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Fallout, radiation doses near Dounreay, and childhood leukaemia

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Abstract

Possible explanations for the recently reported increased incidence of childhood leukaemia around Dounreay were examined in the light of changes in the national incidence of leukaemia that occurred during the period of exposure to fallout from international testing of nuclear weapons in the atmosphere. It was concluded that the increase could not be accounted for by an underestimate of the risk of leukaemia per unit dose of radiation at low doses and low dose rates, nor by an underestimate of the relative biological efficiency of high as compared with low linear energy transfer radiation. One possible explanation was underestimation of doses to the red bone marrow due to the discharges at Dounreay relative to the dose from fallout, though investigation of ways in which this might have occurred did not suggest anything definite. Other possible explanations included a misconception of the site of origin of childhood leukaemia, outbreaks of an infectious disease, and exposure to some other, unidentified environmental agent.

These findings weigh heavily against the hypothesis that the recent increase in childhood leukaemia near Dounreay might be accounted for by radioactive discharges from nuclear plants, unless the doses to the stem cells from which childhood leukaemia originates have been grossly underestimated.

Introduction

An increased incidence of childhood leukaemia has recently been reported in the vicinity of two nuclear installations in the United Kingdom^{1,2}—namely, that at Sellafield, where spent nuclear fuel from nuclear power stations is reprocessed, and that at Dounreay, where a prototype fast breeder reactor has been developed and where there is also a reprocessing operation that deals with fuel from various reactors. Tables I and II summarise the evidence.

The National Radiological Protection Board has published calculations of the estimated radiation doses due to discharges from Sellafield and the risk of leukaemia that might be expected in children living in the nearby village of Seascale.^{3,4} Similar calculations have also been published for Thurso, the town nearest Dounreay.⁵ These calculations are based on assumptions that have generally been accepted by radiobiologists and those concerned with radiological protection, and they lead to the conclusion that the doses received by the children are insufficient to have caused anything like the increase in leukaemia that has been recorded in the vicinity of either installation. It is disturbing, however, that an increased incidence should have been found near two separate installations—and especially near the only two in Britain reprocessing substantial amounts of spent fuel—and this demands further investigation. Increases have also been suggested near several other nuclear installations but it is difficult to know what

TABLE I—Mortality from leukaemia at ages 0-24 years in vicinity of Sellafield.† (Data derived from Gardner and Winter¹)

	Ennerdale rural district			Millom rural district		
	Observed	Expected‡	O:E	Observed	Expected‡	O:E
1959-67	3	3.3	0.91	1	1.6	0.63
1968-78	4	3.3	1.21	6**	1.4	4.35
1959-78	7	6.6	1.06	7*	3.0	2.33

† Sellafield plant is at the southern coastal extreme of Ennerdale rural district. Millom rural district lies immediately to the south.

‡ Based on England and Wales national mortality rates.

* $p < 0.05$, ** $p < 0.01$ (one tailed tests).

TABLE II—Incidence of leukaemia at ages 0-24 years in vicinity of Dounreay. (Data derived from Heasman *et al*²)

	<12.5 km from Dounreay			12.5 to <25 km from Dounreay		
	Observed	Expected†	O:E	Observed	Expected†	O:E
1968-78	0	1.1	0	0	0.99	0
1979-84	5***	0.5	9.75	1	0.45	2.21
1968-84	5*	1.6	3.19	1	1.44	0.69

† Based on all Scotland cancer registration rates.

* $p < 0.05$, *** $p < 0.001$ (one tailed tests).

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attention should be paid to these until a full study of all installations is available.

The possibility that the increased incidence of leukaemia near these two special installations might be due to chance is too unlikely to be acceptable unless all other explanations are ruled out, and we need to find an explanation that will account for both findings. We have therefore examined the evidence relating to the amount of irradiation received by children near Dounreay as a possible cause of leukaemia and viewed the findings in the light of the known effects of the worldwide fallout from the testing of nuclear weapons in the atmosphere. We considered that a hypothesis that failed to explain the increased incidence in one area could not be regarded as a satisfactory explanation in the other.

Radiation exposures to children in Thurso

Children living in Thurso are exposed to radiation from several sources, the most important of which are naturally occurring radiation, fallout from weapons testing, medical x rays, discharges into the sea and to the atmosphere from Dounreay, and discharges into the sea from Sellafield that have spread northwards round the coast. Throughout this paper discharges into the sea from Dounreay include those from the adjoining reactor site (Vulcan Naval Reactor Test Establishment) operated by the Ministry of Defence.^{6,7} There is clear evidence that leukaemia can be caused by exposure to radiation and it is widely assumed that even very low doses will cause a small increase in risk of the disease. If this is true, then all the sources of radiation listed above will contribute to the risk of radiation induced leukaemia in children in Thurso. In the National Radiological Protection Board's study of radiation doses to these children Dionian *et al* have estimated the absorbed dose to the red bone marrow from each source up to 1985 for children living in Thurso, the types of radiation being separated into low linear energy transfer radiation, such as x rays and γ rays, and high linear energy transfer radiation, chiefly α particles.⁵ Detailed figures have been published for the cohort born in 1960 (table III). Three quarters of the estimated dose from low linear energy transfer radiation and 93% of the estimated dose from high linear energy transfer radiation is attributable to natural sources. Given the conventional assumption that high linear energy transfer radiation is 20 times as harmful as low linear energy transfer radiation per unit of absorbed dose, just over three quarters of the dose equivalent to the red marrow is attributable to natural radiation; 13% is estimated to have been due to fallout and very much smaller proportions to discharges from Dounreay (1.3%) and Sellafield (0.3%).

For comparison of the effects produced by different sources of radiation with those possibly produced by the discharges fallout has several advantages. The three recognised pathways of exposure for the discharges are (a) external exposure from radionuclides deposited on the beach or on soil or from the radioactive cloud, (b) internal exposure from inhalation of radionuclides in the air or in resuspended beach sands and sea spray, and (c) internal exposure from ingestion of radionuclides in marine foods, especially shellfish, and terrestrial foods and the inadvertent ingestion of beach sands and soil. These three pathways of exposure are also thought to operate for fallout—that is, external exposure from radionuclides deposited on the ground, both by dry deposition and in rainfall, and internal exposure from inhalation of radionuclides in the air and from terrestrial foods in which radionuclides have been incorporated.

Fallout, moreover, has several radionuclides in common with the

TABLE III—Average dose to red bone marrow integrated to 1985 for person born in 1960 and living in Thurso by source of radiation and radiation type. (Data derived from Dionian *et al*⁵)

Source of radiation	Absorbed dose to red bone marrow (μGy)		Dose equivalent to red bone marrow	
	Low linear energy transfer* (includes x rays, γ rays)	High linear energy transfer (chiefly α particles)	μSv*	%
Natural radiation	2.4 × 10 ⁴	1.3 × 10 ²	2.7 × 10 ⁴	76.8
Fallout	4.6 × 10 ³	3.0	4.7 × 10 ³	13.4
Medical exposure	2.9 × 10 ³		2.9 × 10 ³	8.3
Dounreay discharges	3.6 × 10 ²	4.0	4.4 × 10 ²	1.3
Sellafield discharges	1.2 × 10 ²	9.0 × 10 ⁻²	1.2 × 10 ²	0.3
Total	3.2 × 10 ⁴	1.4 × 10 ²	3.5 × 10 ⁴	100.0

* Calculated assuming that relative biological efficiency of high linear energy transfer radiation is 20.

TABLE IV—Radionuclides occurring in fallout or in discharges from Dounreay or Sellafield and contributing to radiation dose to red bone marrow of child born in Thurso in 1960. (Data derived from Dionian *et al*⁵)

Sources of radiation	Radionuclides	
	Low linear energy transfer	High linear energy transfer
Fallout, Dounreay discharges* and Sellafield discharges†	Strontium-90, ruthenium-106, caesium-137, cerium-144, plutonium-239, plutonium-238‡ external radiation	Plutonium-239, plutonium-238‡
Fallout and Dounreay discharges*	Strontium-89, iodine-131	
Dounreay* and Sellafield‡ discharges only	Zirconium-95, niobium-95, caesium-134, plutonium-241,§ americium-241§	Plutonium-241,§ americium-241§
Fallout only	Carbon-14	

* Discharges to sea and atmosphere.

† Discharges to sea.

‡ Plutonium-238 not listed explicitly by Dionian *et al* as occurring in discharges from Dounreay and Sellafield.⁵ Nevertheless, small amount does occur and was taken into account by Dionian *et al* in their calculations (J Dionian, personal communication).

§ Plutonium-241 and americium-241 are produced in fallout but contribution to dose is very small by comparison with other radionuclides.

|| Carbon-14 is present in Dounreay discharges but in only small quantities compared with other radionuclides.

FIG 1—Yearly number of nuclear explosions in atmosphere during 1945-80. (Data derived from United Nations Scientific Committee on the Effects of Atomic Radiation.⁸)

discharges. Many of these are capable of irradiating the red bone marrow, which is assumed to be the tissue in which leukaemia is induced. Those that contributed appreciably to the dose to the red marrow in children born in Thurso in 1960 were listed by Dionian *et al* in two groups according to the type of radiation produced (low or high linear energy transfer) for each source (table IV).⁵ External low linear energy transfer radiation, six radionuclides producing low linear energy transfer radiation, and two radionuclides producing high linear energy transfer radiation were common to all three sources, and two further radionuclides producing low linear energy transfer radiation were common to both fallout and to the discharges at Dounreay. This contrasts sharply with the picture for the other two main sources of exposure—namely, medical and natural irradiation. The estimated dose to the red bone marrow in children due to medical irradiation is almost entirely from external x rays, whereas the dose due to natural irradiation is from low linear energy transfer external radiation and from the radionuclides potassium-40, polonium-210, lead-210, radium-226, radon-220, and radon-222, none of which occurs in substantial quantities in liquid discharges from Sellafield or in liquid or atmospheric discharges from Dounreay.

Lastly, fallout has the advantage for our analysis that the resulting exposure to radiation has varied greatly over time. Figure 1 shows the number of nuclear explosions in the atmosphere by calendar year. The first

nuclear weapon test in the atmosphere took place at Alamogordo in 1945, before the bombings of Hiroshima and Nagasaki. Atmospheric testing increased after the war and reached a peak in the late 1950s and early 1960s. After the 1962 test ban treaty the level of atmospheric testing fell and has remained low, only France and China continuing to test.

Discharges from the Dounreay site began in 1958⁷ and from Sellafield around 1950.⁴ Estimates of the average yearly absorbed doses from low and high linear energy transfer radiation received in the bone marrow by children born in Thurso in 1960 from these two sources and from fallout have been published by Dionian *et al.*⁵ Figure 2 shows the contributions from Dounreay and fallout; the maximum yearly contributions from Sellafield for both high and low linear energy transfer radiation were very small by comparison with the maximum contributions from either fallout or Dounreay and are omitted. The contributions from medical exposure and

period of peak testing activity and then declined. In every year, however, the estimated dose due to fallout was greater (and sometimes much greater) than that due to the discharges from Dounreay. The estimated dose from high linear energy transfer fallout also reached a peak in the mid-1960s and then declined. By the late 1970s the decline had halted and the estimated yearly dose subsequently remained roughly constant. This constant dose was due to inhaled plutonium-239, which is thought to have a long retention time on bone surfaces and to irradiate the red bone marrow continuously. The estimated yearly high linear energy transfer dose from the discharges at Dounreay tended to increase throughout the period, and from about 1970 it exceeded that from fallout. The maximum estimated yearly high linear energy transfer dose due to the discharges at Dounreay occurred in the early 1980s and was comparable with the estimated dose due to fallout in the mid-1960s.

Possible explanations for increased incidence of leukaemia near Dounreay

Four explanations for the increased incidence of leukaemia near Dounreay seem possible—namely, (a) that some leukaemias were caused by the discharges from Dounreay, in which case others will have been caused by fallout from weapon tests; (b) that estimates of the relative magnitude of the average doses to the red marrow due to fallout and the discharges are wrong; (c) that the dose to the red bone marrow is irrelevant for childhood leukaemia; and (d) that the leukaemias have been caused by some agent other than radiation exposure from the discharges. These four explanations are examined below.

SOME LEUKAEMIAS NEAR DOUNREAY CAUSED BY DISCHARGES AND SOME CAUSED BY FALLOUT FROM WEAPON TESTS

One explanation is that most of the leukaemias near Dounreay are, in fact, caused directly by the discharges. If this is true it follows that doses from fallout must also have been large enough to cause a material increase in the risk of childhood leukaemia, unless explanation (b) or (c) is also true. Fallout, however, is not specific to the area around Dounreay, which enables the effect of fallout to be tested. Airborne material transferred from the stratosphere is widely dispersed in the northern hemisphere. There is some variation with latitude, but this effect is small for the geographical regions considered in this paper. Thus doses from inhaling fallout material from weapons testing may be considered to be independent of geographical location. Deposition of some radionuclides depends on rainfall, and transfer of the deposited material through food chains may depend on local agriculture. Thus doses from ingesting radionuclides in food may vary geographically. For high linear energy transfer radiation most of the dose is thought to arise from inhaled plutonium in the air; thus the high linear energy transfer plutonium dose from fallout in England and Wales, and also throughout Scotland, is estimated to be similar to that in the vicinity of Thurso and to have occurred with a similar temporal pattern. For low linear energy transfer radiation the dose is chiefly due to radionuclides deposited on the ground in rainfall and subsequent uptake through food chains; hence it varies in magnitude from place to place, though the temporal pattern will still be broadly similar. It follows that the average dose from low linear energy transfer radiation in England and Wales as a whole is lower than that in Thurso, where the rainfall is above average for the United Kingdom, though the amount is thought not to differ by more than a factor of two. For Scotland as a whole the estimated doses from low linear energy transfer radiation lie between those for England and Wales and those for Thurso.

Death rates, which were commonly used as a surrogate for the incidence of leukaemia when the disease was almost uniformly fatal, became no longer usable for the study of trends around 1960, when improvements in the treatment of leukaemia in children began to be reflected in a falling mortality (see table V). Incidence rates depend on the efficiency of registration and, though this began in some areas before the second world war, it was not extended nationally until the 1950s; even then it was grossly incomplete in some parts of Britain owing to poor administrative support. In England and Wales registration remained lower than the death rates until 1969 and did not exceed the average level of mortality in the 1950s until 1971 (fig 3). After 1971 there was an increase of around 10%, which persisted until 1979, when the recorded incidence fell to the level of the mortality in the 1950s. The data for Scotland show a similar pattern (fig 3). Published data for childhood cancer are reportedly inflated by some 10% owing to duplicate registrations and the failure to deregister incorrectly diagnosed cases.⁹ This, however, does not account for the observed temporal pattern, as the data obtained by the Childhood Cancer Research Group, in which these errors have been corrected, show the same pattern (C Stiller, personal communication). We are therefore left with the possibility of a small increase in incidence in the

FIG 2—Estimated average yearly absorbed radiation doses to red bone marrow resulting from fallout (---) and Dounreay discharges (—) for high and low linear energy transfer radiation for person born in 1960 in Thurso. (Fetal doses not included but estimated as follows—low linear energy transfer: fallout 86 µGy, Dounreay 8.4 µGy; high linear energy transfer: fallout 6.4×10^{-4} µGy, Dounreay 7.3×10^{-5} µGy.) (Data derived from Dionian *et al.*⁵)

natural radiation are also omitted from figure 2. They will have been roughly the same each year—namely, from medical radiation (low linear energy transfer only) 270 µGy to the fetus and between about 40 µGy and 160 µGy a year after birth, depending on age; and from natural radiation (low linear energy transfer) 690 µGy to the fetus and 950 µGy a year after birth and (high linear energy transfer) about 0.2 µGy to the fetus and between 4.4 µGy and 6.0 µGy a year after birth, depending on age.

Figure 2 shows that the standard yearly dose from low linear energy transfer radiation due to fallout rose to a maximum a few years after the

TABLE V—Proportion of leukaemic children surviving five years or more after diagnosis by calendar period. (Manchester data derived from Draper *et al.*⁹; data for Britain derived from C Stiller (personal communication))

	Year of diagnosis	Percentage of children surviving five years or more
All leukaemias (Manchester)	1954-8	0
	1959-63	3
	1964-8	5
	1969-73	26
Acute lymphatic leukaemia (Britain)	1971-3	36
	1974-6	47
	1977-9	52

FIG 3—Leukaemia mortality (●) and registration (○) rates in patients aged 0-24 years in England and Wales and in Scotland during 1950-84 directly standardised to world standard population.¹¹ (Data derived from reports published by Office of Population Censuses and Surveys and Registrar General, Scotland, and unpublished data supplied by Scottish Health Service Common Services Agency.)

early 1970s, which is proportionally two orders of magnitude less than that observed in Dounreay and, on the basis of studies of radiation induced leukaemia, some five years later in time than would have been expected had it been due to fallout.

If the leukaemia trends in Britain in the 1970s were due to fallout we should expect similar trends to have been recorded in Denmark and Norway, where national cancer registries have long been established and where the same temporal trend in fallout was observed. For high linear energy transfer radiation the estimated doses in those two countries are similar to those in Britain. For low linear energy transfer radiation the estimated doses are higher than in the United Kingdom, especially in Norway because of its high rainfall. Measured concentrations of caesium-137 in Norwegian milk have been about six times those in the

United Kingdom and measured concentrations of strontium-90 about three times the United Kingdom values, whereas concentrations in Denmark have been intermediate between those for Norway and the United Kingdom for ⁹⁰Sr and similar to the United Kingdom values for ¹³⁷Cs.

Data on the incidence of acute leukaemia (which would include almost all childhood leukaemia) are available from 1943 for Denmark and from 1953 for Norway.¹⁰ Figure 4 shows these for ages 0-24 years standardised for age.¹¹

FIG 4—Incidence of acute leukaemia in population aged 0-24 years in Norway during 1953-80 (---) and Denmark during 1943-80 (—) directly standardised to world standard population.¹¹ (Data derived from Hakulinen *et al.*¹⁰)

In neither country was there a peak in incidence in the early 1970s or late 1960s. The increasing trend in Denmark before 1960 is thought to have been at least partly artificial and due to an increase in the proportion of children with leukaemia who were diagnosed correctly.¹²

Thus, though the rates of childhood leukaemia have varied in each of the three countries, there is no convincing evidence of an increase in incidence that could be attributed to fallout, let alone any comparable with that found around Dounreay.

The arguments presented in this paper make the conventional assumption that risk per unit dose is roughly uniform throughout the range of doses that have been received by children living in Thurso. It has sometimes been suggested, however, that for low linear energy transfer radiation the risk per unit dose varies within the low dose range, resulting in a higher risk per unit of absorbed dose for those at the upper end of the range and making the average dose an inappropriate measure. Nevertheless, that the average yearly doses due to fallout from weapons testing have varied up to well over 10 times the maximum yearly average dose resulting from discharge means that if this were so an even greater effect of fallout in comparison with the discharges would be expected. For high linear energy transfer radiation radiobiological work does not, on the whole, suggest a departure from a uniform risk per unit of absorbed dose, even in the low dose range.

ESTIMATES OF RELATIVE MAGNITUDE OF AVERAGE DOSES TO RED MARROW DUE TO FALLOUT AND DISCHARGES WRONG

A second possible explanation of the findings is that the true dose to the red marrow due to the discharges when averaged over all subjects is much higher than that due to fallout. A popular explanation postulates the existence of a small subgroup of people who have received very high doses due to the discharges and who have been omitted from the calculations. We have discounted this as accounting for the findings for the following reasons. Even if a very small proportion of the children had received very high doses and had not been taken into account in the calculations this would have a negligible effect on the overall average dose; for example, if 1% of children had in fact received 10 times the estimated average dose and been omitted, then altering the calculations to take them into account would increase the average by only 10%. Thus to explain the findings it is necessary to postulate that the proportion of children receiving extraordinarily high doses is

substantial. The mechanisms by which this might occur—for example, living on the beach, eating a diet of pure shellfish, or deliberately ingesting large quantities of beach sands—are such that it is not plausible that they would apply to a substantial proportion of children. There are, however, several ways in which it might theoretically be possible for a large discrepancy in the estimates of the relative magnitude of doses from fallout and from the discharges to have occurred.

Firstly, the amounts of radioactive materials assumed to be present in the environment may be wrong. Those from fallout are based on environmental measurements and are therefore unlikely to be grossly in error. Those from the discharges are based primarily on mathematical models, as this approach permits a more comprehensive assessment than would be possible on the basis of environmental measurements alone.⁷ The results obtained by comparing the model predictions with such environmental measurements as have been made in Thurso and the surrounding area suggested that the predicted doses are unlikely to be far out. Indeed, the doses predicted by the models appear to overestimate the concentrations of radionuclides in the environmental materials that are thought to be the most important causes of exposure by a factor of two or three.⁷

Secondly, assumptions regarding individual behaviour, such as the amount of time spent on the beach, quantities of various different types of food eaten, etc., may be wrong; and, thirdly, the metabolic models relating the dose in an individual organ or tissue to an intake of radionuclide may be wrong. As it is impossible to measure the body content of plutonium in vivo at the levels of interest, it is not possible to test all the assumptions directly. Nevertheless, in two studies comparing measured and predicted concentrations of ¹³⁷Cs in the body the models tended to overestimate dose.^{13,14} In Germany measurements of the concentration of plutonium due to fallout from weapons testing have also been made at necropsy for several organs and good agreement has been shown between measured and predicted values.¹⁵ We emphasise that the same metabolic models are used for both discharges and fallout and so cannot distort the relative magnitude of the dose from the two sources in so far as the same radionuclides and methods of intake are concerned. For low linear energy transfer radiation the estimated doses from external radiation are much the same from the discharges and fallout and much additional low linear energy transfer internal radiation was received only from fallout. For high linear energy transfer radiation most of the dose from both fallout and the discharges is due to ²³⁹Pu. For fallout, however, the dose is received mainly from inhalation, whereas for the discharges it is received mainly from ingestion. Substantial differences might therefore be produced if the assumed proportion of plutonium transferred from the lung into the bloodstream is much too high or the assumed proportion transferred from the digestive tract is much too low.

DOSE TO RED BONE MARROW IRRELEVANT FOR CHILDHOOD LEUKAEMIA

The target cells for adult myeloid leukaemia are located in the bone marrow, and there is now evidence that a substantial proportion of childhood leukaemias also arise in the bone marrow, a small proportion of cases arising in the fetal liver or thymus. The question, however, is not completely resolved (M Greaves, personal communication).

We do not know where in the bone marrow the target cells lie, but even if they are restricted to a small region of the marrow it seems unlikely that the ratio of fallout dose to discharge dose for that region would differ substantially from that for the marrow as a whole.

LEUKAEMIAS CAUSED BY SOME AGENT OTHER THAN RADIATION EXPOSURE FROM DISCHARGES

The fourth possible explanation is that these leukaemias are caused not by radiation exposure from the discharges at Dounreay but by some other environmental agent. It is not easy, however, to suggest what such an agent might be. The only agents other than ionising radiations that are known to have caused leukaemia are benzene, some of the alkylating agents and other drugs used for cancer, and two viruses (human T cell lymphotropic viruses types 1 and 2), and none of these has caused the typical acute lymphoblastic leukaemia of childhood.

Viral infection has often been suspected as the most likely principal cause; but no direct evidence of such a cause has been obtained, unless it is thought to have been provided by the occurrence of leukaemia in the donor's marrow cells after the treatment of leukaemia in a child by whole body irradiation and marrow transplantation.¹⁶ Reports of clusters of cases have occurred frequently in the past 50 years and the evidence that clusters may occur more often than would be expected by chance alone is not conclusive.¹⁷ If an infective agent is responsible for the disease it is possible that mini epidemics would be particularly likely to occur under the conditions that have brought together a young workforce in a comparatively isolated area.

Many other environmental agents have been suspected as possible causes from time to time (for example, electromagnetic fields¹⁸ and parental occupation, particularly paternal exposure to chlorinated solvents, pesticides, and incense (J Peters, personal communication)). None has yet been substantiated and there is no obvious reason, other than parental occupation in a nuclear installation, why such factors should have caused an increased number of cases specifically round Dounreay and Sellafield.

Conclusions

The available data weigh heavily against the hypothesis that the recent increase in childhood leukaemia near Dounreay might be accounted for by exposure to radiation due to discharges from the Dounreay and Sellafield plants, unless the doses to the red marrow from the discharges are grossly underestimated by comparison with the doses received from fallout. In particular, the possibility that an underestimate either of the risk of leukaemia per unit of absorbed dose to the bone marrow at low doses and low dose rates or of the relative biological efficiency of high linear energy transfer as compared with low linear energy transfer radiation is ruled out by the lack of any consistent increase in childhood leukaemia after the period of peak fallout. Investigation of the various ways in which underestimates of dose might have occurred does not suggest any ready explanation, but there remains the possibility that childhood leukaemia does not arise from the red marrow and that the radioactive nuclides are disproportionately concentrated in the relevant tissue. Alternatively the increase might be the result of a cluster of cases brought out by an infective agent or perhaps by some other environmental agent. Which, if any, of these explanations is correct can be determined only by further research.

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