APPENDIX H

The Nuclear Reactor Accident at Windscale—October, 1957: Environmental Aspects

The nature and cause of the nuclear reactor accident at Windscale in October, 1957, have been described in the summary report of the Committee of Inquiry set up by the Atomic Energy Authority. This report was published in a Command Paper (Atomic Energy Office, 1957). The events leading up to the accident occurred on the 8th October, during a routine release of the energy which had become stored in the graphite moderator as a result of the normal operation of the reactor. The Committee concluded that the accident had been caused by local overheating of the uranium fuel elements, the canning of which then failed exposing the uranium and allowing it to oxidize. The temperatures in the affected channels continued to rise, leading to the combustion of the graphite. By the evening of Thursday, the 10th October, the fire had spread and was affecting about 150 channels, permitting the release of substantial amounts of the radioactive fission products from the reactor.

The initial action taken was primarily concerned with attempting to reduce the temperature of the graphite. When it was found that a number of channels containing uranium at red heat were on fire, an attempt was made to discharge the affected channels. This was unsuccessful and surrounding channels were then discharged to form a fire break. At about 9 o'clock on the morning of Friday, the 11th October, large quantities of water were poured into the reactor, causing the fire to subside.

The radioactivity released

The amount of radioactivity released during the accident is not known precisely, but approximate estimates were made from the measurements of the radioactive iodine deposited on the ground in this country, and from measurements on air filters obtained both in the United Kingdom and on the continent of Europe. (Some of the filters examined were being run in connection with studies of normal air pollution in a number of towns in the U.K.) The release of iodine 131 has been discussed by Booker (1958), Crabtree (1959) and Chamberlain (1959), and the release of iodine 131 and other fission products was referred to by Chamberlain (1958) and summarized by Dunster *et al.* (1958). The following list shows a re-assessment of the amounts of various isotopes released:

iodine 131	20,000 curies
tellurium 132	12,000 curies
caesium 137	600 curies
strontium 89	80 curies
strontium 90	2 curies

Crabtree (1959) describes the meteorological situation during the period of the release and its effect on the travel and spread of the radioactive cloud. From midday on the 10th October the winds at Windscale were light and variable, with a tendency to blow from the south-west. As the accident proceeded, the weather changed and the winds quickly veered to a northerly direction and gradually backed to north-west during the morning of the 11th October. Some material released at an early stage was thus initially carried mainly north-east, producing a zone of deposition as far east as the West Riding of Yorkshire. Material released at a later stage was carried in a south-easterly direction, causing the main deposition of radioactive iodine over Cumberland and Lancashire. Stewart and Crooks (1958) described how the radioactivity (by then at low concentration) reached Belgium late on the 11th October, Frankfurt late on the 12th October, and eventually circled back to Norway at some time on the 15th October. Figure 1H shows the time integral of the concentration of radioiodine at various positions in Europe following the accident.

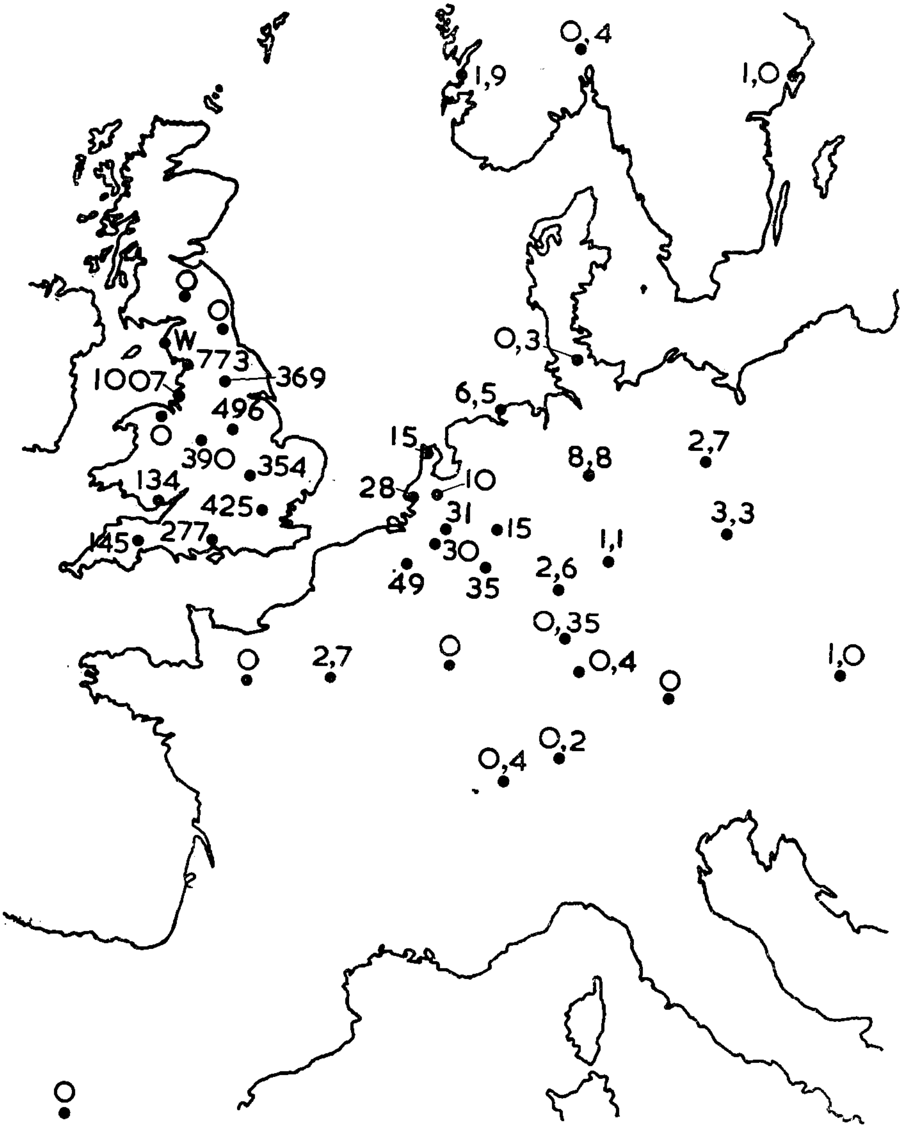

FIG. 1H. Map showing the time integral of the concentration of radioiodine in air (micro-microcurie-days per cubic metre) at various locations in Europe following the Windscale reactor accident in October, 1957.

Problems created by the accident

The immediate problems facing the health physicists fell into two distinct classes. In the first place, the operations in the reactor building and, in particular, the attempts to clear the damaged channels and to provide a fire break exposed the men involved to the possibility of irradiation at considerable dose-rates and serious inhalation of radioactive material. The protective measures taken included the wearing of respirators and very detailed control of radiation exposure. Measurements of thyroid doses of 96 workers in the plant showed a maximum dose of 9·5 rads, the next highest being 2·1 rads, and an average dose of 0·4 rad as a result of the inhalation of iodine 131. The control of external radiation doses was such that during the 13-week period including the accident only 14 workers exceeded the maximum permissible dose of 3 rems, the highest dose being 4·7 rems; this dose is well within the exposure (12 rems) allowable under the Recommendations of the International Commission on Radiological Protection during an emergency. There was also some hair and hand contamination but this was successfully removed by routine procedures.

The other group of problems concerned the possible danger to the general public arising from external irradiation and from inhalation and ingestion of radioactive material. It was possible at an early stage to exclude the necessity for any emergency measures in regard to inhalation or external irradiation, but early measurements of deposition showed that it would be necessary to consider prohibiting the consumption of milk, particularly by children.

Measures taken to protect the public

In order to enable appropriate measures to be introduced for the protection of the public, measurements of radioactivity were made on large numbers of samples of milk and foodstuffs.

In addition to these surveys a substantial number of direct measurements was made of the level of deposited activity over a wide area (Chamberlain, 1958, 1959) and also of the activity caught by filters of various types, more particularly in order to obtain information of value for scientific purposes. The results of the surveys and the derivation of the control levels are summarized by Dunster *et al.* (1958) and the inferences drawn from the measurements are summarized below.

Exposure to external radiation

Before the accident, routine gamma-radiation surveys in west Cumberland made with ionization chambers fixed in survey vehicles had shown that the natural gamma background varied according to position over a range of 4-10 micro-roentgens per hour, with a mean value of 7 micro-roentgens per hour. Most of the survey work following the accident was carried out with scintillation counters originally designed for geological prospecting. These were readily portable and more sensitive for gamma radiation from the deposited iodine than the conventional ionization chambers, although they were not energy independent.

The principal sources of external radiation to which the public were exposed were the deposited iodine 131, tellurium 132 and iodine 132. Dunster *et al.* (1958)

estimated the integrated gamma dose to people living in the area of maximum deposition as 30 to 50 milliroentgens. Integration of the results of Chamberlain (1958) gives a total gamma dose of 75 milliroentgens, no allowance being made for the shielding effect of houses. There would also be small additional external doses from the passing cloud of radioactive material and from deposited long-lived fission products, but it can be concluded from the investigations made that these were less than that from deposited radioiodine.

The results of the external radiation surveys were of considerable help in planning the milk surveys and were also used subsequently by Chamberlain (1958) in more detailed scientific studies of the deposition of iodine 131.

Ingestion of iodine 131

(*a*) *Milk.* During the six weeks after the accident over 3,000 samples of milk were analysed; on occasion over 250 measurements were made per day. The results of these measurements have been reviewed by Booker (1958) and by Dunster *et al.* (1958). The iodine 131 content of milk rose to a maximum three days after the accident when the highest levels recorded were 1·4 μc/litre. Thereafter the concentration in milk decreased in approximately exponential fashion with a half-period of rather less than five days.

The distribution of milk to the population was prohibited when the concentration of iodine 131 exceeded 0·1 μc/litre; the derivation of this figure was described by Dunster *et al.* Restrictions were introduced progressively over the period 11th to 13th October and the final area affected was 200 square miles extending from Windscale southwards to the Barrow peninsula (Fig. 2H). Smaller quantities of iodine 131 were reported in milk from greater distances by Spiers (1959) and others.

The Ministry of Agriculture, Fisheries and Food permitted arrangements to be made for resuming the distribution of milk when all the samples from a district contained less than 0·1 μc/litre and the activity in the milk was decreasing with a half-life of not more than 8 days. Over the greater part of the area these conditions were fulfilled within 25 days of the accident but restrictions were not removed from the most highly contaminated locality until 44 days after the accident, during which time sufficient analyses of strontium in milk had also been made for it to be certain that restrictions need not be continued on account of strontium 90.

(*b*) *Drinking water and other items of diet.* Samples of drinking water were obtained from reservoirs, streams feeding reservoirs and directly from water taps. The levels of radioiodine found during the course of the survey varied from below the threshold of detection (about 100 μμc/litre) to about 1,000 μμc/litre. The possible intake of radioiodine from this source by members of the public was thus very small compared with the potential intake from contaminated milk. Samples of eggs, vegetables and meat were examined from the more highly contaminated areas; they also were shown to be very small sources of iodine 131 in the human diet relative to milk.

Radiation doses incurred in human thyroid glands

The main risk to members of the public arose from the contamination of milk, and the control measures, already described, were introduced to control this hazard. In a few instances, however, there was reason to suspect that the control of milk had not been fully effective. In these instances individuals were invited to the laboratories at Windscale and measurements were made of the activity of iodine 131 in their thyroids. In addition, some members of the public more representative of those in the down-wind area were similarly invited for measurement. The results of these thyroid measurements are given in Table 1H. Details of the method of calculation of the thyroid doses shown in this table have been published (Dunster *et al.*, 1958).

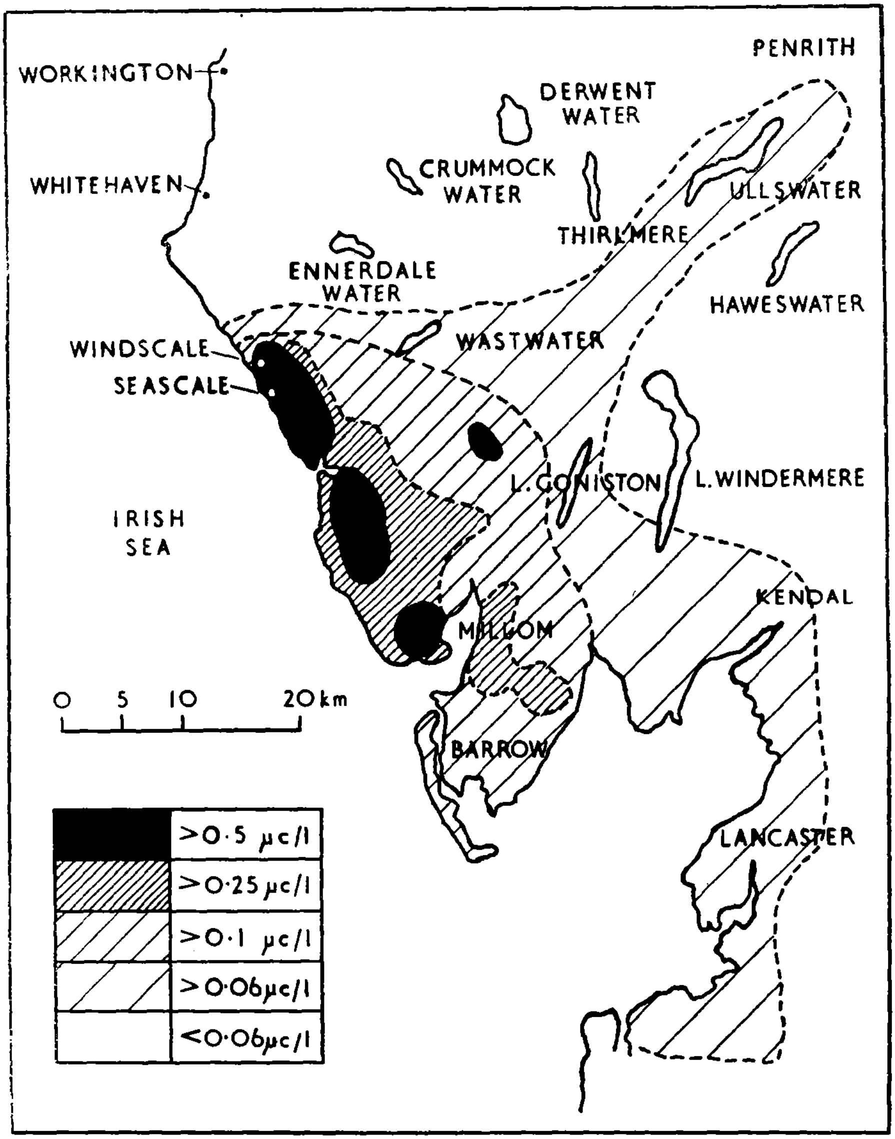

FIG. 2H. Map of the Windscale area showing contours of radioiodine contamination in milk on the 13th October, 1957.

TABLE 1H

Radiation doses in human thyroids

Persons who lived in the down-wind sector but who were not in the Windscale Works at the time of the accident*

Place	Range (miles)	Average dose (rads)		Maximum dose (rads)	
		Adults†	Children†	Adults	Children
Seascale	2	0·5 (18)	0·8 (9)	1·4	3·9
Drigg	4	1·4 (8)	3·9 (3)	2·8	7·3
Holmrock	4·5	1·4 (7)	—	2·7	—
Ravenglass	6	1·8 (8)	12·2 (3)	4·0	16·1
Bootle	11	1·4 (12)	6·0 (11)	3·4	9·8
Millom	19·5	0·4 (29)	—	1·8	—
Ulverston	23	0·5 (5)	4·4 (3)	1·4	11·4
Barrow	24	0·3 (9)	—	1·1	—

* At places having a bearing between 130 and 160 degrees from Windscale.
† The number of persons examined is shown in brackets.

The highest dose to a child's thyroid was estimated as 16 rads and the corresponding figure for an adult's thyroid was 4·0 rads. In addition to the measurements given in the table for persons in the down-wind sector, approximately 113 other thyroid measurements were made on members of the public living in other places in the vicinity. Of these, 107 showed a dose of zero and the highest dose was 1·2 rads.

Since the control of milk was based on large numbers of assays there is every reason to believe that the members of the public were satisfactorily protected against excessive doses of internal radiation. The measurements made on thyroid glands give confirmation to this view. Alternative supplies of milk for certain areas had been brought in and at no time was there any shortage. Of the other possible sources of internal contamination, vegetables, eggs, meat, and water, none was found to require restriction.

The use of contaminated milk for human consumption in any form was prohibited when its content of iodine 131 exceeded a level which might have been injurious to infants. It is important to recognize, however, that none of the milk would have led to an unacceptable irradiation of the thyroid if it had been used for the preparation of cheese, butter, or other manufactured produce.

Strontium 89 *and* 90 *in milk*

The early assays of grass and milk showed clearly that the immediate hazard was from iodine 131 in milk and therefore in the early stages of the survey only a few measurements of strontium 89 and 90 were made. Before the accident in October, 1957, strontium 90 in excess of that observed elsewhere in the country from fall-out of weapon debris was detected in milk from farms adjoining Windscale. In the months July to October, 1957, the ratio of strontium 90 to calcium was 44 micro-microcuries per gramme in milk from a farm within a quarter of a mile of the perimeter of Windscale Works. The values of this ratio decreased rapidly with increasing distance from the Works.

Shortly after the accident, values up to 115 μμc strontium 90/g Ca were observed in milk from the farm nearest the Works. At greater distances values also exceeded those expected from world-wide fall-out; for example, on a farm near the mid-line of the plume in the coastal area the highest value was 26 μμc/g Ca.

On account of the long life of strontium 90 and the possibility that material deposited on the basal tissues of plants might be absorbed when growth re-commenced in the following season, a continuing survey was undertaken (Ellis *et al.*, 1960). When this survey began in November, 1957, it was possible to distinguish the strontium 90 released at the time of the accident from that which had been deposited previously, since the ratio of strontium 89 to strontium 90 in the former material was then about 40, whereas that in the earlier deposit was approximately 1. Similarly, during 1958 an examination of the ratios of strontium 89 to strontium 90 enabled strontium 90 from current world-wide fall-out to be distinguished from that which escaped from Windscale.

The salient results of this survey were:

(*a*) On farms within 2 miles of the Works the deposit of strontium 90 was on average 160 mμc/m^2; the values declined rapidly with the distance from Pile No. 1, and the maximum value, 678 mμc/m^2, was observed on a field adjoining the Works. The ratio of strontium 89 to strontium 90 was generally less than 2 in November, 1957; this shows that the strontium 90 had mainly been deposited before the accident in October. The mean ratio of strontium 90 to calcium in milk produced in different farms in this area ranged from 18 to 141 μμc per gramme of calcium in the summer and autumn of 1958; the highest value for any sample (representative of the production of two weeks on one farm) was 211 μμc per gramme of calcium.

(*b*) On farms 10 to 17 miles from the Works the strontium 90 found in herbage and soil during November, 1957, was mainly due to world-wide fall-out, although there was a contribution from the Windscale Works. Moreover, in the early summer of 1958 the ratios of strontium 89 to strontium 90 in the milk in this area showed that world-wide fall-out was making at least the major contribution to the contamination of milk and by late summer the evidence does not suggest any contribution from the accident.

(*c*) Somewhat higher depositions of strontium 90 were observed on the farms in the hill areas and the levels in milk were also higher than on the coastal plain by a factor of between 2 and 3. This is attributed to the greater deposition of world-wide fall-out associated with the higher rainfall and to the more rapid transfer of strontium 90 to the milk due to the nature of the hill pastures.

(*d*) A few measurements have been made on vegetables grown near the Windscale Works. The results in general are compatible with expectations based on the more comprehensive survey of milk.

(*e*) The survey points to the conclusion that the emergency maximum permissible level of 2,000 μμc Sr-90/g Ca in the total daily diet (Medical Research Council, 1959) was not approached in any area.

Other radioactive materials in vegetation and milk

Analyses were carried out for caesium 137, ruthenium 103 and 106, zirconium 95 and other nucleides in samples of grass and milk. In the zone of highest contamination, the maximum levels in grass were respectively 0·25, 0·21 and 0·3 $\mu c/m^2$. When the restrictions on the use of milk were removed, the highest level of caesium 137 was about 4 mμc/litre which may be compared with a value of 150 mμc/litre subsequently given as a maximum level for such emergencies by the Medical Research Council (1959). The results thus showed that no control measures were needed on account of nucleides other than iodine 131 in milk. The routine measurement of caesium 137 in milk from various parts of the country also showed a transient peak ranging up to 0·3 mμc/litre in several areas as a consequence of the accident (Booker, 1958). Mayneord *et al.* (1958) also found transient levels of caesium 137 in milk from Cardiganshire ranging up to about 0·7 mμc/litre. (No detectable rise in the strontium 90 level was found in these samples.) In the circumstances of the Windscale accident it was found that the concentration in both grass and milk decreased much more rapidly than was assumed by the Medical Research Council for the general case in calculating the permissible levels.

Other measurements

People at various places in the United Kingdom and at some places on the continent of Europe undertook radioactivity measurements as soon as it became known that there had been a serious accident at Windscale. A selection of references to the published results is included in the bibliography. Typical of these measurements are the results reported by Burch (1959) who showed that adults in the Leeds area would have received about 0·2 rad to the thyroid as a result of the accident and Maycock and Vennart (1958) who gave a corresponding figure of 0·04 rad for people in the London area. Mayneord and others (1958) also published results showing the traces of radioactivity from Windscale in milk from South Wales.

Radiation dose incurred by animals

Thyroids from sheep slaughtered in the vicinity of Windscale were assayed in the months following the Windscale accident by the Ministry of Agriculture, Fisheries and Food (McGirr and Ivans, 1958). There were wide variations between the values for individual animals slaughtered at the same time. The highest values were observed 12 days after the accident when the mean was nearly 4 μc iodine 131 per gramme wet weight; the maximum for individual thyroids at that time was 10·5 μc/g. Measurements on sheep samples collected in the Windscale area were also made by Robertson and Falconer (1959). The highest activities found were 2 μc per gramme in four sheep which had grazed in the direction of the maximum deposition and were killed 31 days after the accident. When allowance is made for the rate of build-up of activity in the sheep thyroid, it appears that the highest total radiation dose to thyroids of sheep was probably around 1,000 rads. The experimental evidence of Horstman *et al.* (1959) suggests that economically important pathological changes in the thyroids of sheep would not be induced by total doses of less than some 10,000 rads.

The thyroids of cattle and pigs showed appreciably lower values than those of sheep. Clinical examinations have provided no evidence of radiation injury to animals in the vicinity of Windscale, and an investigation by the Milk Marketing Board (1959) showed no immediate effect in the conception rate of cattle.

Deductions

The fact that the contamination of milk with iodine 131 was a major source of hazard is attributable to two reasons, namely, the preferential release of iodine 131 relative to other fission products from the reactor, and the extent to which it is transferred from herbage grazed by cattle to their milk. Chamberlain and Dunster (1958) have shown from relative quantities of the various fission products present in the reactor that iodine 131 was released some 100 times more readily than the isotopes of strontium.

It is important to consider whether the relationship between the deposition of iodine 131 and the levels in milk observed at Windscale are typical of situations which would usually occur. Many factors can alter this relationship, especially the fraction of the deposit retained on herbage edible by cattle, the extent to which it is removed by rain, the extent to which contaminated vegetation is diluted by new growth and the extent to which animals receive supplies of uncontaminated food. It appears that in the first two weeks after the Windscale accident rain reduced the radioactivity on herbage due to iodine 131 to about half that expected under dry conditions. Simultaneously the transfer of cattle to winter rations, which is usual at that time of year, apparently reduced twofold the proportion of their diet which is derived from free grazing. Taken together it seems that these two circumstances led to levels of iodine 131 in milk some two weeks after the accident being one-quarter of what they might have been under the most unfavourable conditions. When allowance is made for these local conditions the situation observed at Windscale agrees reasonably with assessments based on experimental studies that the deposition of 1 μc of iodine per square metre could lead to a maximum level of 0·16 μc per litre of milk some three days later and that in the succeeding 2-3 weeks it would fall with the half-period of 8 days provided that no mitigating factors were operative (Garner, 1960).

The public health implications of the accident

All the published results of measurements made following the Windscale accident confirm that the only danger from which the public had to be protected was the contamination of milk with iodine 131. This was successfully controlled by prohibiting the consumption of milk produced in an area of approximately 200 square miles.

Following the accident, the Medical Research Council set up, at the request of the Prime Minister, an independent committee to report on the health and safety aspects. The report of this committee was included in the Command Paper on the accident (Atomic Energy Office, 1957). The Committee concluded:

'(i) The information available is adequate to allow an assessment to be made of the possible risks to human health and safety arising from the recent accident at Windscale.

'(ii) After examining the various possibilities we are satisfied that it is in the highest degree unlikely that any harm has been done to the health of anybody, whether a worker in the Windscale plant, or a member of the general public'.

The Committee also referred to the need to keep under observation the strontium 90 content of the milk. The results from the further survey on the strontium 90 content of the milk recommended by the Committee are included above.

Extended and more detailed study was later given to the radiological problems by the Council's Committee on Protection against Ionizing Radiations. This served to refine the calculations which were made at the time of the accident, and on which the practical measures were based, but not to alter them to any important extent. The Committee's recommendations have since been published (Medical Research Council, 1959). They allow an emergency dose to the thyroid of 25 rads from iodine isotopes; to the skeleton a dose of 15 rads from strontium 89 or 1½ rads per year from strontium 90 (corresponding to a concentration of 2,000 μμc strontium 90 per gramme of calcium in the diet); to the whole body from caesium 137, a dose of 10 rads.

Bibliography on the Environmental Aspects of the Windscale Reactor Accident, October, 1957

Atomic Energy Office (1957). Accident at Windscale No. 1 Pile on 10th October, 1957. *Cmnd.* 302. H.M. Stationery Office, London.

Blok, J., Dekker, R. H. and Lock, C. J. H. (1958). Increased atmospheric radioactivity in the Netherlands after the Windscale accident. *Appl. sci. Res. B.*, 7, 150.

Booker, D. V. (1958). Physical measurements of activity in samples from Windscale. *AERE.HP/R.* 2607.

Booker, D. V. (1959). Caesium 137 in dried milk. *Nature, Lond.*, **183,** 921.

Burch, P. R. J. (1959). Measurements at Leeds following the Windscale reactor accident. Iodine 131 in human thyroids and iodine 131 and caesium 137 in milk. *Nature, Lond.*, **183,** 515.

Chamberlain, A. C. (1958). Relation between measurements of deposited activity after the Windscale accident of October, 1957. *AERE.HP/R.* 2606.

Chamberlain, A. C. (1959). Deposition of iodine 131 in Northern England in October, 1957. *Quart. J. R. met. Soc.*, **85,** 350.

Chamberlain, A. C. and Dunster, H. J. (1958). Deposition of radioactivity in North-West England from the accident at Windscale. *Nature, Lond.*, **182,** 629.

Crabtree, J. (1959). The travel and diffusion of the radioactive material emitted during the Windscale accident. *Quart. J. R. met. Soc.*, **85,** 362.

Dunster, H. J., Howells, H. and Templeton, W. L. (1958). District surveys following the Windscale incident, October. *Proc. II int. Conf. Peaceful Uses Atomic Energy*, **18,** 296.

Ellis, F. B., Howells, H., Russell, R. S. and Templeton, W. L. (1960). The deposition of Sr 89 and Sr 90 on agricultural land and the entry into milk after the reactor accident at Windscale in October, 1957. *AERE.AHSB.(RP)R.* 2. (Obtainable from H.M. Stationery Office, London.)

Garner, R. J. (1960). Assessment of the quantities of fission products likely to be found in milk in the event of aerial contamination of agricultural land. *Nature, Lond.*, **186,** 1063.

Gorham, E. (1958). Accumulations of radioactive fall-out by plants in the English Lake District. *Nature, Lond.*, **181,** 1524.

Horstman, V. G., Anderson, D. L., George, L. A., Marks, S. and Clarke, W. J. (1959). Biological effects of iodine 131 in sheep and swine. *U.S.A.E.C. Hanford Works Report HW.*59500, p. 47.

Kimber, G. and Booth, A. (1958). Radioactivity of plant material collected after the accident at Windscale No. 1 pile. *Nature, Lond.*, **181,** 1391.

McGirr, J. L. and Ivans, L. M. (1958). Private communication.

Maycock, G. and Vennart, J. (1958). Iodine 131 in human thyroids following the Windscale reactor accident. *Nature, Lond.*, **182,** 1545.

Mayneord, W. V., Anderson, W., Bentley, R. E., Burton, L. K., Crookall, J. O. and Trott, N. G. (1958). Radioactivity due to fission products in biological material. *Nature, Lond.*, **182,** 1473.

Medical Research Council (1956). The hazards to man of nuclear and allied radiations. *Cmd.* 9780. H.M. Stationery Office, London.

Medical Research Council (1959). Maximum permissible dietary contamination after the accidental release of radioactive material from a nuclear reactor. *Brit. med. J.*, **i**, 967.

Milk Marketing Board (1959). Unpublished data.

Robertson, H. A. and Falconer, I. R. (1959). Accumulation of radioactive iodine in thyroid glands subsequent to nuclear weapon tests and the accident at Windscale. *Nature, Lond.*, **184**, 1699.

Spiers, F. W. (1959). Measurements at Leeds following the Windscale reactor accident. Increase in background gamma-radiation and its correlation with iodine 131 in milk. *Nature, Lond.*, **183**, 517.

Spiers, F. W. (1959). Some measurements of background gamma-radiation in Leeds during 1955-59. *Nature, Lond.*, **184**, 1680.

Stewart, N. G. and Crooks, R. N. (1958). Long-range travel of the radioactive cloud from the accident at Windscale. *Nature, Lond.*, **182**, 627.

J. F. Loutit

W. G. Marley

R. S. Russell