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COMMITTEE ON MEDICAL ASPECTS
OF RADIATION IN THE
ENVIRONMENT
(COMARE)

FIRST REPORT

THE IMPLICATIONS OF THE NEW DATA ON THE RELEASES FROM SELLAFIELD IN THE 1950s FOR THE CONCLUSIONS OF THE REPORT ON THE POSSIBLE INCREASED INCIDENCE OF CANCER IN WEST CUMBRIA

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Frontispiece
County of Cumbria

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FOREWORD

(i) In recent years there has been increasing public concern about the possibility that low levels of environmental pollutants can adversely affect public health. This concern has often centred upon the possible health effects of radioactive discharges from nuclear sites.

(ii) The Government recognised this public concern when it asked Sir Douglas Black to chair the Independent Advisory Group which looked into the possible increased incidence of Cancer in West Cumbria in November 1983 The Group's Report 'Investigation of the possible Increased Incidence of Cancer in West Cumbria' which was published in July 1984 concluded, when considering the discharges from the site (paragraph 6.12) that '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.[1]

(iii) The Report made four recommendations for further epidemiological studies on the population resident around the Sellafield site:-

(a) a case control study of the records of cases of leukaemia and lymphoma diagnosed among young people up to the age of 25, resident in West Cumbria;

(b) a study of the medical records of all children born since 1950 to mothers resident in Seascale at the time of birth;

(c) a study of the medical records of school children who have attended schools in the area;

(d) a more detailed re-analysis of the electoral ward study already carried out in the Northern Region to include, among other things, analysis of the data by place of birth.

These studies have been commissioned by the Department of Health and Social Security, but have not yet been completed. In addition an extensive study of cancer incidence and mortality around nuclear installations (also mentioned in the Black Advisory Group Report) is nearing completion and the Office of Population Censuses and Surveys (OPCS) have initiated a follow up of the population in West Cumbria in 1940. No detailed reconsideration of the epidemiological data is justified until the results of at least some of these studies become available.

(iv) The Black Report also drew attention to the uncertainties in the assumptions made in the dose and risk estimation procedures. To improve knowledge in this area the group made further recommendations (6 and 7) concerning the desirability of direct measurements in humans whenever possible, and the need for more information on dose and risk assessment in children and in relation to High Linear Energy Transfer (LET) radiation (ie alpha particles from actinides such as plutonium which produce very intense but localised radiation).

(v) The Report's last recommendation was that there should be a designated body with significant health representation, to enable decisions on action with regard to the control of permitted radioactive discharges to take account of all relevant factors.

(vi) The Committee on Medical Aspects of Radiation in the Environment (COMARE) was established to implement this recommendation.

(vii) COMARE is an advisory committee with members appointed by the Chief Medical Officer for their medical and scientific expertise. It was set up to offer government independent medical and scientific advice on the health effects of ionising and non-ionising radiation in the environment whether natural or man-made.[1]

(viii) Its terms of reference are "to assess and advise Government on the health effects of natural and man-made radiation in the environment and to assess the adequacy of the available data and the need for further research". The Chairman and members are listed in Appendix A of this report.

(ix) The Committee held its first meeting on 25 November 1985 and has met three times since then. The limited time available to date has meant that it has yet to consider the topics outlined in paragraph (iv) in detail.

(x) This is its first Report to Government and deals with the implications of new information relating to the discharges from the Sellafield Site that have been provided by British Nuclear Fuels plc (BNFL) and others since the publication of Sir Douglas Black's Report.

I: INTRODUCTION

1. Over the last few years the possibility that unexpected clusters of cancer have occurred in those living near nuclear installations has been considered on several occasions[2-10]. Usually these have related to possible excesses of childhood leukaemia. The situation at Seascale, a village a few miles south of British Nuclear Fuels plc (BNFL) nuclear fuel reprocessing site at Sellafield has already been the subject of a report by the Independent Advisory Group chaired by Sir Douglas Black.[11]

2. Since publication of the Black Advisory Group Report new information has become available, mainly related to the releases of radioactivity from the Sellafield site in the 1950s. At our first meeting we were asked as our first priority to advise government on the implications of these new data for the conclusions drawn in the Black Report about the relationship between the discharges from the Sellafield site and the observed incidence of leukaemia in the village of Seascale.

3. This first report from COMARE therefore deals briefly with the background to the Black Advisory Group Report and the nature and sources of the new information that has become available; it considers how the new data affect the conclusions of the Black Advisory Group Report. It does not re-assess the epidemiological data, since that would be premature, but rather concentrates on how the new data affect the dose and risk estimates, following as far as possible the same methods as were used in the Black Advisory Group Report.

4. We emphasise that throughout this report we are chiefly concerned with estimates of dose which are based upon environmental monitoring data used in conjunction with complex biological and mathematical models. The risks resulting from the estimated doses are based on extrapolation from earlier studies on the effects of radiation. Each step in this process is invested with an element of uncertainty, which cannot always be quantified. The cumulative effects of these sequential uncertainties cannot be exactly estimated.

5. We also emphasise that in this report we are not in general concerned with the direct measurement of risk using morbidity and mortality data.

6. While we would like to thank all those who provided us with information for their assistance we should also make it clear that the report expresses the views of committee members and not necessarily those of the Secretariat or the Assessors. Those who contributed directly to the many helpful discussions are listed in Appendix B. To help explain some of the more technical terms necessarily used in this report there is also a Glossary at Appendix C, and words included in the Glossary are underlined the first time that they appear in the text.

II: BACKGROUND INFORMATION ON THE BLACK REPORT AND NRPB REPORT R 171

7. The Black Advisory Group asked NRPB to calculate the doses from the Sellafield discharges likely to have been received by young people resident in Seascale village since the 1950s. In order to do this the Group asked BNFL to make available to NRPB all relevant monitoring and discharge data. In addition the Group asked BNFL for a list of incidents leading to off-site consequences since Sellafield began its operations in 1952. This list formed Appendix 1 of NRPB R 171[12] the document specially prepared by NRPB for the Black Advisory Group. The estimation of doses in NRPB R 171 and their derived risks in the Black Advisory Group's Report (published in July 1984) were based on these data which were used in a series of mathematical models.

8. Exposure from environmental radiation whether due to discharges from a nuclear site, nuclear weapons fallout or natural background radiation occurs via three routes:-

a. external exposure from gamma rays via airborne and deposited radionuclides;

b. internal exposure via radionuclides inhaled from the air;

c. internal exposure via radionuclides ingested in food and drink.

9. Various information is available from which doses from the Sellafield discharges received by members of the local population can be estimated. These include details of:-

a. quantities of radioactivity released; details of the radionuclides contained in the discharge; the route of release and physical and chemical form; meteorological conditions during the release;

b. measured levels of radionuclides on the ground and in the sea, rivers and air;

c. measured levels of radionuclides in food and drink produced in the area and consumed by the local population;

d. measured levels of radionuclides in human tissues.

10. This information can then be used in mathematical models together with statistics on population habits and food consumption patterns to estimate the quantity and types of radionuclides to which the local population are likely to have been exposed. While some of these 'habit' data will have been collected specifically in relation to the West Cumbrian population, others will come from nationally collected figures.

11. The relationship between the results of these calculations and actual exposures received by the population of interest will depend to a considerable extent upon the quantity and quality of the information that can be collected. Where little information is available (as is the case in the 1950s for the Seascale population) caution is required in interpreting the results of these estimates.

12. These data can then be used to derive an estimate of the dose received by any particular cells or tissue of interest using a range of metabolic parameters such as gut transfer factors, tissue distribution patterns and excretion rates for each radionuclide of interest.

13. From these estimated doses it is then possible to derive estimates of the risk of leukaemia (or other relevant disease of interest) using information on the relationship between radiation dose and risk of cancer.

14. As has already been mentioned in the Introduction (para 4) these calculations result in estimates of doses and risks rather than direct physical measurements of doses or biological measurements of risk. They depend on many assumptions, for example, the distribution of radionuclides in tissue; the relative biological effectiveness of different radionuclides, and the site of the sensitive stem cells for the induction of leukaemia. In NRPB R 171 this was assumed to be the red bone marrow, and the cells were assumed to be uniformly distributed through the marrow. While these were reasonable assumptions to make they are not the only assumptions that are possible in this context.

15. In NRPB R 171 estimates of doses to the red bone marrow from all three routes of exposure detailed in para 8 were considered and used to derive estimates of risks for the induction of leukaemia in young people resident in Seascale and under 20 years of age. In order to understand the way the new information on discharges affects these dose and risk estimates it is necessary to explain in more detail the way NRPB calculated the doses from internal exposures.

16. For the particular situation of the discharges from Sellafield and the doses and risks to the young people of Seascale, NRPB decided that the best estimate of internal dose from ingestion of radionuclides (8(c) above) would be derived from the use of measurements of radionuclides in soil and terrestrial and marine foods, ie environmental monitoring data.

17. For calculating the doses from inhalation (8(b) above) of radionuclides, measurement data were more limited. Information on atmospheric and marine discharges were therefore used to calculate intakes by inhalation from air and seaspray.

18. Routine environmental monitoring was rudimentary before 1957. NRPB therefore had to make many extrapolations from limited data in calculating the doses for the period 1952 to 1957. For estimation of the dose from ingestion they relied heavily upon a series of 40 measurements of levels

of Strontium 90 (Sr-90) in milk collected in 1958 from the two farms closest to Seascale (Figures 1 and 2). The levels of Sr-90 and other radionuclides in the total diet were derived from these milk measurements using food chain models.

19. In the list originally provided by BNFL there had not been any on-site incidents with off-site consequences before the Windscale Fire in 1957. However, included in the information provided to NRPB from BNFL on discharges of radionuclides from the Sellafield site were details of the release from the Windscale piles of about 400 g of irradiated fuel in 1954/55, with a further 40 g in the late 1950s. On the assumption that the irradiated fuel was released from the plant over a period of time, and that there would have been other routine releases from the plant, NRPB considered that the assumption of a constant level of Sr-90 in the diet up to and including 1958 would not underestimate the doses to the Seascale population (Figure 3). For other ingested, inhaled or external exposures from radionuclides levels in milk, other foods and the environment were derived either from the Sr-90 levels or from the discharge data.

20. For later years of operation of the plant the environmental monitoring data made available to NRPB progressively improved. Where appropriate measurements of levels in environmental materials were available, NRPB used them in the analysis, but where they were not available, estimates were again made from discharge data. Measurements of intakes of radionuclides in the later years were therefore more reliable than for earlier years.

21. The Seascale children were divided into a series of seven groups (<u>cohorts</u>) assumed to have been born in seven consecutive five year periods from 1945-1975. The <u>1950 cohort</u> comprised those born between 1950 and 1954 in Seascale. The doses to the red bone marrow for each cohort were estimated from the available data for each cohort assuming a period of exposure lasting from birth to age 20 or to 1980, whichever was the earlier.

22. The Black Report drew attention to 'the unavoidable uncertainties on dose in this situation and the model we have used does not exclude other possibilities' in paragraph 6.12 of their report.

III: NEW INFORMATION ON DISCHARGES AND RELEASES FROM THE SELLAFIELD SITE IN THE 1950s

a. New Information on 1954/5 Episode leading to Releases of Uranium Oxide Particles from the Sellafield Site

23. In November 1984, NRPB informed DHSS that they had been approached on a personal basis by Dr D Jakeman who between 1954 and 1956 had been an employee of the Research and Development Branch of United Kingdom Atomic Energy Authority (UKAEA) at their Windscale (Sellafield) Site. He had then worked on development of the filters in the discharge stacks of the Windscale Piles. During the period when the Black Inquiry was collecting evidence Dr Jakeman was abroad. It was not until his return to a post at UKAEA Winfrith Heath in 1984 that he was able to inform UKAEA that he might have information of relevance to any further investigation. Dr Jakeman had a series of discussions with NRPB and BNFL and subsequently produced a Report[13] in April 1985 which contained his interpretation of the environmental and possible public health impact of a release of uranium oxide particles from the stack of the Windscale Piles during 1954 and 1955. This report was sent to NRPB, BNFL and DHSS, and has not been published. However we understand that UKAEA are intending to publish a report on this subject by Dr Jakeman, which we have not seen.[14]

24. The April 1985 report said that while working at Sellafield in 1954/5, Dr Jakeman and a colleague had detected unexpectedly high levels of radioactivity in their gardens. In 1955, UKAEA produced a report[15] stating that uranium oxide from spent fuel cartridges removed from the piles and inadvertently exposed to air, was being released to atmosphere. This report

concluded that a total of 100-200 g of uranium oxide had been released.[15] In 1955 UKAEA appointed a group of independent experts to assess the health implications of the available data.[16] Dr Jakeman told us that in July 1956 he submitted a report to the Research and Development branch of UKAEA which contained his findings and drew attention to the levels on the ground from his own observations. In 1957 more environmental monitoring data were considered by UKAEA and the figure of 100-200 g was revised up to 440 g total release.[17] These reports[15,17] were given to NRPB for incorporation into the calculations made for the Black Advisory Group Report and appeared in the NRPB Report R 171.[18]

25. Dr Jakeman questioned the reported magnitude of the release. Based on his knowledge of the efficiency of the filters at the time and his recollection of the environmental levels of radioactivity he had measured he believed that about 50 times more than the reported 440 g (ie around 20 kg) of uranium oxide had been released to the environment. Following discussions between Dr Jakeman, BNFL, UKAEA and NRPB, which took into account information on the number of spent fuel rods likely to have been oxidised,[15] the estimate of 20 kg was accepted by BNFL as more likely to be correct than the earlier estimate of 440 g. This value (20 kg) was used in Dr Jakeman's report of April 1985, where he also stressed that this figure was approximate and that a range of 10-50 kg was possible (see Footnote 1).

26. BNFL told us that the reassessment was based on the assumption that all the fission products (corrected for contribution from the Windscale Fire in 1957 and weapons fallout) measured in soil core samples after

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Footnote 1: We understand Dr Jakeman in his report,[14] has revised his estimate to 30 kg.

1957 in the vicinity of Sellafield, had originated from the uranium oxide particle release. BNFL's actual calculated figure for the release was about 12 kg but, given the uncertainties in the calculations, it was agreed that a figure of about 20 kg was a more realistic estimate of the actual release than the previous value of 440 g. BNFL believe this higher figure is more consistent with the performance of the filters in practice compared to their specification.

27. Dr Jakeman and others have suggested that the method of core sampling of the soil employed in 1957 was likely to result in an underestimate of the releases, because the larger particles would be sparsely deposited and would be likely to be missed by the sampling method employed.

28. Uranium metal fuel, after removal from the Pile, contains a spectrum of radionuclides including Caesium 137, Caesium 134, Strontium 90, Strontium 89, Zirconium 95/Niobium 95 together with small amounts of some alpha emitters (see glossary). Following any oxidation these will be contained in oxide fuel particles of varying size, which as they are released from the stack are transiently in the air (from which they may be inhaled) but will then be deposited on the ground and so enter the food chain, mainly in milk and meat over a period of time.

29. The revision of the magnitude of this release necessitated by the new information provided by Dr Jakeman and the fact that the bulk of the release was believed to have occurred over a relatively short time in 1954/5 meant that the previous extrapolation from the Sr-90 levels in

milk in 1958 used to estimate the doses from the ingestion route before 1957 (para 19 and Figure 3) was no longer appropriate. NRPB have therefore re-calculated the doses to take account of the 1954/5 incident and also of additional data subsequently received from BNFL (see III (b) below) in an Addendum to R 171.[18]

30. In the Addendum to R 171, NRPB have assumed that the entire release of uranium oxide fuel particles occurred in mid 1954 and that the levels of Strontium 90 in milk in 1958 represented the 'tail' of a curve of declining levels in milk since the 1954 release (Figure 3). As before, levels of other radionuclides in milk and other foods were then derived, using mathematical models, from the estimated milk levels of Sr-90. Since it was known that at least some uranium oxide was still being released in 1957, NRPB believe that this assumption will not underestimate the calculated doses from ingestion to the local population from the 1954/5 release.

31. Estimated doses via the inhalation route also needed to be revised upwards, although the inhalation route contributes a relatively small part (4.2%) of the overall estimated dose equivalent from the discharges (Table 2) to the 1950 cohort.

III: (b) BNFL MAJOR REVIEW OF SELLAFIELD DOCUMENTS

32. There had also been a Press Report[19] in February 1985 concerning a previously unknown release of radioactive iodine-131 to the atmosphere in 1952, based on a document recently deposited in the Public Record Office by UKAEA. The discovery of additional information on releases in the 1950s naturally raised the question of the completeness of the data provided for the Black Report.

33. BNFL therefore instituted a major review of information relating to Sellafield discharges and environmental monitoring in early years. This included a search of all documents (some 10,000) relating to any aspects of the Sellafield site which had been reviewed by UKAEA before deposition in the Public Records Office under the 30 year rule. They scrutinised these documents for any additional data relating to releases from the Sellafield site in the 1950s. Similar files containing documents dated later than 1957/8 could not be searched because of the timing of the UKAEA review procedures under the thirty year rule for the release of public documents. Special attention (by examining specifically relevant documents) was also given to the period up to 1964 because routine monitoring of atmospheric discharges was not possible before then.[20]

34. BNFL also told us that the search of the archives included all classified documents falling within the limits outlined in paragraph 33 above, that the files were sequentially numbered within defined sub-classes and that none of the numbered files was missing. They are therefore confident that they have made all reasonable efforts to ensure that the data within the classes searched by them are complete. They also told us that where routine measurements of discharges had not taken place, best estimates were obtained by detailed examination of plant operations compared wherever possible with environmental monitoring data. Where there was doubt an attempt was made to identify reasonable upper limits.[20]

35. Details concerning about 20 items of new or reassessed data on discharges were identified. Further details of these releases are given

in the Addendum to NRPB R 171. The archival search produced evidence that UKAEA had appointed, in 1955, a group of independent experts to assess the health implications of the available data on the uranium oxide particle releases at that time. We noted however, that the record searching did not produce the personal report provided by Dr Jakeman to UKAEA in 1955 in relation to the 1954/5 releases.

36. BNFL inform us that this report was left by Dr Jakeman with his line management on his resignation from UKAEA and was not included in the official files. Investigations by the UKAEA concluded that it was most likely to have been destroyed with other papers in his personal file following the then normal procedures after his resignation. Thus Dr Jakeman's approach to NRPB in 1984 depended entirely on his personal knowledge of the local situation in the 1950s.

37. NRPB calculated that the majority of the additional information result in only minor modifications of their estimates of doses.[18] A few, such as the 1954/5 release of irradiated fuel particles, changes in the Argon 41 discharges from the Windscale Piles and a plutonium release in 1952 did have more significant effects on their estimates of doses to the red bone marrow.

38. Any releases which could be added on to previous estimates, or which were revisions of previous estimates, were included in the revised dose calculations. In addition, any release which contributed about 1% or more of the dose equivalent to the red bone marrow from Sellafield discharges in that year, as calculated in R 171, was included in the calculations.

39. Based on the information available, NRPB believe that this procedure ensures that over 95% of the total dose from the Sellafield discharges had been taken account of in their calculations.

III: (c) EFFECTS OF ALL ADDITIONAL RELEASES ON RED BONE MARROW DOSES AND LEUKAEMIA RISK CALCULATIONS

40. In this section we consider some of the different ways that the available discharge data and environmental monitoring data have been used to calculate estimated dose equivalents and to make assessments of risks of leukaemia.

i. NRPB Report: Addendum to R 171

41. The 50-fold increase in the estimate of the quantity of uranium oxide released from the stack, plus the other additional data discovered by BNFL, result in a two-fold increase in the estimated dose equivalent from the Sellafield discharges to the red bone marrow for young people born in Seascale in 1950-54 (the 1950 cohort) and resident there until 1970. In the revised NRPB calculations children born in the 1960s and later received smaller increases from these discharges as the levels of radionuclides from this release entering the food chain declined.

42. According to NRPB the relatively small increase in the calculated dose to the 1950 cohort (compared to the 50-fold increase in the estimated release of uranium oxide in 1954/5) results from the fact that in the original NRPB R 171, the dose estimates were wherever

possible based on environmental monitoring data, which already partly reflected the effects of the 1954/5 release, rather than solely on discharge data (ie the figure of 440 g of uranium oxide that is now accepted to be an underestimate).

43. The dose and risk estimates in the Addendum to R 171 are higher because the environmental data (ie the milk levels of Sr-90) are now interpreted as the decaying tail of an earlier peak, whereas in NRPB R 171 they are interpreted as part of a steady-state level of Sr-90 in milk (Figure 3). NRPB did not extrapolate back from environmental levels to calculate an estimate of the emissions from the stack; they did however use the 20 kg estimate for uranium oxide release as the basis of their inhalation dose estimates in the Addendum to R 171.

44. There is a larger contribution from the inhalation route in the Addendum to R 171 to reflect the now accepted larger discharges. However, since the particles were available in the air for inhalation for a relatively short period of time compared to the time they were available on the ground for incorporation into food, the inhalation route makes a relatively small contribution to the total dose equivalent to the 1950 cohort (Table 2). In the case of the 1950 cohort only 4.2% of the total dose equivalent to the red bone marrow is derived from the inhalation route in the revised dose estimates in the Addendum to R 171.

45. The increase in estimated dose equivalent from the discharges in the 1950s has affected both the densely ionising and high LET radiation (eg alpha rays) and the less biologically effective less densely ionising

low LET radiation (eg X-rays) (Table 3). However the effect on the high LET component has been greater than the effect on the low LET component. The children born in the early 1950s who received the maximal additional exposure experienced a four-fold increase in the high LET dose from the Sellafield discharges and up to a two-fold increase in the low LET dose component, depending upon the duration of residence and the time of residence of the cohort in Seascale while for most cohorts the additional dose was much less (Table 3).

46. However, it should be realised that part of the increase in the estimated high LET component is because NRPB now consider that actinides are transferred twice as efficiently from the gut into the body than was previously thought to be the case (ie the gut transfer factor has been changed from 5×10^{-4} to 1×10^{-3}). This is in line with an anticipated recommendation from the International Commission on Radiological Protection.

47. This increase should also be seen in the context of the estimated dose to the red bone marrow from natural background radiation. For comparison for the 1950 cohort, the total revised dose to the red bone marrow up to the age of 20 years from the Sellafield discharges including doses from the Windscale Fire is now 6.3 millisievert (mSv) compared with 22 mSv from natural background (Table 4). Therefore, these increased dose estimates are still much less than those that have been calculated as being received during the same period from nuclear weapons testing fallout plus natural background radiation. However, the dose from the Sellafield Discharges and the Windscale Fire contains a greater percentage of high LET component than does the dose from all background

radiation. Table 2 shows the estimated contribution of high and low LET dose equivalents to the three pathways of exposure from the Sellafield Discharges for the 1950 cohort.

48. We noted that the NRPB mathematical models used above in the dose estimation procedure relied heavily on the levels of Strontium 90 recorded in 1958 in milk from two farms, one adjacent to Seascale village, the other 1.5 km from Seascale village (Figures 1, 2 and 3). Although the levels in milk from each farm varied throughout the year over a fairly narrow range, there was almost a 10-fold difference between the average level detected at the two farms (after assuming and subtracting an identical contribution from nuclear weapons fallout).

49. Differences in farming practices could lead to differences in uptake of deposited radionuclides from both nuclear weapons fallout and the Sellafield Discharges and so result in different levels of Sr-90 in milk from the two farms. In this case subtracting the same estimated contribution from background radiation from the measured levels would tend to increase the observed difference between the levels in milk from the two farms and ideally separate levels for background radiation should be calculated for each farm. However, NRPB inform us that there are insufficient data available to justify deriving such specific figures for the background radiation contribution, and they used national background levels corrected for local rainfall rates.

50. Such variability in milk levels from two farms in the same area; the problems in allowing for other factors such as nuclear weapons

fallout and the fact that no measurements were available for the time of the release of uranium oxide in 1954/5 emphasise the uncertainties in this all important environmental monitoring data, which formed the basis of NRPB's dose estimates for the early years both in NRPB R 171 and in their Addendum. These uncertainties are underlined and confirmed by the new information that several incidents involving off-site releases occurred in the 1950s.

ii. Dr Jakeman's Reports

51. Dr Jakeman in his Reports[13] used mathematical models designed to assess atomic weapons fallout, information on the number of particles released from the stacks and the NRPB uptake model to calculate the doses likely to be received by the Seascale young people. In his second report he estimated a risk of death from leukaemia due to radiation exposure of one per 2500 children born and living in Seascale between 1950 and 1955. Since he estimated there were probably about 200 children in Seascale at that time he concluded that this was equal to 0.08 deaths. Dr Jakeman stressed the uncertainties in this estimate (but see Footnote 2).

Footnote 2: (a) In his reports[13] Dr Jakeman suggests that measurements of Sr-90 and Cs-137 levels made after 1957, and used in his estimates of risks, may have been inaccurate because of the sampling method employed. He believed levels of radioactivity at Seascale were four times higher than those implied by NRPB for their risk assessment. After our Report had been completed we understand NRPB have recalculated (in Appendix E to the Addendum to R 171[18]) their risk assessment using these higher levels but still making the same assumptions as were made in the main report (eg that models designed to assess exposures from atomic weapons fallout are applicable to estimating doses from this incident).

Footnote 2 continued

(b) NRPB's results using Dr Jakeman's assumptions on environmental levels indicate that children born in 1954-5 and living within a few kilometres of the Sellafield site would have been at the greatest risk. They estimate that the Sellafield discharges would have produced a risk of death of 1 in 14000 for children born in Seascale in 1954 and resident there for 20 years compared with the risk of death of 1 in 33000 children reported by NRPB in their own calculations in the Addendum to R 171. Dr Jakeman pointed out to us that these calculations do not include a factor to represent what he considers to be the uncertainties in the assumptions made in the models.

(c) We understand that Dr Jakeman will be publishing a report based on his interpretation of the data and including the NRPB's risk calculations based on his environmental assumptions.[14] We have not seen this report but we welcome its publication.

iii. Dr Chamberlain's Reports

52. Dr Chamberlain, a retired employee at UKAEA and a consultant to them, also produced several documents[21] for us on the implications of the 1954/5 release. In his calculations he placed more weight on other environmental monitoring data which were available largely as part of a programme of monitoring of atmospheric fallout from nuclear weapons tests in the 1950s and did not rely on the Sr-90 levels in milk alone. He suggested that the doses likely to have been received by the Seascale young people are, if anything, overestimated by NRPB.

iv. Recalculation of estimates of risk of leukaemia using the same methods as were employed in the Black Advisory Group Report

53. We can repeat the calculation of the risk of leukaemia from the Sellafield discharges and the Windscale Fire carried out in para 4.47 of the Black Advisory Group report. This was based on the assumption (almost certainly producing an over-estimate) that all deaths from leukaemia in England and Wales in the under 20 year olds are due to exposure to background radiation. The additional dose equivalent of 6.3 mSv received by the 1950 cohort (ie 175 children born 1950-54) (para 21 Section II) from the Sellafield discharges and the Windscale Fire up to the age of 20 years would be expected to give rise to a further 0.02 cases of leukaemia for the entire under 20 population of Seascale up to 1980 (ie the seven cohorts taken together) the expected number of cases would be $\frac{0.1 \times 6.3}{28.1} \times 7$ = approximately 0.16 cases (compared with 0.09 cases expected in para 4.47 of Black Report), thus increasing the risk of leukaemia due to the discharges to the young people of Seascale by about 80%.

54. However, because the 1954/5 release has its major impact on the 1950 cohort (who were the only cohort who would have been in Seascale throughout the entire period of the release) and this cohort was, by chance, chosen as the reference cohort in the Black Advisory Group Report, simply repeating the calculation in para 4.47 overestimates the impact of the new data on the estimated dose equivalents to Seascale young people over the period 1945-80. If, instead, the calculated dose equivalents received by each of the seven cohorts (5.0 + 6.3 + 6.8 + 3.3 + 3.5 + 3.2 + 1.5 mSv) (see Table 4) are summed, then the total risk is 0.08 compared to 0.09 calculated in the Black Advisory Group Report.

v. Summary of estimated consequences of additional information

55. We spoke to Dr Jakeman, Dr Chamberlain and NRPB on several occasions and noted that although each approached the dose and risk estimation procedure from different points of view and gave emphasis to different aspects of the available data there was general agreement on the data available. All accepted that there were considerable uncertainties in the estimates produced, although the degree of emphasis placed on these uncertainties varied. We were impressed that, although differences between the three approaches and the approach of the Black Advisory Group did exist, nevertheless the dose and risk estimates from these sources to the total population of Seascale children between 1950 and 1980 did not, in the final analysis, differ by a large factor, when due account was taken of the inherent uncertainties in the calculations being undertaken. Assuming the data to be reasonably complete none of

them suggests that the doses received by the relevant population groups were sufficient to explain the observed excess of leukaemia using current models although there are many uncertainties and assumptions made in all of the dose and risk estimates suggested.

56. We also noted that the five years between 1952 and 1957, when the new information had its major impact on the estimated doses, formed a relatively small part of the total period under consideration in the Black Report; none of the reported cases of leukaemia were born in Seascale before 1957 and therefore the uncertainties in the exposure data in this early period, when routine site discharges were relatively low compared to later years, is unlikely to affect the overall model-based estimates of doses and risks to any significant degree, or to reconcile them any any more effectively with the leukaemia observations.

IV: DISCUSSION

57. In this report, we address two questions of public concern. First, does the new information on discharges from the Sellafield site markedly affect the previous estimates of risk given in the Black Report? Secondly, is it possible that there have been other still undetected discharges of radioactivity to the environment in that geographical area which would have had a noteworthy effect on risk?

58. As regards the first of these concerns, we note that NRPB's revised dose and risk estimates, taking the additional data on releases into account but using a method based primarily on environmental monitoring data, and using essentially the same models as previously still do not yield results that could account for the cases of leukaemia observed at Seascale.[18]

59. We have received two other interpretations of the new data[13,21] and the effect that they might have had on the estimated doses. If we were to assume the data to be reasonably complete neither of these suggests that the doses received by the relevant population group were sufficient to explain and excess of leukaemia using dose/risk estimates currently used in the field of radiation protection.

60. Furthermore, direct comparison with possible risks from background radiation for leukaemia induction using the assumptions employed in the Black Advisory Group Report, do not suggest that the estimated doses are sufficient to explain the leukaemia rate observed at Seascale.

61. Turning to our second concern, regarding the completeness of the data, we would reiterate para 6.10 of the Black Report, "one cannot completely exclude the possibility of unplanned dishcarges which were not detected by the monitoring programmes and yet delivered a significant dose to humans via an unsuspected route." The incident brought to light by Dr Jakeman is a compelling example of the inadequacies of both the discharge records and the environmental monitoring data from the 1950s. We have to stress that we cannot exclude the possibility that other significant releases from the plant could have occurred and not been detected during the period when controls and monitoring were more rudimentary than they are at present.

62. Given the large number of agencies involved in the nuclear industry in relation to the Sellafield site over the years it is impossible to be certain that all possible classes and sources of records have been searched. Relevant material may have been lost or destroyed in the intervening period. We note, for example, that the record searching carried out by the relevant authorities did not produce

the 1955 report provided by Dr Jakeman to UKAEA in relation to the 1954/5 releases which BNFL believe was destroyed along with Dr Jakeman's other personal records when he left UKAEAs employment. We understand that this was the usual procedure at that time.

63. The way in which the new data came to light inevitably undermines confidence in the adequacy of the information available upon which a judgment has to be formed and underlines the difficulty in making any estimate of possible population effects for this period. Even though the data is obviously more complete than it was, the fact that knowledge of an emission of 20 kg of uranium oxide can depend solely upon the evidence of one individual with personal experience of the situation at that time must suggest a real possibility that other emissions might have been unrecorded. The fact that routine monitoring also failed to detect the release underlines the rudimentary nature of these procedures at that time. Other data subsequently came to light from information in the Public Records Office. We are concerned that so many additional releases could be discovered so soon after the assessment made by NRPB and the Black Advisory Group.

64. It is most important to ensure that calculations in relation to future emissions are not again hindered by lack of adequate monitoring data. We have been assured that both on-site and off-site controls are now much more stringent, and make such episodes unlikely to occur in the future.

65. In addition to the uncertainties regarding releases noted above, we are concerned about the uncertainties inherent in the dose and risk estimation procedure used. These include uncertainties in:-

i. estimation of environmental pathways;

ii. estimation of doses to the local population;

iii. estimation of risks.

These uncertainties relate to the field of radiation protection and the dose estimation procedure as a whole. These uncertainties were identified in the Black Report and some of these led to Recommendations 6 and 7 (para iv; Foreword). We wish to draw attention to two points in particular. Firstly, in the light of the increased exposure to actinides which has resulted from recalculation of the doses from the Sellafield discharges (due partly to the new data and partly to the changed gut transfer factor for actinides) there is a need for further investigation and consideration of the uncertainties attached to the risk assessment of low dose exposures, given at low dose rates from radionuclides such as plutonium and americium emitting high LET radiation. Secondly, there is a need to consider further the selection of organs and target cells in dose estimation, especially in the context of lymphatic leukaemia. The emphasis that has been given to the red bone marrow may not be entirely appropriate. However, it will be one of the Committee's future tasks to address these and other uncertainties. For the purposes of the present report we have used the established dose and risk estimation procedures based on mathematical models

66. The recorded group of childhood leukaemia cases in Seascale which was documented in the Black Report, is only one example of reports of the occurrence of malignancies in children and adults in the vicinity of nuclear installations. Much still remains to be established about the

Seascale population, and the three studies currently underway in that area as well as other national and local epidemiological studies (see para iii in Foreword) will contribute further to our knowledge in this area. This report deals only with the limited information on leukaemia used in the Black Advisory Group Report.

67. Taking the evidence presented in the Black Advisory Group Report, there is an apparent excess incidence of leukaemia in Seascale and there continue to be four possible explanations for this apparent excess:-

a. it is due to chance;

b. it is due to exposure to environmental radiation;

c. it is due to a high sensitivity to leukaemia induction of members of the population of Seascale (we know of no evidence for this and in view of the mobile nature of this population this seems unlikely);

d. it is due to some as yet undetected environmental agent such as a chemical or a virus.

It is quite likely that the excess was caused by some combination of two or more of the above factors.

68. Although there is no straightforward explanation of the leukaemia cases in terms of the radiation exposure data available to us, it is equally true that there is no straightforward explanation in any other terms. It is impossible, in these circumstances, to exclude <u>any</u> specific

potential contribution towards the causation of the excess of leukaemias, including the possibility of a radiation effect.

V: CONCLUSIONS

69. The new information from Dr Jakeman and from BNFL shows that there were substantial releases of radioactivity from Sellafield in the early 1950s of which the Black Advisory Group were not aware (III(a) and III(b)). In particular a release of the order of 20 kg of Uranium oxide to atmosphere and starting in 1954/5.

70. The way in which these data came to light is unsatisfactory and undermines our confidence in the adequacy and completeness of the available data. Although we accept that every reasonable effort has been made to ensure completeness of the information now available to us we feel that the monitoring programme and record keeping for the 1950s were such that we cannot be certain that all releases have now been recognised.

71. We therefore consider that the level of uncertainty about the information available and about the risk to the population from the Sellafield discharges is now greater than at the time of publication of the Black Report.

72. We would like to thank Dr Jakeman for his valuable contribution in correcting the available information relating to these early discharges and in bringing this information to our notice.

73. We believe that the dose and risk estimates presented by NRPB represent a reasonable picture based on conventional assumptions in the

field of radiation protection. However we have reservations about this conventional framework. A very complex chain of reasoning, involving many uncertainties, is necessary to go from the release data and the sparse environmental monitoring data to a prediction of any possible adverse health effects.

74. The multitude and complexity of assumptions needed in order to make the dose and risk assessments are topics to which we wish to return at a later date.

75. Notwithstanding the above complexity, we note that the increased doses during the thirty year period between 1950-1980 are still well below the doses that are estimated to have been received, during this period, by the population from natural background and from nuclear weapons testing fallout combined.

76. The NRPB analysis[18] concludes that 0.1 additional cases of leukaemia would be expected from all sources of radiation in the Seascale study population; Dr Jakeman[13] suggests 0.08 cases in the 200 children born in Seascale during 1950-55; Dr Chamberlain [21] suggests the NRPB calculations tend to overestimate the risk, while calculations using the risk estimates employed in the Black Advisory Group Report based on assumptions with regard to the effects of background radiation suggest 0.16 additional cases of leukaemia due to the Sellafield discharges in all those born in Seascale between 1945-1980 and resident there until 1980 or their 20th birthday. It should be noted that these calculations of risks do not refer to comparable populations and therefore cannot be

directly compared (but see Footnote 2). However none of them are sufficient alone to explain the observed leukaemia rate in Seascale village.

77. The NRPB calculations show that the new data on releases and the change in the gut transfer factor for actinides, increases the dose from the Sellafield discharges to the population in the vicinity of Sellafield from high and low LET radiation by different amounts: up to two-fold for low LET radiation and up to four-fold for high LET radiation depending upon the time and duration of residence in Seascale.

78. These increased doses are still well below those that would readily explain the observed cases of leukaemia in Seascale using conventional risk estimates. Thus the substance and essential conclusions of the Black Advisory Group Report remain unchanged. In order to reach different conclusions it would be necessary to assume either that the calculated doses received or the tissue sensitivity of young persons are at present radically underestimated.

79. It is possible that important releases occurred in the past but went unrecorded or undetected by the rudimentary monitoring carried out in the early years. The events since the publication of the Black Report increase our concern with this possibility, although it cannot be quantified. This emphasises and underlines our concern regarding the uncertainty with regard to the validity of any conclusions.

80. It is impossible within this broad band of uncertainty, to exclude environmental radiation or indeed any other factor as a contributory

Footnote 2: We understand that more comparable risk estimates for the 1950 cohort will shortly be published by Dr Jakeman[14] and in appendix E of the NRPB addendum to R 171, which we have not seen. For the 1950 cohort the risk of developing radiation-induced leukaemia from the discharges is calculated as 1: 33000 by NRPB[18] and 1: 14000 by Dr Jakeman[14]. The calculations we have repeated based on the Black Report lead to an estimated risk for the same cohort of 1: 8000 from the Sellafield discharges plus the Windscale Fire cause of the cases of leukaemia observed at Seascale, although we stress that there is no firm evidence for the existence of any causal relationship between environmental radiation and these leukaemias

81. It is most important to ensure that in calculations of dose and risk in relation to future emissions are not hindered by lack of adequate monitoring data or lack of appropriate epidemiological data.

82. We are informed that great improvements have been made in monitoring programmes, and that such improved methods have been employed for a long time. We advise government, however, that they should satisfy themselves as to the adequacy of the current monitoring programme at or near all such installations.

83. While we hope that the additional epidemiological data being obtained will clarify the situation further; we must also say that since we shall never know the actual average doses received by the population that the cases are drawn from and, as was pointed out in the Black Report, since we shall never know the actual doses received by those children who contracted leukaemia (para 6.10), it is likely that we shall never be able to establish with certainty whether there is any relationship between the cases of leukaemia in Seascale and the radioactive discharges from the Sellafield site.

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APPENDIX A

COMMITTEE ON THE MEDICAL ASPECTS OF RADIATION IN THE ENVIRONMENT

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APPENDIX B

Those giving oral evidence

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Miss J Dionion	NRPB	Chilton
Dr D Jakeman	UKAEA	Winfrith
Dr A C Chamberlain	UKAEA (Consultant)	Harwell
Mr P Mummery	BNFL	Risley
Dr D Anderson	BNFL	Risley

APPENDIX C

GLOSSARY OF TERMS AND ACRONYMS

Absorbed dose

The amount of energy absorbed per unit mass of a given tissue. It is measured in grays (or, in the old units, rads).

Actinides

The group of 15 elements with atomic number from that of actinium (89) to lawrencium (103) inclusive. All are radioactive. The group includes uranium, plutonium, americium and curium.

Alpha emitter (α)

A radionuclide that emits alpha particles.

Alpha particle (or alpha radiation)

A positively charged particle emitted during the radioactive decay of some radionuclides eg certain of the actinides. It consists of 2 protons and 2 neutrons and has a net charge of +2 (it is thus identical with a helium nucleus). It is the least penetrating of the 3 common types of radiation, viz alpha particles, beta particles and gamma (or x-) rays, being stopped by a sheet of paper, about 40 µm of body tissue or a few cm of air. It is a high Linear Energy Transfer (LET) type of radiation.

Americium (Am-241)

An actinide. It is an alpha and gamma emitter with a half-life of about 460 years. It is formed as a decay product of plutonium-241.

Argon 41 (Ar)

This is a beta emitting radionuclide with a half-life of about two hours: it is a gas.

BNFL

British Nuclear Fuels PLC.

Bequerel (Bq)

The Standard International (SI) Unit for the number of nuclear disintegrations taking place per second in a quantity of radionuclide containing matter.

$$1 \text{ Bq} = 1 \text{ radioactive disintegration per second}$$
$$= 27 \times 10^{-12} \text{ curies.}$$

Beta emitter (B)

A radionuclide that emits beta particles.

Beta particles (or beta radiation)

A particle emitted during radioactive decay of some radionuclides. It can be positively or negatively charged and is similar to a positron or an electron. Such particles are more penetrating than alpha particles (up to 40 mm in body tissue or a few metres in air or a few mm in plastics). It is a low Linear Energy Transfer (LET) type of radiation.

COMARE

The Committee on Medical Aspects of Radiation in the Environment.

Caesium-134 (Cs-134)

This is a beta and gamma emitting radionuclide with a half-life of about 2 years.

Caesium 137 (Cs)

This is a beta emitting radionuclide with a half-life of about 30 years.

Cohort

A term commonly used in epidemiological studies to denote a group of subjects with some common feature such as place of residence or place of work. In this report the term refers to groups of children born in specific 5 year periods in Seascale and resident in the area until 20 years of age (or until 1980). The '1950 cohort' is thus the group of children born in Seascale during the period 1950-4 inclusive and resident in Seascale until age 20.

Curie (Ci)

The old unit of radioactivity (the number of nuclear disintegrations per second occurring in one gram of radium - 226).

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ disintegrations per second}$$

$$27 \text{ Ci} = 10^{12} \text{ Bq.}$$

DHSS

The Department of Health and Social Security.

Decay

The process by which radionuclides emit ionising radiation (usually alpha, beta or gamma radiation) often changing from one element to another as they do so.

Dose equivalent

The quantity obtained for radiological protection purposes by multiplying the absorbed dose by a quality factor to allow for estimated differences in effectiveness of the various ionising radiations in causing harm to humans. The quality factor currently used for gamma rays, X-rays and beta particles is 1, for neutrons is 10 and for alpha particles is 20. The dose equivalent is measured in sieverts (or, in old units, rem).

Gamma emitter (γ)

A radionuclide that emits gamma radiation.

Gamma rays (or gamma radiation)

A high energy photon (a discrete particle of energy that is propagated as an electromagnetic wave having short wavelength) emitted from the nucleus of a radionuclide during radioactive decay. Such radiation is usually very penetrating, only being shielded by several metres of concrete or other dense material. It is a low Linear Energy Transfer (LET) type of radiation.

Gut Transfer Factor

This is a measure of the extent to which a radionuclide is absorbed from the gut into the bloodstream following ingestion.

Lymphoid tissue and lymphatic organs

The organs and tissues of the body containing appreciable numbers of lymphocytes, for example lymph nodes, thymus, spleen, tonsils.

Lymphoma

A tumour of the lymphoid tissue.

NRPB

The National Radiological Protection Board.

Natural Radiation (background radiation)

Natural radiation pervades the whole environment. Radiation reaches the earth from outer space. The earth itself contains radionuclides and natural radionuclides are present in the food we eat and in some of the elements contained in our body. Everyone is exposed to such radiation, which is frequently referred to as background radiation. The principal sources of background radiation are as follows:-

a. Cosmic rays: High energy ionising radiations from outer space. Most of such radiation is absorbed as it penetrates the earth's atmosphere, and thus the resulting dose decreases as the altitude decreases. The average annual effective dose equivalent for the UK population from this source is about 0.30 mSv.

b. Terresterial gamma rays: All materials in the earth's crust contain radionuclides (eg potassium-40 and radionuclides in the uranium-238 and thorium-232 series) and the population is continuously exposed externally to gamma radiation resulting from this decay. The average annual effective dose equivalent for the UK population from this source is about 0.4 mSv.

c. Radon decay products: The decay of the naturally occurring radionuclides thorium-232 and uranium-238 results in the production of radon gas which can move through rocks, soils or building material in which it is generated and be released from the surface. Out of doors radon is soon dispersed but indoors it can accumulate due to limited ventilation, the concentrations varying widely and being dependent on such factors as local geology and the degree of ventilation. The average annual effective dose equivalent for the UK population from this source is about 0.80 mSv.

d. Internal radiation: There are a variety of radionuclides naturally present in air, food and water which irradiate the body internally after ingestion or inhalation. The principal radionuclide is potassium-40, which is always present in natural potassium. Other contributions to internal dose are from Lead-210, Polonium-210 and Radium-226. The average annual effective dose equivalent for the UK population from this source is about 0.37 mSv.

Niobium 95 (Nb)

This is a beta emitting radionuclide with a half-life of about 35 days (it is formed during the decay of zirconium 95).

OPCS

The Office of Population Censuses and Surveys.

Pile

The part of a nuclear reactor which contains the fuel and its moderating system.

Plutonium

An actinide that can exist in several different isotopic forms. The principal isotopes, together with their main decay pathways, are listed below.

Plutonium-238, an alpha emitting radionuclide with a half-life of about 86 years.

Plutonium-239, an alpha emitting radionuclide with a half-life of about 24,000 years.

Plutonium-240, an alpha emitting radionuclide with a half-life of about 6,600 years.

Plutonium-241, a beta emitting radionuclide with a half-life of about 13 years, and which decays to an alpha emitter, americium 241.

Plutonium-242, an alpha emitting radionuclide with a half-life of 379,000 years.

Quality Factor

The factor by which absorbed dose of a given radiation is mutiplied in order to obtain its dose equivalent for radiation protection purposes.

Rad

The old unit of absorbed dose of ionising radiation.

100 rad = 1 gray.

Radionuclide

A type of atomic nucleus which is unstable and can spontaneously decay by emission of ionising radiation (usually alpha, beta or gamma).

Relative Biological Effectiveness (RBE)

The ratio of absorbed dose of reference low LET radiation to the absorbed dose of given radiation which produces the same level of biological effect. It allows compensation to be made for the different effectiveness of the various types of radiation in producing a particular biological effect.

Rem

The old unit of dose equivalent. The absorbed dose (rad) is multiplied by the Quality Factor for the particular type of radiation.

100 rem = 1 sievert.

Sellafield site

The composite name given to the BNFL site in West Cumbria which includes the Windscale nuclear fuel reprocessing facility and the Calder Hall nuclear reactor.

Sievert (Sv)

The Standard International (SI) unit of dose equivalent. The absorbed dose (in grays) is multiplied by the Quality Factor of the particular type of radiation.

1 Sievert = 100 rem.

Stacks

Tall ventilation chimneys from the Windscale piles; they contain filters to remove particulates.

Stem cells

The bone marrow contains immature cells that can divide and give rise to the different types of cells seen in circulating blood; these cells are known as stem cells.

Strontium-89 (Sr-89)

A beta emitting radionuclide with a half-life of about 50 days. It is chemically similar to calcium and tends to concentrate in bone.

Strontium-90 (Sr-90)

A beta emitting radionuclide with a half-life of about 28 years. It is chemically similar to calcium and tends to concentrate in bone.

UKAEA

The United Kingdom Atomic Energy Authority.

Uranium metal fuel (irradiated) : uranium oxide fuel

Uranium metal fuel oxidises in air to uranium oxide; the approximate radionuclide composition of 20 kg of irradiated uranium oxide fuel is as follows:-

2.06×10^{10} Bq	Plutonium-239
2.95×10^{13} Bq	Strontium-89
1.04×10^{12} Bq	Strontium-90
6.98×10^{10} Bq	Caesium-134
1.18×10^{12} Bq	Caesium-137
3.04×10^{7} Bq	Americium-241
1.16×10^{14} Bq	Zirconium-95 Niobium-95

(From Table 3-17 in Addendum)

Windscale Plant

The nuclear fuel reprocessing facility situated within the Sellafield site.

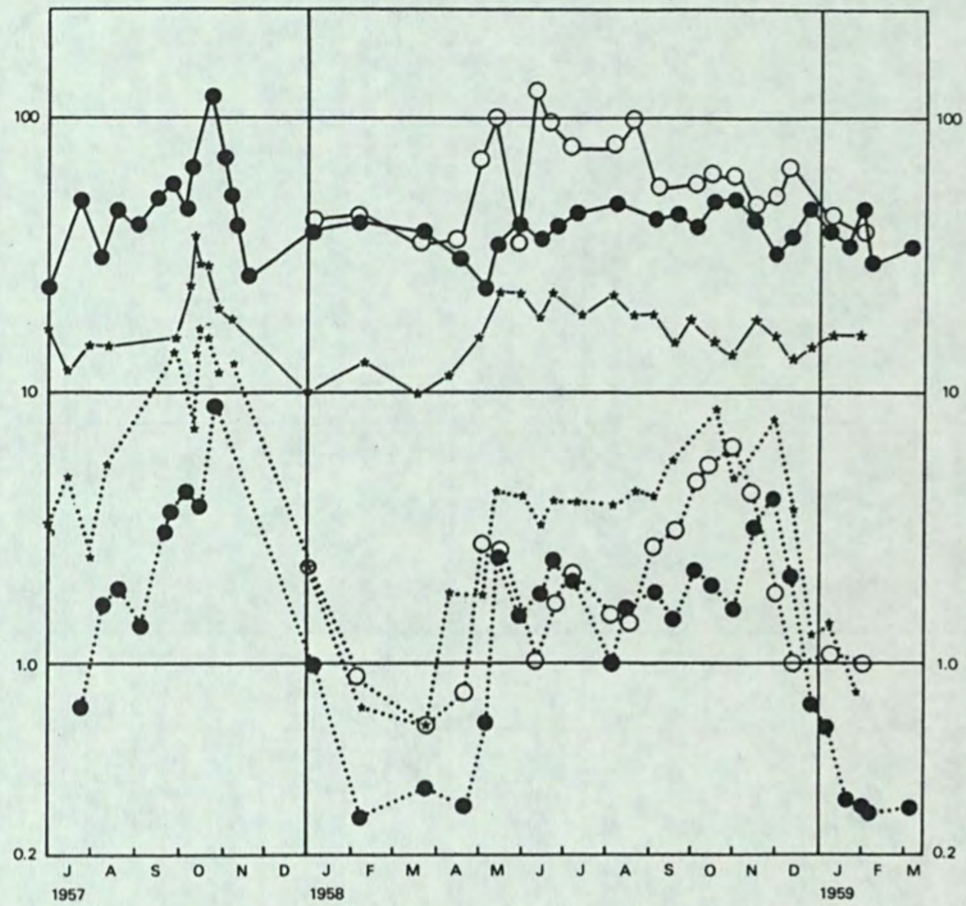
X-ray

Photons with energy greater than about 100 electron volts usually emitted by an X-ray machine or an excited atom. They are similar to gamma rays but usually of lower energy and lower penetration. They are a low Linear Energy Transfer (LET) type of radiation.

Zirconium 95 (Zr)

This is a beta emitting radionuclide with a half-life of about 65 days. It decays to niobium-95.

Figure 1 Strontium-90 and Sr-89/Sr-90 ratio in milk from the near-in farms A, B and C.[20]



Key:

——— μμ Ci Sr-90/g Ca in milk

········ Ratio Sr-89/Sr-90 in milk

1 μμ Ci = 0.037 Bq

● Farm A

○ Farm B

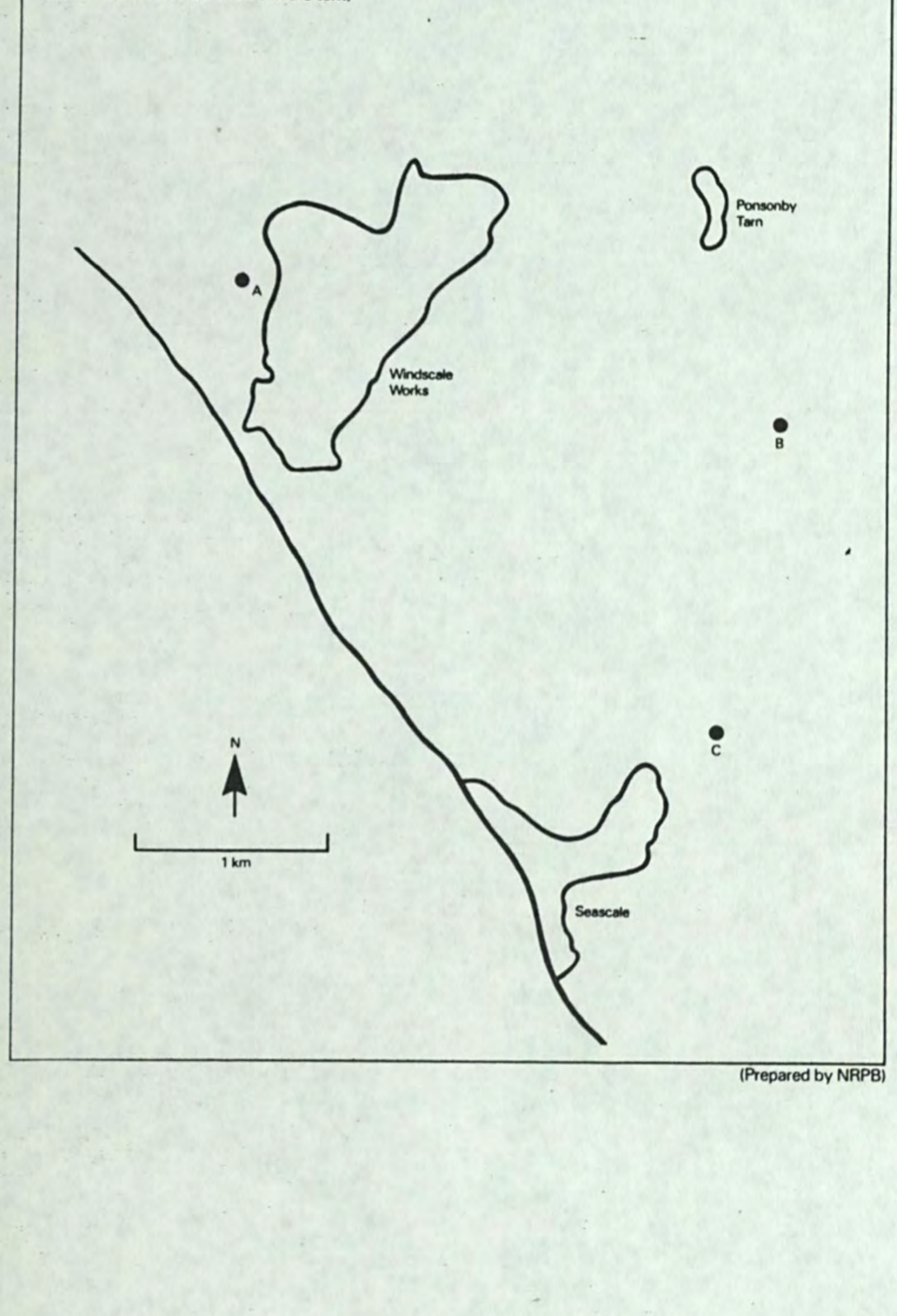
★ Farm C

Notes:

Farm B: 1958 average = 2.71 Bq/l (2.29 Bq/l without fallout)

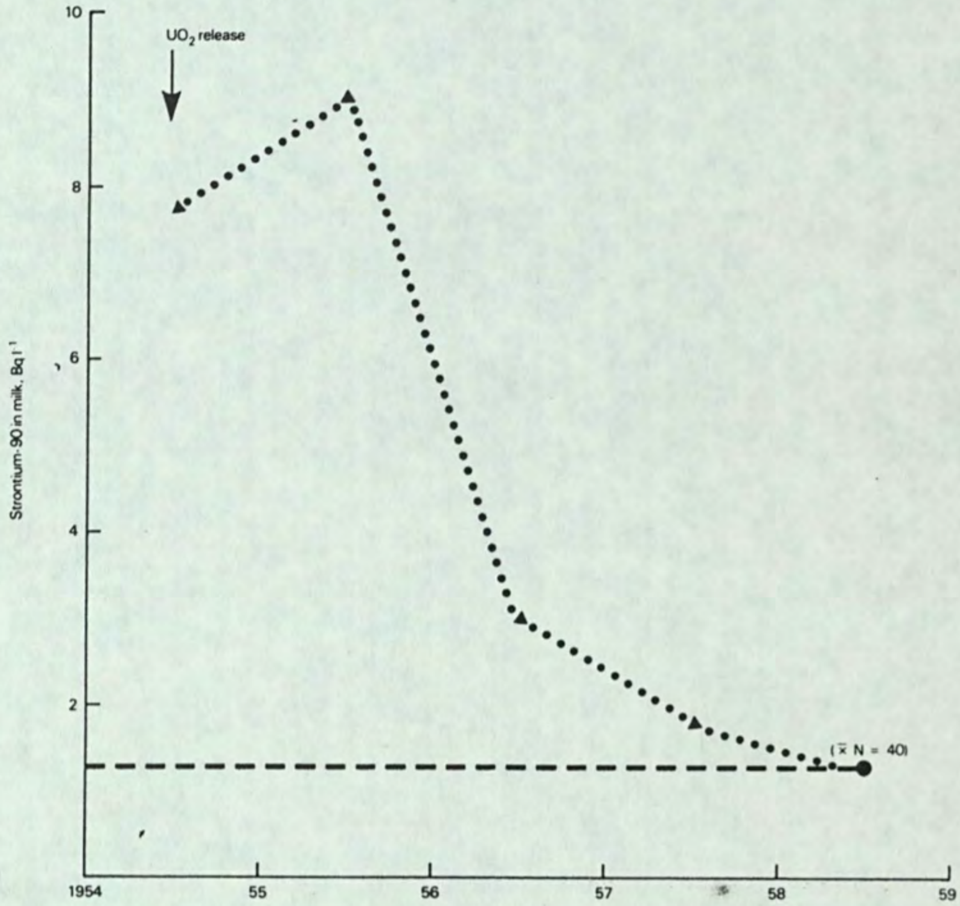
Farm C: 1958 average = 0.71 Bq/l (0.29 Bq/l without fallout)

Figure 2 Location of farms near to the Windscale Works
(Farms B and C are referred to in the text)



(Prepared by NRPB)

Figure 3 Assumptions about Strontium-90 in milk at Seascale village
(Note: Soil and milk values corrected for weapons fallout)



Soil
deposition of
Sr-90 Bq m-2

Measured — — — this extrapolation was used in NRPB-R 171

Model predicted • • • • this extrapolation was used in NRPB-R 171 Addendum (since the total emission was assumed to take place in mid 54, the average value for the year 54 – 55 was less than for 55 – 56.)

(Prepared by NRPB)

TABLE 1

STAGES IN DEVELOPMENT OF SELLAFIELD SITE

Stages in Plant Development	Date Operational	Date Shut Down	Ownership of Site
Site Available July 1947	Work Commenced September 1947	-	Ministry of Supply 1947-54
1st and 2nd Pipeline to Sea	Laid June 1950	-	
No 1. Pile Critical	October 1950	October 1957	
No 2. Pile Critical	June 1951	October 1957	UKAEA 1954-71
First Re-processing Plant and associated facilities	January 1952 et seq	1969	
Re-processing Plant converted to Head End Plant for oxide fuel	1969	1973	BNFL 1971-Present
First Calder Hall Reactors	August 1956	-	
All Calder Hall Reactors	1958	-	
Prototype Advanced Gas Cooled Reactor	1963	April 1981	
Second Re-processing Plant and Associated Facilities (Magnox)	1964 et seq	-	
Spent Oxide Fuel Storage Plant	1968 et seq	-	
Prototype Fast Reactor Fuel Fabrication Plant	1970		
Third Pipeline to sea	Laid 1976	-	

TABLE 2

Integrated dose equivalent to the red bone marrow for children born in Seascale in 1950, and resident in Seascale up to age 20, from inhalation, ingestion and external exposures from the Sellafield discharges. (Adapted from Table C1 of NRPB Addendum to R-171.)

Route	High LET		Low LET		High + Low LET
	μGy	μSv*	μGy	μSv*	μSv*
Inhalation	11	220	6	6	226 (4.2% of total dose equivalent is via inhalation route)
Ingestion	4	84	1700	1700	1784 (34% of total dose equivalent is via ingestion route)
Inhalation and Ingestion Sub-total	15	304	1706	1706	2010 (38% of total dose equivalent is via internal exposure)
External	-	-	3400	3400	3400 (62% of total dose equivalent is via external exposure)
Total (Inhalation and Ingestion and External)	15	304	5106	5106	5410

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

TABLE 3

Comparison of the integrated doses to the red bone marrow from the Sellafield discharges for the average child born in 1950 as determined in NRPB Report R-171 and in the Addendum*

Radionuclide or type of radiation	Dose to age 20 (µGy)	
	NRPB R-171	Addendum to R-171
Low LET		
Sr^{89}	-	$1.1\ 10^{2}$
Sr^{90}	3.2×10^{2}	$8.1\ 10^{2}$
Cs^{137}	3.2×10^{2}	$4.9\ 10^{2}$
S^{35}	1.2	$1.7\ 10^{2}$
Other	$2.6\ 10^{2}$	$2.2\ 10^{2}$
External	$1.7\ 10^{3}$	$3.4\ 10^{3}$
Total	$2.6\ 10^{3}$	$5.2\ 10^{3}$
High LET		
Total	3.7	$1.6\ 10^{1}$

(* from Table 4.7 in NRPB Addendum to R-171)

TABLE 4

Contribution of low and high LET radiation by source to the radiation dose to the red bone marrow received by young people in Seascale; doses estimated to age 20 or 1980 whichever is earlier*

Dose in μSv

Date of birth		1945	1950	1955	1960	1965	1970	1975
Source								
Sellafield discharge	Low LET	$4.4\ 10^{3}$	$5.2\ 10^{3}$	$4.6\ 10^{3}$	$2.1\ 10^{3}$	$2.2\ 10^{3}$	$2.3\ 10^{3}$	$1.4\ 10^{3}$
	High LET	$2.2\ 10^{2}$	$3.2\ 10^{2}$	$5.4\ 10^{2}$	$1.1\ 10^{3}$	$1.2\ 10^{3}$	$8.4\ 10^{2}$	$9.2\ 10^{1}$
Windscale Fire	Low LET	$4.8\ 10^{2}$	$5.6\ 10^{2}$	$5.2\ 10^{2}$	$7.8\ 10^{1}$	$4.0\ 10^{1}$	$2.2\ 10^{1}$	$9.4\ 10^{0}$
	High LET	$1.7\ 10^{2}$	$2.8\ 10^{2}$	$1.6\ 10^{2}$	$2.8\ 10^{-4}$	$3.0\ 10^{-8}$	$3.2\ 10^{-12}$	$3.4\ 10^{-16}$
Weapons Fallout	Low LET	$1.3\ 10^{3}$	$2.3\ 10^{3}$	$3.5\ 10^{3}$	$4.0\ 10^{3}$	$2.2\ 10^{3}$	$8.4\ 10^{2}$	$2.9\ 10^{2}$
	High LET	$1.9\ 10^{1}$	$4.4\ 10^{1}$	$6.6\ 10^{1}$	$5.2\ 10^{1}$	$8.4\ 10^{0}$	$1.9\ 10^{0}$	$3.2\ 10^{-1}$
Medical	Low LET	$3.9\ 10^{3}$	$3.9\ 10^{3}$	$3.9\ 10^{3}$	$3.9\ 10^{3}$	$1.8\ 10^{3}$	$1.1\ 10^{3}$	$6.0\ 10^{2}$
Natural Background	Low LET	$2.0\ 10^{4}$	$2.0\ 10^{4}$	$2.0\ 10^{4}$	$2.0\ 10^{4}$	$1.5\ 10^{4}$	$1.0\ 10^{4}$	$5.6\ 10^{3}$
	High LET	$1.9\ 10^{3}$	$1.9\ 10^{3}$	$1.9\ 10^{3}$	$1.9\ 10^{3}$	$1.4\ 10^{3}$	$9.8\ 10^{2}$	$4.6\ 10^{2}$
Total	Low LET	$3.0\ 10^{4}$	$3.2\ 10^{4}$	$3.3\ 10^{4}$	$3.0\ 10^{4}$	$2.1\ 10^{4}$	$1.5\ 10^{4}$	$7.9\ 10^{3}$
	High LET	$2.2\ 10^{3}$	$2.6\ 10^{3}$	$2.6\ 10^{3}$	$3.0\ 10^{3}$	$2.6\ 10^{3}$	$1.8\ 10^{3}$	$5.6\ 10^{2}$

(* Derived from Table 4.8 in the NRPB Addendum to R-171)

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