

2.20 Leukaemia mortality in Cumbria 1951–1978 was lower than national rates when all ages are considered together. Overall death rates from leukaemia have doubled, both in Cumbria and in England and Wales, over this time period. However, in England and Wales these increases were restricted to persons over 75 years of age, whereas at some younger ages there have been decreases.

2.21 In West Cumbria, the age-standardised incidence of malignant disease among both men and women during 1969–77 was significantly lower than in England and Wales overall (Tables 2.6 and 2.7), and had not altered to a statistically significant extent when the incidence in 1974–1977 was compared with that in 1969–1973. When leukaemia is considered, again the

Table 2.6 Registrations of malignant neoplasms of lymphatic and haemopoietic tissue
West Cumbria (Males)

ICD Number		1969–1973			1974–1977			Significance of trend 1969/1973 to 1974/1977
		Number of Cases	Crude registration rates per million per year	Standardised registration ratios (SRR)	Number of Cases	Crude registration rates per million per year	Standardised registration ratios (SRR)	
200	Lymphosarcoma, and reticulm cell sarcoma	12	35·8	98·4	3	11·4	29·5*	**
201	Hodgkin's Disease	11	32·8	100·5	10	30·4	107·5	
203	Multiple Myeloma	13	38·8	148·0	9	30·4	99·6	
204	Lymphatic Leukaemia	4	11·9	34·7	15	53·3	145·4	**
205	Myeloid Leukaemia	8	23·9	80·2	9	34·2	100·1	
206	Monocytic Leukaemia	—	—	—	—	—	—	
207	Other and Unspecified Leukaemia	3	9·0	111·6	3	11·4	145·7	
204–207	All Leukaemias	15	44·8	60·0*	27	98·9	117·6	**
140–209	All Malignancies	1,003	2,293·0	90·2*	922	3,306·7	93·5*	

Table 2.7 Registrations of malignant neoplasms of lymphatic and haemopoietic tissue
West Cumbria (Females)

ICD Number		1969–1973			1974–1977			Significance of trend 1969/1973 to 1974/1977
		Number of Cases	Crude registration rates per million per year	Standardised registration ratios (SRR)	Number of Cases	Crude registration rates per million per year	Standardised registration ratios (SRR)	
200	Lymphosarcoma, and reticulm cell sarcoma	8	26·1	177·4	7	25·1	81·2	
201	Hodgkin's Disease	8	23·2	114·0	3	7·2	49·1	
203	Multiple Myeloma	11	31·9	131·7	11	35·8	126·7	
204	Lymphatic Leukaemia	11	31·9	151·9	7	25·1	154·8	
205	Myeloid Leukaemia	10	29·0	113·3	5	17·9	52·9	
206	Monocytic Leukaemia	—	—	—	—	—	—	
207	Other and Unspecified Leukaemia	3	8·7	111·6	3	14·3	145·7	
204–207	All Leukaemias	24	69·6	129·0	15	57·3	84·7	
140–209	All Malignancies	897	2,605·4	89·3*	872	2,951·3	91·0*	

(Tiplady, 1981, 1983)

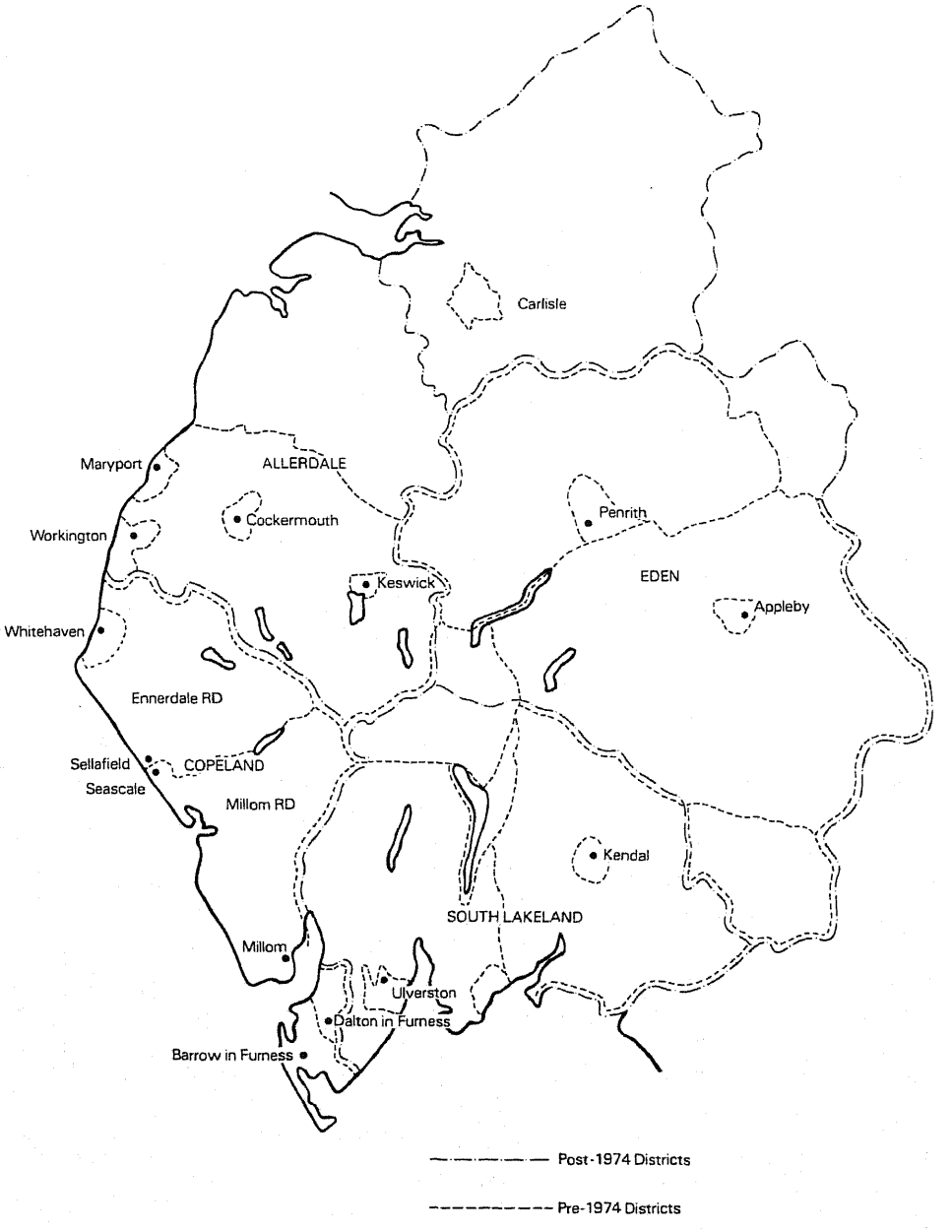
*Indicates SRR significantly differs from 100 at $p < 0{\cdot}025$
**Indicates difference between SRR's 1969/73 and 1974/77, significant at $p < 0{\cdot}025$

incidence was not significantly higher than expected in either sex. There were decreases in the registration rates for lymphosarcoma and reticulm cell sarcoma, but these are likely to be related to changes in diagnostic classification, which are known to have taken place nationally.

2.22 This evidence, while reassuring in that it demonstrates a generally low incidence of malignancy in West Cumbria considers all ages together and relatively large geographical areas. It does not exclude the possibility of a localised excess of cancer in young people living near Sellafield.

2.23 The Office of Population Censuses and Surveys (OPCS) study (Alderson et al 1984) used death certificate and cancer registry data to examine the incidence of cancer in Copeland District (Millom Rural District, Ennerdale Rural District and Whitehaven Municipal Borough) (Fig 2.3).

Figure 2.3 The Post-1974 County of Cumbria



The population was separated into a 0–14 year age group and a 15–74 year age group. As mentioned in paragraph 2.9, 0–14 years is the commonly accepted age-span for studying childhood tumours. Death certificate data for the period 1959–80 and incidence data for 1961–80 were used. A control location was selected which 'matched' the Sellafield location (Copeland District) consisting of Penrith Rural District, North Westmorland Rural District and Kendal Municipal Borough.

2.24 Census data for 1961, 1971 and 1981 were used for population estimates. Expected numbers were calculated using incidence and mortality rates by 5-year age-groups, for males and females separately, in the most appropriate 'standard' population. This was thought to be the Northern Region less the Tyne and Wear conurbation.

2.25 The results showed increased rates for leukaemia (all types aggregated) and lymphoid leukaemia in 0–14 year old males in Copeland District (Table 2.8) but not in females. When the 22 year period of the study was subdivided into 3 shorter periods (1959–65, 1966–75, 1976–80) there was no evidence for an increase in the Standardised Mortality Ratio (SMR) or the Standardised Registration Ratio (SRR) across the 3 periods when compared to the changes in the control location for either all cancers, all leukaemia or lymphoid leukaemia (Table 2.9). The population figures used in the OPCS study were approximate, but the study was considered adequate by the authors to identify a twofold increase in cancer rates.

Table 2.8 Cancer deaths and registrations in Copeland District

Site	Sex	1959–80 Cancer Deaths 0–14 years			1961–80 Cancer Registrations 0–14 years		
		Observed	Expected	SMR	Observed	Expected	SRR
All Malignant Sites	M	16	15·2	105·3	29	19·81	146·4
	F	9	10·26	87·7	12	14·45	83·0
Testis	M	0	0·09	0·0	1	0·4	250·0
All leukaemias (21–25)	M	10	6·67	149·9	14	5·99	233·7**
	F	3	4·43	67·7	5	4·5	111·1
Lymphoid Leukaemia	M	7	5·46	128·2	11	4·76	231·1*
	F	3	3·62	82·9	4	3·66	109·3
Myeloid Leukaemia	M	3	0·85	352·9	2	0·76	263·2
	F	0	0·70	0·0	0	0·61	0·0

Other sites studied and giving SMR/SRR not statistically significant were:— liver, bone, thyroid, all lymphoid, multiple myeloma, monocytic leukaemia, other leukaemia, leukaemia unspecified, lung, Hodgkin's , lymphosarcoma/lymphoid, benign brain/nervous, unspecified brain/nervous.

(Alderson et al, 1984)

*p <0·05
**p <0·01

Table 2.9 Comparison of SMR's and SRR's for Copeland and Control location for three time periods, by sex, site of malignancy, and age

Age Years	Site	Sex	Location	SMRs				SRRs			
				1959–65	1966–75	1976–80	No.	1961–65	1966–75	1976–80	No.
0–14	All Malignancies	M	Copeland	100	100	136	16	105	144	206	29
			Control	65	120	—	7	102	119	173	15
		F	Copeland	84	124	—	9	58	102	63	12
			Control	—	33	170	3	56	122	195	11
	All Leukaemia	M	Copeland	141	199	—	10	224	262	172	14
			Control	—	56	—	1	—	54	—	1
		F	Copeland	119	47	—	3	82	87	204	5
			Control	—	—	246	1	157	68	318	4
	Lymphoid Leukaemia	M	Copeland	141	146	—	7	224	236	231	11
			Control	—	—	—	0	—	—	—	0
		F	Copeland	119	61	—	3	82	114	145	4
			Control	—	—	514	1	157	88	456	4
15–74	All Malignancies	M	Copeland	99	97	91	1,353	96	84	89	1,582
			Control	72	81	82	860	57	69	85	983
		F	Copeland	102	102	108	1,074	97	87	96	1,465
			Control	91	94	89	733	73	77	96	983
	All Leukaemia	M	Copeland								
			Control	104	109	164	29	18	89	119	21
		F	Copeland	89	173	131	34	84	148	118	31
			Control	154	111	129	24	138	77	153	21
	Lymphoid Leukaemia	M	Copeland	109	70	38	16	78	91	96	18
			Control	104	109	206	17	18	88	95	10
		F	Copeland	89	248	55	19	84	255	46	19
			Control	154	149	71	15	138	129	116	13

(Alderson et al, 1984)

2.26 Dr P Cook-Mozaffari, as well as collaborating with the Office of Population Censuses and Surveys in the above investigation, is continuing a study of cancer rates around nuclear establishments initiated by Dr J A Baron. Preliminary results have shown raised leukaemia mortality in Copeland among persons under the age of 25 years during 1969–78 compared to England and Wales and to other rural Cumbrian districts.

2.27 A study based on data from the Manchester Children's Tumour Registry (set up in 1954) and the Northern Children's Cancer Registry (set up in 1968) reported cancer incidence rates and acute lymphoblastic leukaemia incidence rates in children under 15 years of age on an area basis (Craft and Birch, 1983). The incidence rates in Copeland District, which includes Sellafield (Figure 2.3) were among the highest of six areas examined in three time periods (1968–72, 1973–77 and 1978–82) (Table 2.10). However, there was no suggestion of any distinctive consistent pattern.

Table 2.10 Incidence per 100,000 person-years of all malignant disease and of acute lymphoblastic leukaemia in children under 15, resident in Cumbria 1968–82

Area	1968–72	1973–77	1978–82
All Malignant Disease			
Carlisle	6·7(8)	6·1(7)	9·6(10)
Allerdale	6·3(7)	9·4(10)	11·6(11)
Eden	17·6(9)	6·3(3)	11·4(5)
Copeland*	15·8(15)	10·6(9)	10·5(8)
S. Lakeland	14·7(15)	10·2(10)	8·8(8)
Barrow	9·8(9)	6·9(6)	13·0(10)
Acute Lymphoblastic Leukaemia			
Carlisle	1·6(2)	1·8(2)	1·9(2)
Allerdale	0·9(1)	3·8(2)	1·0(1)
Eden	0	0	0
Copeland*	6·3(6)	3·5(3)	2·6(2)
S. Lakeland	1·0(1)	5·1(5)	6·6(6)
Barrow	3·3(3)	1·2(1)	2·6(2)

*The Sellafield Site and Seascale village are in Copeland district. Figures in brackets are number of cases on which calculations are based.

(Craft and Birch, 1983)

2.28 All of the studies discussed in paragraphs 2.19–2.27 are open to the criticism that the geographical spread of the study was large and might conceal a local raised incidence of childhood leukaemia near Sellafield.

2.29 Cancer incidence and mortality in young people in smaller areas of Cumbria were examined by Urquhart, Palmer and Cutler (1984) using data obtained from OPCS. They found that 7 deaths from all cancers and 4 deaths from leukaemia had occurred in persons under 25 years of age in Seascale and four selected nearby coastal villages between 1963–82. These are statistically significant ($p<0.02$ in each instance) excesses over the numbers expected on the basis of death rates for England and Wales (Table 2.11). In

Table 2.11 Deaths per 100,000 person-years 1963–82 (and numbers of deaths) for England and Wales and for selected parts of Cumbria

Age	England and Wales	Copeland	Millom RD*+	Seascale and Coastal Villages
All Malignancies				
0–14	6·7	6·2(22)	7·7(6)	19·7(4)
15–24	7·9	12·3(27)	20·9(9)	27·5(3)
0–24	7·2	8·5(49)	12·4(15)	22·4(7)
All Leukaemias				
0–14	2·8	2·8(10)	3·8(3)	9·7(2)
15–24	2·1	3·2(7)	11·6(5)	18·3(2)
0–24	2·5	3·0(17)	6·6(8)	12·7(4)

*The population of Millom Rural District is about 20% of that of Copeland. The coastal villages and Seascale are the five coastal parishes in Millom Rural District nearest Windscale to the South and consist of Seascale itself, Drigg and Carleton, Bootle, Waberthwaite, and Muncaster. The population is about 5% of that of Copeland.

+There were 50 non-cancer deaths in Millom Rural District in the under 15 age group and 20 in the 15–24 age group; the non-cancer death rates are similar to those for England and Wales.

(Urquhart et al 1984)

the same age group in Millom Rural District, which includes Seascale (Figure 2.3), 8 deaths occurred from leukaemia in the same period ($p<0.01$). This paper also drew attention to an increase in the number of deaths from all cancers among the 15–24 years of age group in Maryport in 1973–82 as compared with 1963–72 (Table 2.12). However, no increase under the age of

Table 2.12 Deaths per 100,000 person-years from malignancy in 15–24 year old group (and numbers of deaths)

Years	E & W	Copeland	Millom RD*	Allerdale*	Maryport+
1963–72	8·4	12(11)	10(2)	—	0(0)
1973–82	7·4	14(16)	32(7)	6(7)	29(5)

*1974–81 only
+Maryport is a small part of Allerdale.

(Urquhart et al, 1984)

15 years was found. Maryport harbour is one of several places along the coast where silt (containing traces of radioactive material discharged from Sellafield) is preferentially deposited, and the paper suggested a possible connection between these two phenomena. However, interpretation of this increase, as with others in the papers we have looked at, is made difficult by the many rates examined—the more rates that are examined, the more high ones will be found by chance alone. When small numbers of cases are involved these high rates can occur purely by chance, and have no particular local interpretation.

2.30 At our request Dr M K Palmer extended this work to an examination of deaths from cancer in the under 25 year old population of the 5 coastal parishes immediately south of Sellafield (Bootle, Drigg and Carleton, Seascale, Muncaster and Waberthwaite) compared with the rest of Millom Rural District for the years 1963–80 (Tables 2.13 and 2.14). He found a greater

Table 2.13 Comparison of Observed and Expected Leukaemia Deaths in Millom RD during 1963–80

Age Group	*5 Coastal Parishes*			*Rest of Millom RD*		
	O	E	O/E	O	E	O/E
0–4	1	0·17	5·9	0	0·37	0
5–14	1	0·34	3·0	1	0·71	1·4
15–24	2	0·18	11·0	3	0·54	5·6
Total	4	0·69	5·8	4	1·62	2·5
Statistical Significance		p=0·005			p=0·08	

(Palmer, 1984)

O=Observed deaths
E=Expected deaths

Table 2.14 Comparison of Observed and Expected Deaths from Cancers other than Leukaemia in Millom RD during 1963–80

Age Group	*5 Coastal Parishes*			*Rest of Millom RD*		
	O	E	O/E	O	E	O/E
0–4	1	0·30	3·3	0	0·68	0
5–14	1	0·50	2·0	0	1·05	0
15–24	2	0·63	3·2	1	1·87	0·5
Total	4	1·43	2·8	1	3·60	0·3
Statistical Significance		p=0·065			—	

(Palmer, 1984)

O=Observed deaths
E=Expected deaths

than five-fold excess (statistically significant) of deaths from leukaemia in the under 25 year old population of these five coastal parishes (4 observed cases, 0·69 expected; p=0·005), and a 2·5-fold excess (not quite statistically significant) of deaths from leukaemia in the under 25 year old population of the rest of Millom Rural District (4 observed, 1·62 expected; p=0·08). Mortality from cancers other than leukaemia in young people under 25 years of age was also raised in the five coastal parishes (4 observed, 1·43 expected), which approaches the conventional level of statistical significance; in the remainder of Millom Rural District only one death from these cancers occurred compared to 3·60 expected. It must be noted that there are coastal parishes to the north of Sellafield, and also others further to the south than the five collectively grouped.

2.31 Gardner and Winter (1984a) examined data obtained for the Atlas of Cancer Mortality for England and Wales (Gardner et al 1983) which covered the years 1968–78. For Cumberland during this period at all ages there were deficits of 6% for men and 2% for women in the number of cancer deaths observed when compared with the numbers expected at national death rates, and slightly fewer leukaemias than expected (Table 2.15). Among specific

Table 2.15 Mortality by cause of death and sex in Cumberland during 1968–78

Cause	Men			Women		
	O	E	SMR	O	E	SMR
All	20,904	19,801	106*	19,755	18,570	106*
Non-cancer	16,811	15,464	109*	16,213	14,961	108*
Cancer	4,093	4,338	94*	3,542	3,608	98
Leukaemia	104	113·2	92	96	93·5	103

Key

O=Observed; E=Expected number of deaths at age, sex and cause specific rates in England and Wales 1968–78;

SMR= 100 ×(O/E)=Standardised Mortality Ratio. ICD 8 numbers are 140–209 for cancer and 204–207 for leukaemia.

*Significantly different from 100 at p<0·01.

(Gardner and Winter, 1984a)

types of cancer there were significant excesses (10–15%) for stomach, large intestine and pancreas. When Millom Rural District (containing Seascale) and Ennerdale Rural District (containing the Sellafield site, figure 2.3) were considered separately, the death rates at all ages were similar to those for Cumberland as a whole except for a raised leukaemia rate in Millom Rural District, which was not statistically significant (Table 2.16). If the under 25 year old group only is considered, there were apparent raised cancer death-rates in both areas during 1968–78 but not during the earlier years 1959–67. In Millom Rural District the excess was largely accounted for by leukaemia, for which there was a four-fold excess in the 1968–78 period, but this was not the case in Ennerdale Rural District. Looking at leukaemia deaths in young people under 25 years of age in Cumberland during 1959–67, there were statistically significant excesses in Carlisle County Borough and Wigton Rural District, while in the later period 1968–78 only Millom Rural District had a statistically significant excess.

Table 2.16 Mortality by cause of death and age in Ennerdale and Millom Rural Districts

Cause	Time period	Ennerdale RD			Millom RD		
		O	E	SMR	O	E	SMR
All ages							
All causes	1959–67	—	—	—	—	—	—
	1968–78	3,897	3,684	106*	1,785	1,737	103
Cancer	1959–67	564	548·5	103	234	266·9	88+
	1968–78	726	765·6	95	330	359·7	92
Leukaemia	1959–67	15	15·6	96	6	7·6	79
	1968–78	16	20·6	78	13	9·5	137
Age 0–24 yr							
All causes	1959–67	—	—	—	—	—	—
	1968–78	167	145·8	115	63	60·5	104
Cancer	1959–67	7	9·1	77	3	4·5	67
	1968–78	14	9·3	150	10	4·0	253+
Leukaemia	1959–67	3	3·3	91	1	1·6	63
	1968–78	4	3·3	121	6	1·4	435*

All causes figures not calculated for 1959–67; ICD 7 (1959–67) and ICD 8 (1968–78) numbers are, respectively, 140–207 and 140–209 for cancer and 204 and 204–207 for leukaemia.

Significantly different from 100 at *$p<0·01$, +$p<0·05$.

(Gardner and Winter, 1984a)

2.32 Assessment of the above data is complicated by the fact that these studies did not use the same periods of time, age groups and/or geographical areas. The selection depended mainly on the sources of data (Table 2.5). Where large areas are looked at, possible local excesses disappear. Using smaller areas excesses of childhood cancers are found in certain areas, but this approach increases the possibility that statistically significant excesses are found by chance as more areas are examined. The data collected by the YTV team spans the longest period.

2.33 The above results can be summarised as suggesting an approximately four-fold higher rate of leukaemia mortality in the under 25 year old population in Millom Rural District during 1968–78—or twofold during 1959–78 (Gardner and Winter, 1984)—and an approximately 10-fold higher rate of leukaemia incidence in the under 10 year old population of Seascale (paragraph 2.4; Urquhart et al 1984). No unusual cancer rates are found among the over 25 year old population of Millom Rural District or in Ennerdale Rural District.

CANCER INCIDENCE DATA FOR SMALL AREAS IN THE UNITED KINGDOM

2.34 The above results suggested that Seascale and Millom Rural District might have experienced unusually high incidence rates of leukaemia in young people. However, the findings are based on small numbers of cases. Excesses of cancer over the levels expected were also reported in Carlisle and Wigton among people under the age of 25 years during 1959–67 (Gardner and Winter 1984), and we are aware of leukaemia 'clusters' reported in other areas of the country, not all in the neighbourhood of nuclear plants. It was thus important to compare the rates in Seascale and Millom Rural District with levels in similar communities throughout the region and country to enable us to assess how unusual such increased rates may be.

2.35 Dr A. Craft used the Northern Children's Cancer Registry to calculate cancer and leukaemia incidence rates among under 15 year-olds for each of the 765 electoral wards in the region (Craft and Openshaw, 1984). He estimated that the Registry contained more than 98% of the 0–14 year old cases of childhood cancer occurring in the catchment area. He was able to use incidence rather than death certificate data, an increasingly important point now that therapy for childhood leukaemia has improved and a significant proportion of the patients survive for many years. These data are available for 1968–82. The expected rates used to calculate Standardised Mortality Ratios (SMRs) are based on population figures from the 1981 Census. This could be a source of error, since the size and age distribution of the under 15 year old populations of the wards in earlier years might have been different. For example, the childhood populations of Seascale, the 5 coastal parishes and the rest of Millom Rural District in the last 3 Censuses are shown in Tables 2.17 and Figure 2.4. Thus, although an over-estimation of the risk in

Table 2.17 Childhood Population of Seascale, the 5 coastal parishes and the rest of Millom Rural District in the 1961, 1971 and 1981 Censuses

	Area	1961 Census	1971 Census	1981 Census
0–14 Year old Population	Seascale	606	603	411
	5 Coastal Parishes	1,275	1,085	741
	Rest of Millom Rural District	2,623	2,278	1,849

(Palmer, 1984)

Seascale could be occurring, there is evidence for a similar decline in the young population in adjacent areas over the years. The change of population numbers under 15 years of age in other more distant wards of the region is not known. Dr Craft intends to recalculate incidence rates incorporating earlier census figures to provide a more accurate assessment.

2.36 In this study of 765 electoral wards Seascale ranked sixth highest in incidence rates for all childhood cancers (Table 2.18). The rate in Seascale,

Table 2.18 Ranking of cancer incidence rate per 1,000 children—top ten of 765 electoral wards in Northern Region

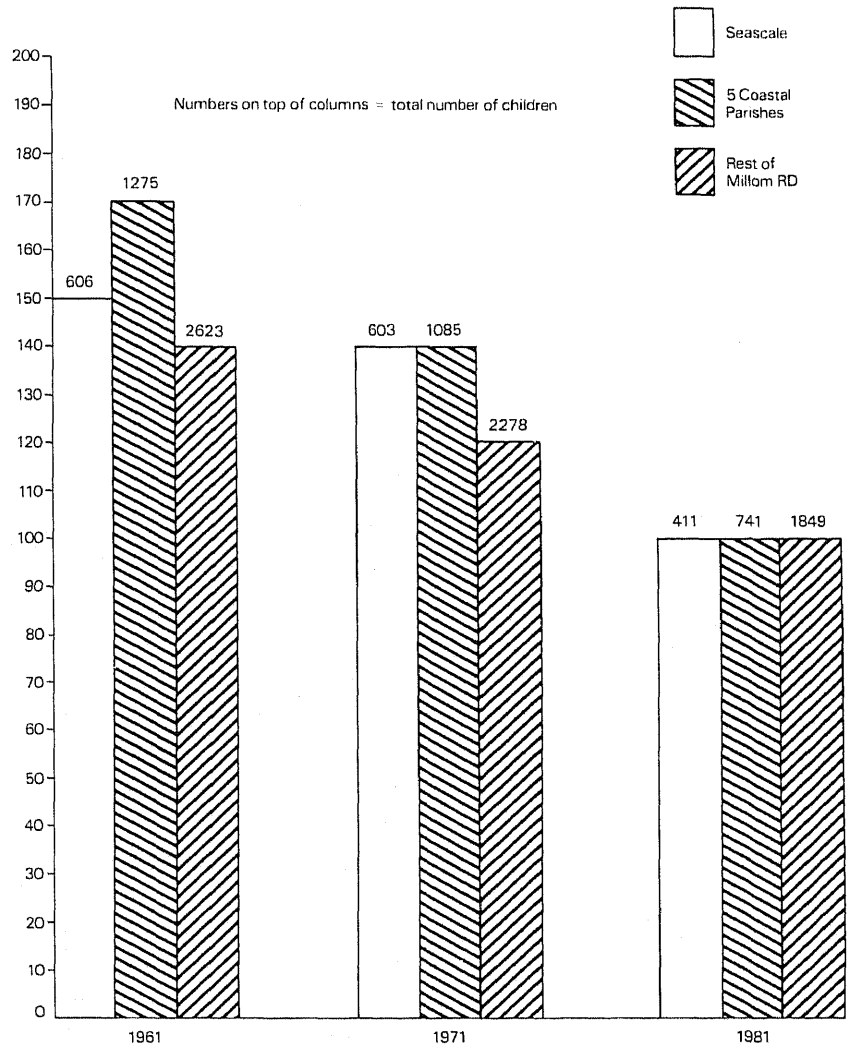
Ward Rank Order	Number of Cancer Cases	Population 0–14 years	Rate/1,000 Children	Poisson Probability	Ward Incidence Regional Incidence
1	2	97	20·61	0·012877	11·78
2	2	133	13·88	0·026891	7·93
3	2	165	12·12	0·034471	6·92
4	2	183	10·92	0·041544	6·24
5	3	281	10·67	0·013771	6·10
6*	4	411	9·73	0·006318	5·56
7	6	676	8·87	0·001397	5·07
8	2	231	8·65	0·062698	4·94
9	8	953	8·39	0·000342	4·79
10	5	605	8·26	0·004643	4·72

*Seascale

(Craft and Openshaw, 1984)

although based on only four cases, is statistically significantly raised ($p=0·006$) above the regional incidence by an estimated factor of between 5 and 6 fold. When the wards with the highest rates were plotted on a map, no obvious goegraphical pattern emerged.

Figure 2.4 Percentage of children 0—14 in Seascale, 5 Coastal Parishes and Rest of Millom RD in 1971 and 1961 Census data relative to 1981 Census data.



(Palmer, 1984)

2.37 For the years studied, Seascale had the third highest incidence rate of childhood 'lymphoid malignancy' among the 765 electoral wards (Table 2.19). Again the rate in Seascale is based on (the same) 4 cases, but is

Table 2.19 Ranking of lymphoid malignancy incidence rate per 1,000 children—top ten of 765 electoral wards in Northern Region

Ward Rank Order	Number of cases	Child Population	Rate/1,000 Children	Poisson Probability	Ward Incidence Regional Incidence
1	2	144	13·88	0·003622	22·82
2	1	97	10·30	0·057317	16·94
3*	4	411	9·73	0·000134	15·99
4	1	165	6·06	0·095528	9·96
5	1	172	5·81	0·099373	9·55
6	1	174	5·74	0·100468	9·44
7	1	184	5·43	0·105925	8·93
8	1	189	5·29	0·108641	8·69
9	1	198	5·05	0·113510	8·30
10	1	203	4·92	0·116203	8·09

*Seascale (Craft and Openshaw, 1984)

statistically significantly ($p=0·0001$) raised over the regional level by a factor of about 16. If the population of under-15 year-olds is taken as the high figure of 606 for the whole period (1961 Census data, Table 2.17), the estimated incidence rate in Seascale is still higher than the fourth ranking ward. Again there was no tendency for wards with higher rates to be in West Cumbria rather than in other parts of the Northern Region.

2.38 Comparisons with other areas were also carried out by Gardner and Winter (1984b), who examined leukaemia mortality among young people under the age of 25 years in each of the 469 Rural Districts in England and Wales during 1968–78. They found 7 with statistically significant raised leukaemia death rates in the under 25 year-old group. This is fewer than might be expected (about 12) to occur by chance if the underlying rates were the same in all areas, and the observed differences were due only to the limited number of calendar years and hence limited numbers of deaths studied. Millom Rural District, however, had the second highest rate out of 152 similar sized Rural Districts (Table 2.20).

Table 2.20 Distribution of mortality from leukaemia under 25 years of age in 152 rural districts of England and Wales of similar size to Millom Rural District*

Standardised Mortality Ratio (SMR)	Number of Rural Districts*	
	Observed	Predicted
0–	35	35·7
50–	43	50·2
100–	26	25·9
150–	26	22·5
200–	14	9·2
250–	5	5·4
300–	1	1·8
350–	0	0·9
400+	2	0·4
Total	152	152

*Similar-sized Rural Districts are those with an expected number of leukaemia deaths of between 1 and 2 in persons aged 0–24 years during 1968–78. Millom Rural District had an expected number of 1·4 deaths, but 6 deaths were recorded giving an SMR of 435. This value is the second highest in the Observed column of this Table.

+Observed=SMRs as they occurred; Predicted=SMRs as predicted on the basis of a Poisson distribution for each Rural District with its specific expected number of deaths.

(Gardner and Winter, 1984b)

2.39 Gardner and Winter also considered the distribution of mortality rates that would be expected among the 152 Rural Districts of a similar size to Millom Rural District if they all had the same underlying leukaemia age-specific death rates in young people under the age of 25 years. Because of the limited time period studied, from 1968–78, the expected numbers of deaths were between 1 and 2 in each of the Rural Districts—the expected number in Millom Rural District being 1·4. Assuming that the number of observed deaths in each Rural District followed a Poisson distribution, Table 2.20 shows the comparison of the observed and predicted distributions*. It can be seen that they are not very different overall, which is confirmed by a formal statistical test. Millom Rural District, as said above, had the second highest mortality rate, being one of the two areas with an SMR over 400 compared with the 0·4 areas predicted.

2.40 It is important to note that in neither of the latter two studies were the rates in the areas of interest (Seascale and Millom Rural District) above the observed range, but they were close to the top. Thus, the Seascale incidence and Millom Rural District mortality rates for leukaemia among young people are unusual, though not unparalleled.

2.41 It has already been mentioned that the discharges from Sellafield are much larger than those from other nuclear plants around the country (paragraph 1.10). We are aware of work in progress on the incidence of leukaemia and cancer around other nuclear power stations in England and Wales but none was completed in time for us to consider in our report.

OTHER DATA

(i) Scottish Data

2.42 A report by Heasman et al (1984) was made available to us. The stud showed a statistically significantly higher registration rate for myeloi leukaemia ($p<0.05$) in the 0–24 year old group between 1968–74 on the West Coast of Scotland, but this was diminished during 1975–81. There was a lower registration rate for lymphoid leukaemia during the earlier period, and while the registration rate for all leukaemias was higher on the West Coast than in the rest of Scotland, this excess did not reach statistical significance. While it is possible that the excess of myeloid cases was due to incorrect coding, registration or diagnosis, there is obviously need for further investigation of this matter and we understand that this is now being undertaken.

(ii) Down's Syndrome in Maryport Town

2.43 While we were preparing this report the Daily Mirror reported that 4 women born in the same street in Maryport all subsequently had children with Down's Syndrome (Foot P. 1984a). Later a further 4 cases of Down's Syndrome in the children of mothers living in Maryport were reported (Foot 1984b, Foot 1984c). There was also a suggestion that several cases of Down's Syndrome in Eire might be related to discharges from Sellafield (Sheehan and Hillary, 1983). To interpret these data it is clearly necessary to have more details of the population from which these groups are drawn. Apart from the fact that this subject fell outside our terms of reference, its proper assessment would require detailed studies of maternal age-specific rates of congenital disease. Such an investigation was not feasible in the time available. Recognising these concerns we have, however, made a recommendation for further research at the end of this Chapter.

*There is a well-known statistical result stating that when a small number of events are shared out without bias the numbers in each share differ according to a formula, the Poisson distribution. This formula can be used to test whether an observed distribution of events is more variable than could be explained by chance (eg the numbers of leukaemia cases in Rural Districts of England and Wales).

DISCUSSION

2.44 Seascale had the third highest incidence rate of lymphoid malignancy in under 15 year-olds among 765 electoral wards in the region covered by the Northern Children's Cancer Registry between 1968–82, and Millom Rural District had the second highest death rate from leukaemia in under 25 year-olds among 152 similar-sized Rural Districts between 1968–78 throughout England and Wales. This does not necessarily mean that radioactive waste discharged from the Sellafield site into the atmosphere and sea nearby is the cause of the increase. The effect of chance or some other unidentified cause cannot be excluded, and the fact that the other electoral wards and Rural Districts with increased rates were geographically scattered outside the area around Sellafield is relevant here.

2.45 In the electoral ward study the number of leukaemia cases registered in each ward was necessarily small because of the rarity of the disease, the small size of electoral wards, and the limited time period of observation. In Seascale there were four cases during 1968–82, and in Millom Rural District there were 6 leukaemia deaths in Millom Rural District during 1968–78. Even though the above studies are based on small numbers, nevertheless they are consistent in demonstrating a higher incidence of leukaemia in young people resident in the area.

2.46 Most cases of childhood leukaemia are of unknown cause, and therefore caution is necessary in interpreting the results described above. An observed association between two factors does not prove a causal relationship. Some third, possibly unthought of factor might be the cause. We have already seen that Seascale is not a typical West Cumbrian village. It has been suggested to us that such factors as the consumption of unpasteurised milk and the discharge of untreated sewage into the sea may be relevant. But there is no scientific evidence that these are important in the aetiology of childhood leukaemia. Radiation is the only established environmental cause of leukaemia in children within the limits of present knowledge. While there is evidence that radiation-induced leukaemia in adults usually results in myeloid leukaemia, there is not known to be such an association of myeloid histology with radiation-induced childhood leukaemia.

2.47 In the Annex to Chapter 3 and in Chapter 4 we will look at the environmental features of the area to see whether radiation exposure or exposure to any other environmental factor is likely to be contributory to this high incidence.

RECOMMENDATIONS FOR FURTHER EPIDEMILOGICAL RESEARCH

2.48 Having reviewed the epidemiological evidence available we feel the following studies could provide additional information.

Case-control study

2.49 We recommend that a case-control study to investigate relevant features of the records on cases of leukaemia and lymphoma which have been diagnosed in young people under the age of 25 years in the West Cumbria Health Authority area since 1950 should be undertaken. The intention would be to compare them with a control group of young people—appropriately selected—who have not developed leukaemia or lymphoma. We suggest that both leukaemias and lymphomas be studied because there are sometimes difficulties in differentiating between these two diseases, and we would exclude other childhood cancers because the evidence for any excess of these in the area is less strong.

2.50 We recognise there will be many difficulties in setting up a study of this kind, covering a 30 year period and based on index cases many of whom will have died. Nevertheless, we believe it is important to investigate the possibility of studying the index cases in more detail than has yet been done.

2.51 We have been involved in discussions with the Department of Health and Social Security about this study, and the initial work is in hand.

Birth cohort study

2.52 We recommend that a study be carried out on the records of all children born since 1950 to mothers resident in Seascale at the time of birth to examine cancer incidence and mortality (i.e., a birth cohort study).

2.53 The routine analysis of leukaemia incidence and mortality data using currently available statistics is restricted to people developing cancer while resident in an area. However, given the mobility of the population, this approach has limitations. A birth cohort study would identify all cases of cancer diagnosed among children born in Seascale, even after they have left the area.

2.54 Preparations for this study have commenced, and a list of births to mothers resident in Seascale between 1950–1983 is being compiled. This list will form the basis of the birth cohort study.

School studies

2.55 The registers for some local schools are available. The feasibility o using this information to trace records on the children and to establish th incidence of cancer among them should be examined.

Further work using the cancer registries

2.56 Dr Craft's study on cancer incidence in the 765 electoral wards in the catchment area of the Northern Children's Cancer Registry has already been mentioned. Because of the short time available to Dr Craft to complete this study in time for our report, the number of children at risk was based on those resident in the electoral wards and under 15 years of age in the 1981 Census. We are aware that the population of Seascale has fluctuated over the last 30 years, and do not know how the populations of other electoral wards in the area have fluctuated in this period.

2.57 We recommend that Dr Craft should be asked to extend his calculations using 1961, 1971 and 1981 Census population data where appropriate. It may also be useful if the data could be recorded to include place of residence at birth as well as at diagnosis.

2.58 Childhood leukaemia is more common under the age of five, and if the proportion of children under the age of five was excessively large in Seascale compared to the national figure, this could result in an apparent excess of cases in the 0–14 year-old age group.

2.59 We recommend that cancer incidence by electoral ward in the Northern Children's Cancer Registry area be standardised for age at diagnosis in order to determine whether the excess of leukaemia in Seascale might be related to any unusual features of the age distribution of the children there.

Down's Syndrome

2.60 Preliminary data from the area (Dr Terrell, 1984) suggest an incidence of Down's Syndrome for Maryport of 1 in 660 from 1968–1983. This figure is not much different from the expected population incidence of 1 in 600 births (Mikkelsen M, 1981). We know of no cases of Down's Syndrome occurring in Seascale itself, not is there any suggestion of a high incidence in other surrounding areas. However, because the incidence of Down's Syndrome is strongly related to maternal age and because total ascertainment of cases requires the collation of multiple sources, these data must all be regarded as preliminary.

2.61 The evidence on whether parental irradiation causes chromosomal aneuploidies such as Down's Syndrome is conflicting (reviewed by Bond DJ and Chandley AC, 1983). There was no detectable increase in the condition amongst the survivors in Japan of the atom bombs. Among 12 studies which have been published examining the history of medical radiation exposure in mothers of cases there are conflicting results. The majority of these studies do, however, suggest a detectable positive relationship which does not always achieve statistical significance.

2.62 Given that there is, therefore, some reason for believing that parental irradiation may be a cause of chromosomal anomalies such as Down's Syndrome, we recommend that a detailed study to determine the maternal age-specific frequency of congenital chromosomal disorders in the vicinity of Sellafield should be undertaken.

References

Alderson M R, Ashwood F L, and Cook-Mozaffari P (1984) Mortality and Cancer Registrations in the vicinity of nuclear installations in England and Wales. Submission to Black Advisory Group, (SDB 596/H24).

Bond D J and Chandley A C (1983) Oxford Monographs on Medical Genetics *11* Aneuploidy; Oxford University University Press.

Boyd J T, Doll R, Faulds J S and Leiper J (1970) Cancer of the lung in Iron ore (haematite) miners. Br J Ind Med 27 (2) 97–105.

Clough E A (1983) Further Report on the BNFL Radiation Mortality Study. J Soc Radiol Prot *3* (3) 18–20 (SDB 26/I2).

Cook-Mozaffari P (1984) Deaths from cancer in South Coastal Cumbria (Copeland District). Submission to Black Advisory Group (SDB 587/H13).

Craft A W and Birch J M (1983) Childhood Cancer in Cumbria. Lancet, December 3rd, 1299 (SDB 532/H21).

Craft A W and Openshaw S (1984) Childhood Cancer in Northern Region, 1968–82. Personal communication to Sir Douglas Black (SDB 555/H21).

J Cutler (1983a) Young Leukaemia Cases in Seascale. Personal communication to Sir Douglas Black (Report 2, SDB 178/I1/P1).

J Cutler (1983b) Childhood Cancer near Windscale. Statement to the Black Advisory Group, 12th December 1983 (SDB 177/I1/P1).

Faulds J S and Stewart M J (1956) Carcinoma of the lung in haematite miners. J Path Bact *72* 353–366.

Foot P (1984a) Just Coincidence, Daily Mirror, February 9th 1984, p4 (SDB 709/C6).

Foot P (1984b) Coincidence Strikes again, Daily Mirror, February 23rd 1984, (SDB 709/C6).

Foot P (1984c) Riddle of the sands, Daily Mirror, April 19th 1984, (SDB 709/C6).

Gardner M J and Winter P D, (1984a) Cancer in Cumberland during 1959–68 with reference to cancer in young people around Windscale. Lancet, 24 January 1984 (SDB 334/H4).

Gardner and Winter (1984b) Further analysis of leukaemia in young people in Rural Districts of England and Wales (SDB 345/H10; SDB 400/H10).

Gardner M J, Winter T D, Taylor C P and Acheson E D (1983) Atlas of Cancer Mortality in England and Wales, Wiley.

Heasman M A, Kemp I W, MacLaren A M et al. (1984) Incidence of leukaemia in young persons in the West of Scotland. Lancet May 26, 1984 188–1189 (EV7).

Mikkelsen M (1981 in Trisomy 21, Burgio G R, Fraccaro M, Tiepolo L, and Wolf U eds p 211, Springer Verlag.

Palmer M K (1984) Deaths from cancer at ages under 25 in 5 coastal parishes compared with the rest of Millom Rural District, 1963–80. Submission to Black Advisory Group (SDB 588/H28).

Sheehan P M E and Hillary I B (1983) An unusual cluster of babies with Down's Syndrome born to former pupils of an Irish Boarding School. Brit Med J *287* 1428–1429.

Stevenson M D and Walker B (1984) The incidence of acute childhood leukaemia in Seascale, Cumbria. Submission to Black Advisory Group (SDB 442/P2).

Terrell J D, Down's Syndrome in West Cumbria. Submission to Black Advisory Group (SDB 443/I6/P4).

Tiplady P (1981; 1983) Leukaemia and other Cancers in Cumbria. Submission to Black Advisory Group, Appendix A (SDB 254/I6).

J Urquhart (1983) Young Cancer Cases in Millom, West Cumbria. Personal Communication to Sir Douglas Black (Report 2, SDB 178/I1/P1).

Urquhart J, Palmer M and Cutler J (1984) Cancer in Cumbria: the Windscale connection. Lancet, 24 January (SDB 335/H4).

CHAPTER 3

SOME ENVIRONMENTAL ASPECTS OF THE SELLAFIELD SITE AND ITS RELATIONSHIP TO THE NUCLEAR POWER INDUSTRY IN THE UNITED KINGDOM*

INTRODUCTION

3.1 A summary of the main features of nuclear reactors and of the scientific background to the generation of power from nuclear fuel is contained in Chapter Three of the Royal Commission on Environmental Pollution (RCEP) Sixth Report: Nuclear Power and the Environment, published in 1976. The background material presented here was derived in part from that Report, and has been updated with data provided by British Nuclear Fuels plc (BNFL), the National Radiological Protection Board (NRPB), the Electricity Boards and relevant Government Departments where necessary. We have not critically assessed all the information in this chapter, which is provided largely to facilitate understanding of the following chapter.

3.2 The civil use of nuclear power to generate electricity commenced in the United Kingdom (UK) with the development of magnox reactors in the 1950s. In the 1970's the first Advanced Gas-Cooled Reactors were commissioned. Nuclear establishments in the United Kingdom are shown in Figure 3.1.

3.3 The 'nuclear fuel cycle' includes all operations involved in the fabrication and treatment of nuclear fuel, and is represented in simplified form in Figure 3.2. Sellafield is the nuclear site in the UK where spent fuel from nuclear power stations is reprocessed. There is a smaller scale reprocessing operation at Dounreay, which deals with fuel from fast breeder reactors.

*The Annex to Chapter 3 deals with non-radiation related environmental aspects of Cumbria.

Figure 3.1 Nuclear establishments in the U.K. (Exludes M.O.D. sites)

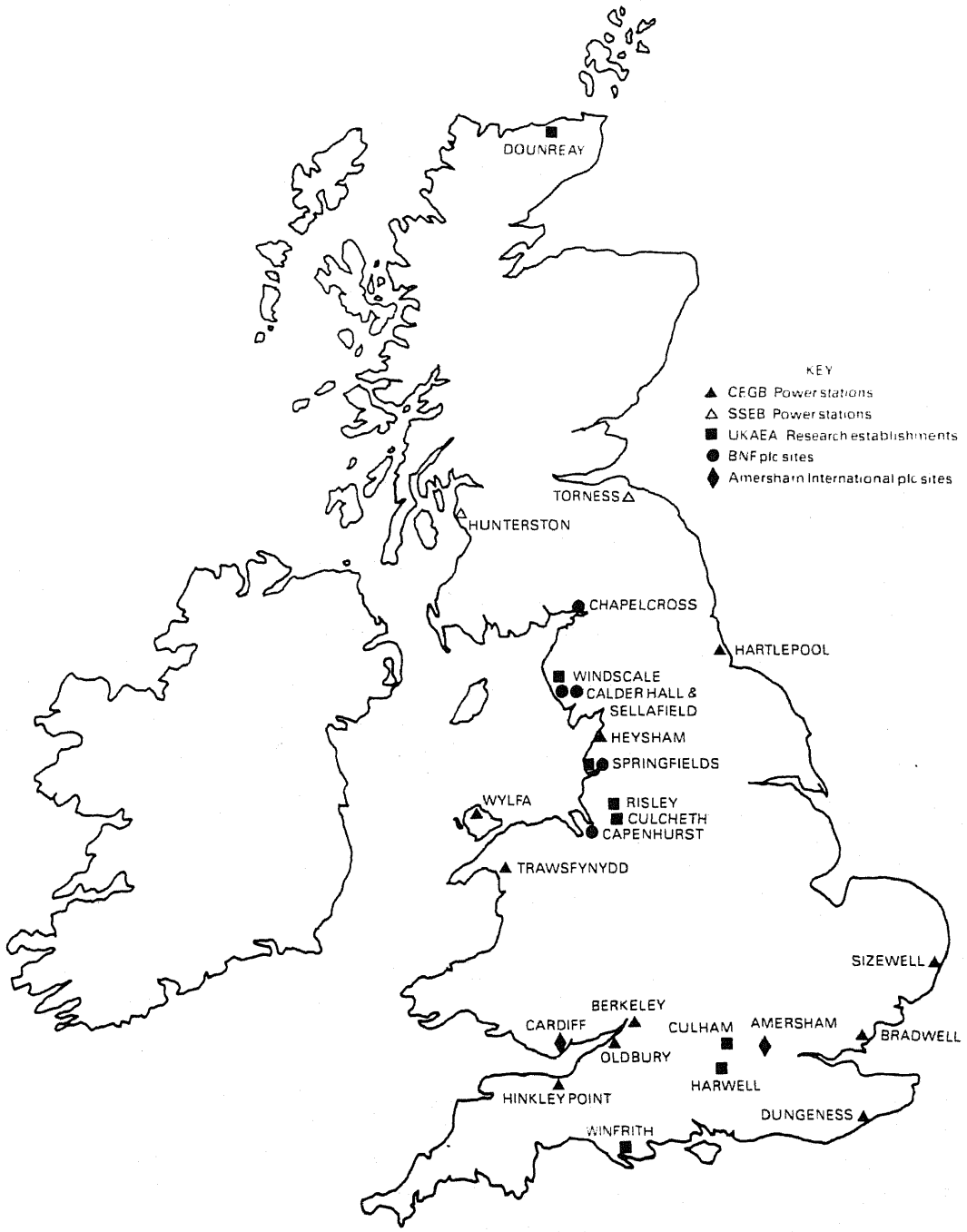
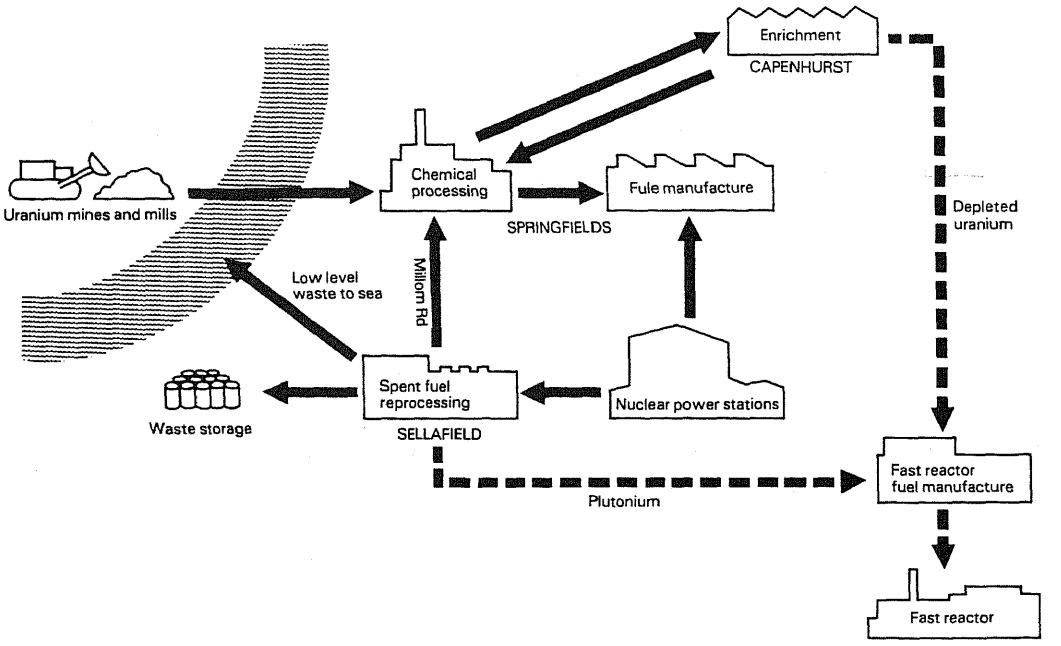


Figure 3.2 The nuclear fuel cycle



(adapted from a BNFL diagram)

THE SELLAFIELD SITE

3.4 The Sellafield site is located in West Cumbria near the coast. It was acquired in 1947 for the production of plutonium for defence purposes. Two nuclear reactors and a spent fuel reprocessing plant were in operation by 1952. Responsibility for the site was transferred from the Ministry of Supply to the United Kingdom Atomic Energy Authority (UKAEA) when it was formed in 1954 and subsequently transferred to BNFL when that company was formed in 1971. The various stages of development of the site are set out in Table 3.1

Table 3.1 **Stages in the development of the Sellafield site**

	Date Operational	**Date Shut down**
Site available July 1947	Work commenced Sept 1947	—
First and Second Pipeline to Sea	Laid June 1950	—
No. 1 Pile	Critical Oct 1950	Oct 1957
No. 2 Pile	Critical June 1951	Oct 1957
First Reprocessing Plant and Associated Facilities	Jan 1952 et seq.	Reprocessing Plant converted to Head End Plant for oxide fuel and used 1969 to 1973
First Calder Hall Reactor	Aug 1956	—
All Calder Hall Reactors	1958	—
Prototype Advanced Gas-Cooled Reactor	1963	April 1981
Second Reprocessing Plant and Associated Facilities (magnox fuel)	1964 et seq.	—
Spent Oxide Fuel Storage Plant	1968 et seq.	—
Prototype Fast Reactor Fuel Fabrication Plant	1970	—
Third Pipeline to Sea	Laid 1976	—

3.5 Reprocessing of magnox fuel from nuclear power stations around the country and from power stations at Latina in Italy and Tokai Mura in Japan takes place at the Windscale reprocessing plant situated on the Sellafield site. The site is also used for the storage of oxide fuel from the UK advanced gas cooled reactors and from overseas. There is also a plant for fabricating fuel for the UKAEA prototype fast reactor and there are 4 nuclear power reactors (Calder Hall) (Table 3.2). About 7 kilometres south of Sellafield on the coast at Drigg there is an authorised disposal site for low level radioactive waste, also owned and operated by BNFL.

Table 3.2 **Sellafield Site—principal civil functions 1983**

1. Receipt, storage and reprocessing of spent magnox fuel
2. Treatment and storage of products of processing
3. Receipt and storage of spent oxide fuel
4. Fabrication and storage of plutonium fuel elements for fast breeder reactors
5. Operation of Calder Hall reactors
6. Treatment and storage or disposal of waste products
7. UKAEA Research Laboratory

3.6 The nuclear component of the present energy supply of the United Kingdom depends on Sellafield (Figure 3.2). Nuclear power stations send their spent fuel to Sellafield either for reprocessing (if they use magnox fuel), or for storage (if they use zirconium-clad or stainless steel clad fuel). Facilities for on-site storage of spent fuel at power stations throughout the country are limited and if facilities for accepting spent fuel at Sellafield were to cease for any reason, then in due course the nuclear power stations would cease to function until further arrangements could be made for the storage of spent fuel.

RELATIONSHIP BETWEEN ON-SITE OPERATIONS AND DISCHARGES

3.7 It is important to differentiate between airborne and liquid discharges due to reprocessing and airborne and liquid discharges from a nuclear power station producing electricity. Figure 1.1 shows the magnitude of the collective dose commitments assessed by NRPB for the general public from discharges from different sites in the UK permitted to release radioactivity into the environment. The contribution from Sellafield is assessed to be far greater than that from any other site in the UK. For the purpose of this report we have assumed that the radiological risk arising from nuclear power operations in areas adjacent to other nuclear sites is likely to be substantially less than that in areas adjacent to Sellafield.

3.8 The discharges of radioactive waste from Sellafield arise from a variety of operations giving rise to particular combinations of isotypes—of differing radiobiological significance—which vary from time to time. BNFL told us that UK population exposure arises mainly from past and present liquid discharges from irradiated fuel storage and from reprocessing. Figure 3.3 shows the 'total alpha' and Figure 3.4 the 'total beta' liquid discharges since 1980 with BNFL's forward projections until the year 2000 based on their plans as announced up to October 1983. The projections are based on oxide fuel reprocessing in the Thermal Oxide Reprocessing Plant (THORP), commencing in 1990 and on both magnox and oxide fuel reprocessing continuing at least until the year 2000. BNFL announced in June 1984 that it is studying how quickly the discharges to sea could be reduced to as near zero as possible. The scheme to be implemented will be decided after discussions with Government Departments and regulatory bodies.

Figure 3.3 Annual total beta discharges to sea from Sellafield (Figure supplied by BNFL)

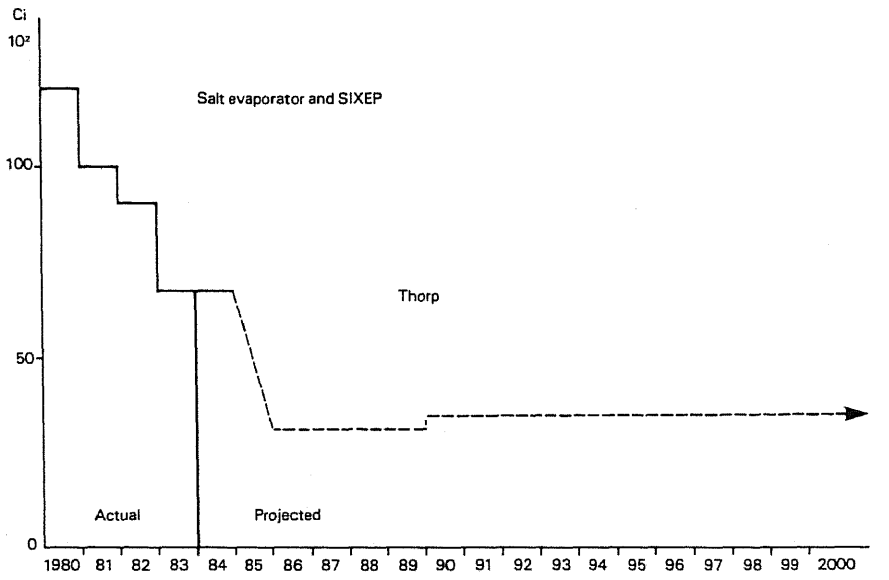
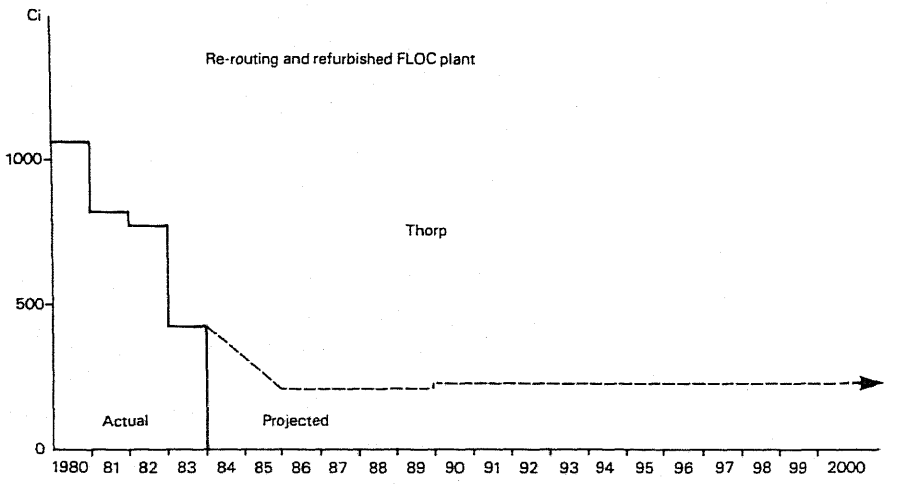


Figure 3.4 Annual total alpha discharges to sea from Sellafield (Figure supplied by BNFL)



3.9 The defence programme determined operations at—and therefore radioactive discharges from—the Sellafield site in its early years. The requirements of the civil nuclear power programme arose in the 1960's and have now become dominant. We were told by BNFL that at present approximately 70% of the 'total alpha' and 70% of the 'total beta' liquid discharge is attributable to storage and reprocessing of magnox fuel from Central Electricity Generating Board (CEGB) and South of Scotland Electricity Board (SSEB) nuclear power stations, and around 10% to reprocessing magnox fuel from overseas. About 1½% of liquid discharges is due to on-site storage of oxide fuel from UK nuclear power stations and a further 3% from storage of oxide fuel from overseas stations.

3.10 The Ministry of Defence (MOD) and BNFL have informed us, as an indicator of the potential significance of defence activities, that the operation of Calder Hall and Chapelcross nuclear power stations (for which MOD can request a change in the mode of operation to produce plutonium for defence purposes) has been responsible for about 15% of the liquid discharges from Sellafield over the past ten years. MOD and BNFL have also informed us that the radio-isotypes arising from meeting defence requirements have not differed from those arising from civil operations except in the case of Polonium in the early years. In their assessment of population exposure arising from Sellafield discharges, NRPB have taken account of this, and in particular of the accidental release of Polonium to the atmosphere in 1957 which occurred due to the increased temperatures reached during the Windscale fire.

DESCRIPTION OF FUEL REPROCESSING*

3.11 Magnox fuel has to be reprocessed to avoid the consequences of corrosion when stored under water for longer than about two year Reprocessing also permits Uranium and Plutonium to be recovered thu reducing the need for Uranium ore. Spent fuel from the nuclear power stations is initially stored at the power stations while its radioactivity decays to a level which permits its transport to Sellafield. It is then transported by British Rail in steel flasks (crash-resistant containers specially designed to tranport the fuel to Sellafield). BNFL told us that a small amount of spent fuel travels by road from Chapelcross. Fuel from abroad arrives by ship at Barrow, from where it is transported by British Rail to Sellafield. The spent fuel is placed in cooling ponds on arrival at Sellafield to await reprocessing. We understand that after the magnox fuel has been stored in water for about two years corrosion of the magnesium alloy containing the Uranium leads to corrosion of Uranium and release of fission products into the water. For this reason reprocessing should normally take place promptly so that total residence time in the ponds is less than about two years. The enforced cessation of reprocessing in 1973/4, due to a number of factors including the industrial relations problems widespread throughout UK industry at the time, increased pond stocks and residence time. As a consequence there were enhanced radiation levels for the workforce and enhanced discharges, primarily of Caesium isotopes, which were the source of the peak site discharges in 1974 and 1975. Discharges and pond stocks have been substantially reduced since then but the beta discharges from the site are still dominated by those arising from the magnox storage ponds. BNFL's forward projections (Figures 3.3 and 3.4) recognise the further reductions which are expected with the availability of new plant.

*Information in this section came from BNFL and the RCEP 6th Report.

3.12 Up to some 1,500 tonnes of irradiated magnox fuel is reprocessed at Sellafield each year and about 1,100 tonnes of irradiated magnox fuel is at present stored on site awaiting reprocessing.

3.13 Spent fuel from nuclear reactors other than magnox is either clad in zirconium or stainless steel. This does not corrode as rapidly as magnox fuel and can thus be kept for much longer periods in the cooling ponds. At present about 1,200 tonnes of spent oxide fuel from overseas is stored on site together with about 350 tonnes of UK spent oxide fuel. None of this spent fuel will be reprocessed until the Thermal Oxide Reprocessing Plant (THORP) is completed in 1990 (Table 3.3)

Table 3.3 **Major new plant at present under construction at the Sellafield site**

	Operational
1. New spent fuel storage and decanning complex	Phased from early 1985
2. Site Ion Exchange Effluent Treatment Plant (SIXEP)	Early 1985
3. Salt Evaporator Effluent Treatment Plant	Early 1985
4. Waste Treatment Complex	1988
5. Vitrification plant for high activity liquid waste	1988
6. Thermal Oxide Reprocessing Plant (THORP)	1990

3.14 Magnox power stations are no longer being built, but we were told that those presently in use could have an anticipated further life of 8 to 15 years. Therefore it is expected that there will be a need to reprocess magnox fuel at Sellafield up to about the year 2000.

MANAGEMENT OF RADIOACTIVE WASTE

3.15 After reprocessing, all radioactive products except low activity waste are stored on site, and therefore need not be considered further in this report. Some low activity waste is discharged to sea (liquid) to atmosphere (gaseous) or sent to the Drigg Site (where solid material is buried in trenches) subject to the authorisation under the Radioactive Substances Act 1960.

3.16 Low level liquid waste is discharged to sea via pipelines crossing the railway line and the river Ehen to discharge 2·1 kilometres to seaward of the low tide line.

3.17 Gaseous wastes consist largely of inert gases and Iodine. They may contain particulate material which could leave the site as part of airborne emissions, and therefore high efficiency particle absorbers (HEPA) are installed where appropriate.

3.18* The International Commission on Radiological Protection (ICRP) has issued guidance on the control of occupational and public exposure to radiation with the exception of natural and medical exposures. These recommendations form the basis of a European Directive on Radiation Protection and have been endorsed by the NRPB. In summary, the dose equivalent to members of the public should be limited both by complying with a dose limit and by keeping all doses as low as reasonably achievable (ALARA), economic and social factors being taken into account. The dose limit relates to the sum of the annual effective dose equivalent from external irradiation and the committed effective dose equivalent from intake of radioactive materials in the same year. It is to be applied to the average member of the 'critical group'. A 'critical group' is a term applied to those people in the exposed population, generally only few in number, who are likely to receive the highest levels of dose. Because 'critical groups' are

*Paragraphs 3.18–3.21 were largely provided by NRPB.

exposed at a higher level than the rest of the population they are chosen to be relatively homogeneous with respect to characteristics that affect the doses received. The currently recommended dose limit is 5 mSv (500 mrem) in a year. The effect of the additional requirement to keep all doses as low as reasonably achievable and of the widespread use of maximising assumptions in assessing the dose equivalent actually received by members of 'critical groups' is such as to make it very likely that the average dose equivalent over a lifetime to a member of a 'critical group' is no more than 1 mSv in a year. The NRPB would expect the control of radioactive wastes to be such as to achieve this long-term average and thus the corresponding lifetime dose equivalent of 70 mSv.

3.19 The additional risk of death for a group of men and women uniformly exposed over a lifetime at an average level of 1 mSv in a year would be estimated to rise from zero in the first few years to about 1 in 10^5 per year (1 in 100,000) after several decades. The average additional risk of death to the whole populations for which the 'critical groups' represent the highly exposed sub-groups is believed to be less than 1 in 10^6 per year (1 in a million) (ICRP 26).

3.20 Since it is not possible to measure a committed dose equivalent directly, both ICRP and NRPB provide secondary limits expressed as annual limits of intake in becquerels (curies) per year. These can be further developed to give derived limits, eg for the concentration of radioactive materials in a foodstuff such as fish or milk. These derived limits are then specific to a 'critical group' of known habits and food consumption in a known environment, although generalised derived limits covering any reasonable behaviour patterns and environmental conditions can also be developed. These secondary and derived limits are appropriate as a basis for control procedures. Since they are based on specific metabolic models and organ sizes and on representative factors relating dose equivalent to risk at all ages and for both sexes, they should be used with discretion when estimating the consequences of exposure of individuals or small groups who may not be representative of the more general groups for which the limits were intended.

3.21 Occupational exposure limits are set at 10 times the level for exposure of the public. This is based on an ICRP estimate of the annual risk of death of 10^{-2} per Sv (10^{-4} per rem), which produces a radiation risk which is comparable to the fatal accident risk in an 'averagely safe' industry. So far no change in cancer mortality or in the incidence of any other disease has been demonstrated in such workers at Sellafield (Clough, 1983) though we are aware of further studies in progress.

3.22 The ICRP recommendations are given in terms of the dose actually received by members of the public in any one year from external radiation and intakes of radionuclides, plus any dose that will be received during the life of the individual from radionuclides retained in the body beyond the year in question. Measurements of levels of radioactivity in fish, meat and the environment are made in becquerels (curies) per unit mass or volume of material sampled. To calculate exposure from the monitoring data it is therefore necessary to know:—

i. the amount of the radioactive material that will come into contact with the person over a given period of time via all possible pathways (eg inhalation, ingestion, contact);

ii. how much of the material will remain in the body, how much will be excreted and over what period of time, (this usually involves an assessment of the 'biological half-life' of the material);

iii. in which tissues or organs the radioactive material taken into the body will be preferentially concentrated;

iv. the rate of radioactive decay of the radionuclide;

v. the type of radiation emitted, ie alpha, beta or gamma radiation, and the energy of the radiation emitted, so that some assessment of the amount of tissue irradiated can be made.

3.23 A more detailed assessment of the assumptions made in the calculation of population exposure from monitoring results will be found in Chapter 4.

3.24 Before the pipeline authorisation was made in 1952, investigations of the sea currents and likely biological pathways by which discharges might give rise to population doses were carried out, (Dunster, 1956; Dunster, 1958; Seligman, 1956; Fair and Maclean, 1956). These studies formed the basis of the initial, very conservative authorisation in February 1952 (Wix et al, 1960). Monitoring of the sea food and of the environment since then has continued and become increasingly more detailed. We were told that the present MAFF marine monitoring programme has an annual budget of around half a million pounds. The monitoring programme is dealt with in more detail in Chapter 4.

3.25 The present limits for liquid discharges from the Sellafield site are authorised jointly by the Department of the Environment and the Ministry of Agriculture, Fisheries and Food (MAFF). The authorisation deals separately with alpha and beta emitters, and provides upper limits for discharges over three monthly periods, with further overall limits on annual discharges permitted. At present discharges of $2{\cdot}78 \times 10^{15}$ Bq (75,000 Ci) of 'total beta' emitters, taken together, and 74×10^{12} Bq (2,000 Ci) of 'total alpha' emitters are permitted in each consecutive 3 month period. There is an overall limit of 222×10^{12} Bq (6,000 Ci) on 'total alpha' discharges per annum, and limits on the amounts of Ruthenium-106, Strontium-90 and Cerium-144 permitted within the 'total beta' authorisation. Limit on the discharge of Caesium-137 is via the beta limit and the 'as low as reasonably achievable' (ALARA) clause (see para 3.18). There is no limit on the authorisation for Plutonium-241 or Tritium, both of which are very low energy beta emitters, but these discharges are measured and the quantities published in BNFL's annual report.

3.26 The present authorisation dates from 1971, when the authorised limit for 'total alpha' discharges were amended following an expected increase in workload. At that time environmental monitoring suggested that the environmental levels of radiation from the discharges resulted in levels of radiation exposures to the public within the ICRP recommended dose limits.

3.27 In February 1983 the authorisation was varied to formally require BNFL to keep all discharges 'as low as reasonably achievable' (ALARA) although it had been the practise for a number of years before this for this principle to operate (eg the placing of zeolite resin skips in the cooling ponds to reduce Caesium-137 discharges was required by the authorising department on these grounds). 'Total beta' discharges for 1983 were less than $2{\cdot}5 \times 10^{15}$ Bq (67,200 Ci) and 'total alpha' discharges were 14×10^{12} Bq (378 Ci) which are some 22% and 6% respectively of the authorised limits.

3.28 Figures 3.5, 3.6, 3.7 and 3.8 show the pattern of liquid discharges since they commenced. Peak discharges of beta activity, $9{\cdot}2 \times 10^{15}$ Bq (245,000 Ci) took place in 1975 and included $6{\cdot}3 \times 10^{15}$ Bq (170,000 Ci) of Caesium isotopes. Peak alpha activity discharges were $1{\cdot}8 \times 10^{14}$ Bq (4,900 Ci) per annum in 1973.

Figure 3.5 Discharges to sea of 'total alpha' activity from Sellafield site (Figure supplied by BNFL)

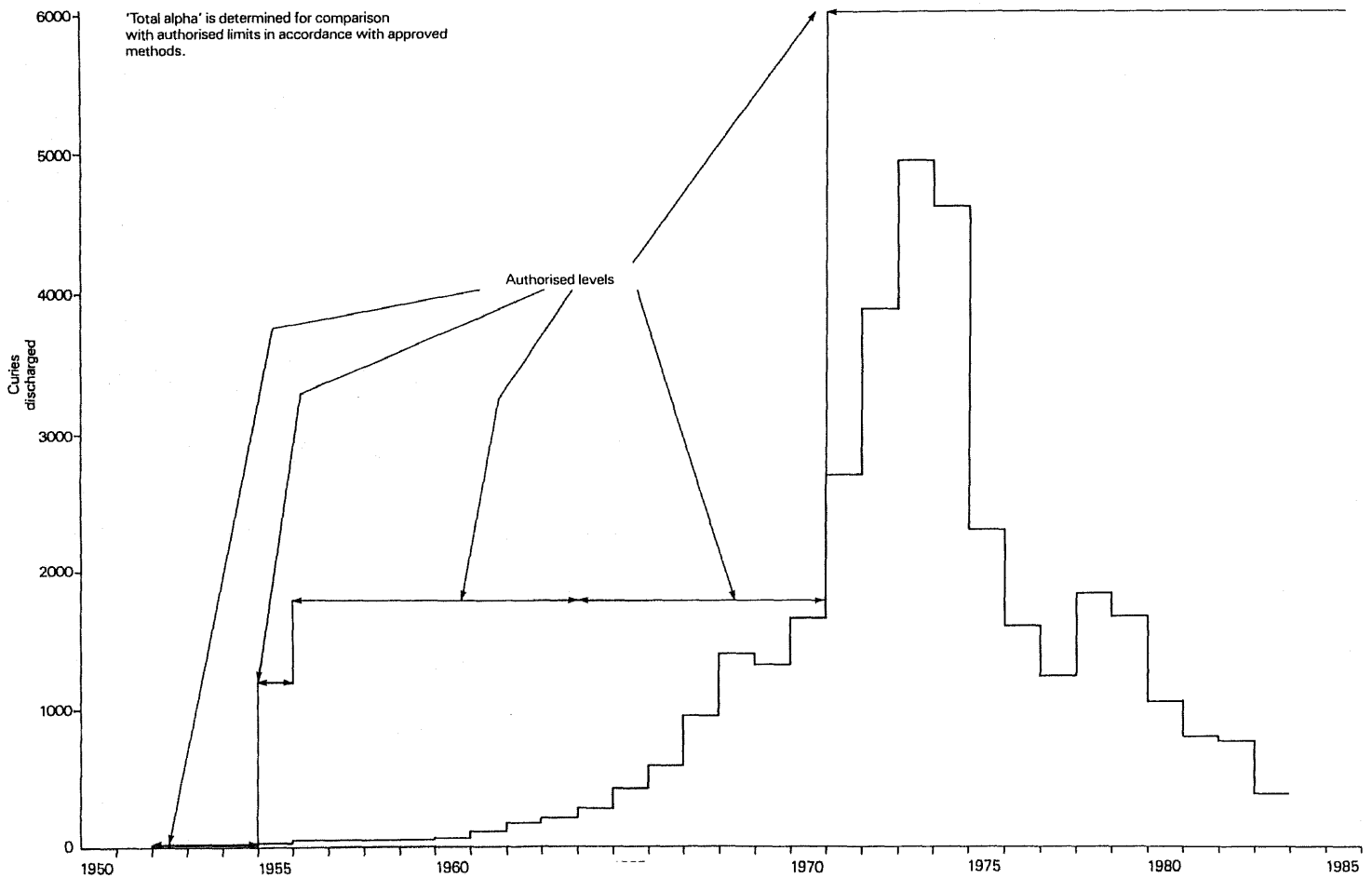


Figure 3.6 Discharges of 'total beta' activity to sea from Sellafield site (Figure supplied by BNFL)

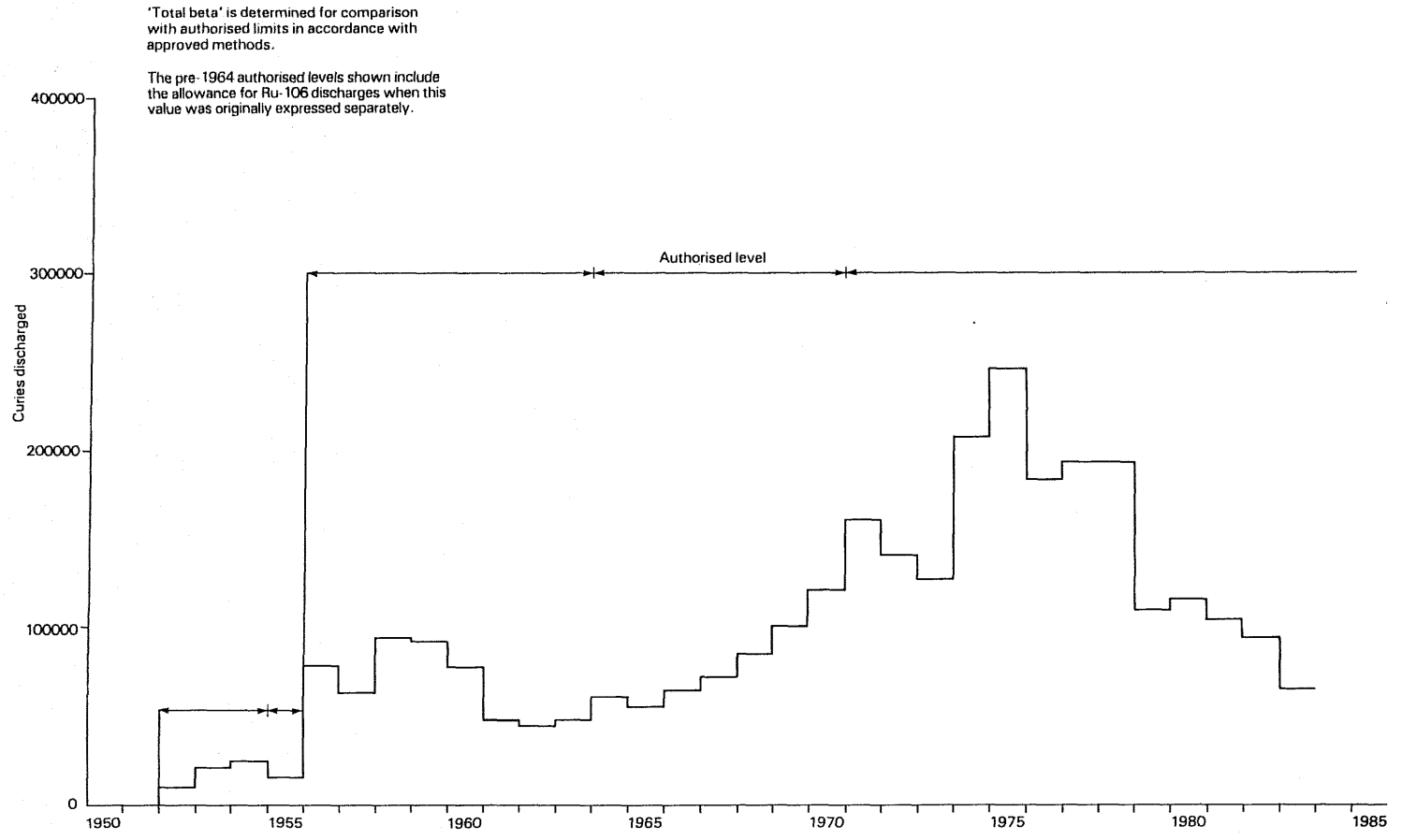


Figure 3.7 Discharges to sea of Caesium-137 from Sellafield site (Figure supplied by BNFL)

1955, 1956 scaled from Sr 90 discharges by NRPB

1952, 1953, assumed to be the same as 1954 discharges by NRPB

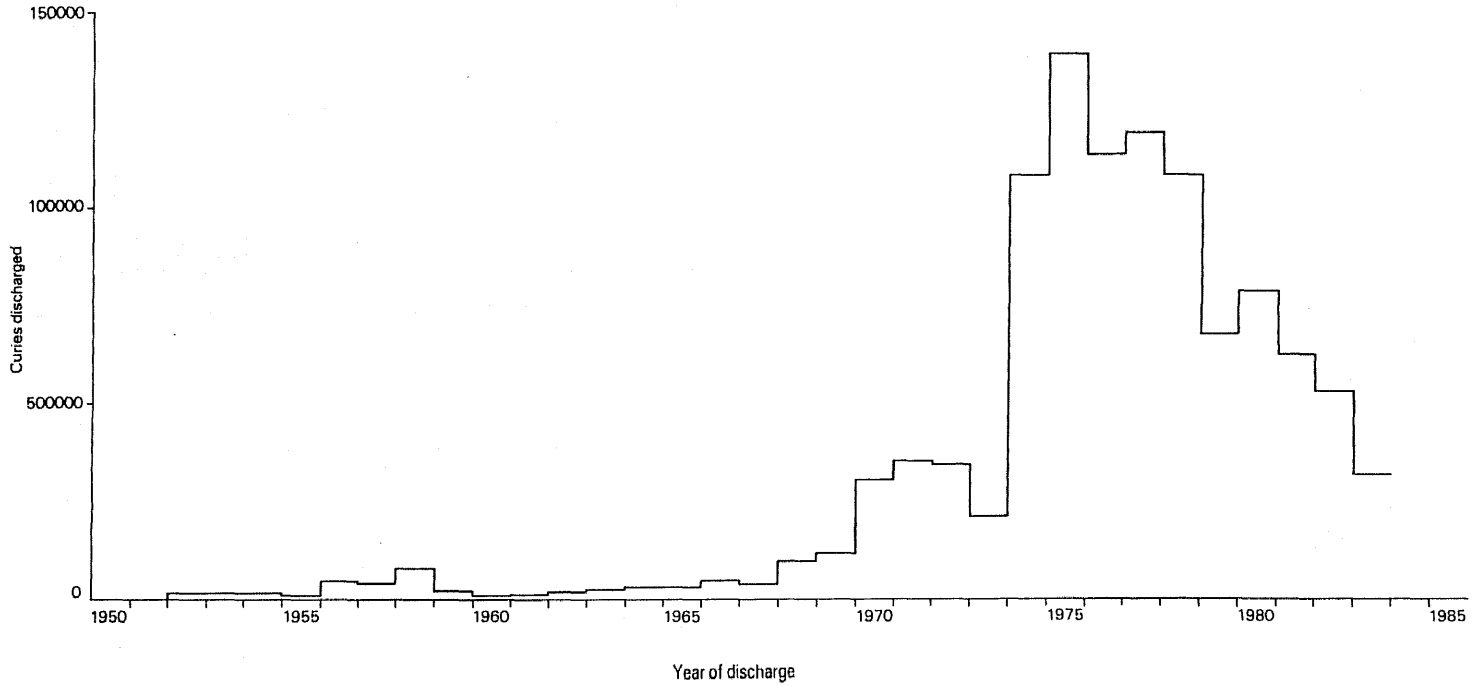


Figure 3.8 Discharges to sea of Plutonium-241 from Sellafield site (Figure supplied by BNFL)

Values of Pu-241 prior to 1972 are estimates based on appropriate values of Pu-241:Puox depending on fuel reprocessed at that time.