

MAXIMUM PERMISSIBLE DIETARY CONTAMINATION AFTER THE ACCIDENTAL RELEASE OF RADIO- ACTIVE MATERIAL FROM A NUCLEAR REACTOR

REPORT TO THE MEDICAL RESEARCH COUNCIL
BY ITS COMMITTEE ON PROTECTION AGAINST
IONIZING RADIATIONS*

After the accident to No. 1 pile at Windscale on October 10, 1957,¹ the Atomic Energy Authority asked the Medical Research Council for advice on the maximum intake of certain radioactive isotopes that should be regarded as permissible, under emergency conditions, for members of the general population living in, or deriving food from, an area contaminated owing to an accident to a reactor.

The Council's Committee on Protection against Ionizing Radiations, together with its Subcommittees on Internal and External Radiations, has considered this problem, and concludes that the intake of radioactive materials by ingestion of contaminated food would generally be the limiting source of hazard after any such accident. Intake by inhalation, or radiation from the exterior, would become of importance only in rather special circumstances.

In the following report, therefore, the Committee proposes maximum permissible levels of dietary contamination for the relevant isotopes in the emergency conditions envisaged. In proposing these levels, the Protection Committee has used the fullest information available on the radiation doses that would be delivered to different body tissues and at different ages by the isotopes concerned, and on the ways in which these materials would enter the body. The Committee wishes to stress, however, that knowledge of the metabolism of radioisotopes is continually increasing and that the subject of permissible doses is constantly under review. In several instances where information has been inadequate we have used the more cautious, rather than the more likely, assumption; and it is probable that some of our recommended levels are lower than may be regarded as permissible when more information becomes available—for example, on the duration of dietary contamination to be expected following a reactor accident.

The main problem relates to the intake in food of a small group of radioactive isotopes which are produced in high yield by fission of reactor fuel, and which in addition become highly concentrated in certain organs of the body. The Committee's recommendations are expressed in terms of the maximum permissible daily intake of each of these isotopes at various ages, having regard to the metabolism of each element and the period during which the contamination of the food supply is likely to continue.

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In view of the specialized problems involved in the assessment of hazards from internal irradiation, estimates are given of the absorbed dose or dose-rate of radiation likely to result in the organs concerned from the proposed levels of intake. It is hoped that these calculations will make it easier to review the significance of the present proposals, and to compare them with the recommendations of the International Commission on Radiological Protection (I.C.R.P.).²

It must, however, be appreciated that the recommendations of I.C.R.P., which have been taken into full consideration in the present proposals, do not refer to the problem of an emergency exposure of members of the general population. I.C.R.P. has made recommendations on the maximum permissible intake of numerous radioisotopes for those persons occupationally exposed to radiation. The Commission added that "in the case of the prolonged exposure of a large population the maximum permissible levels should be reduced by a factor of ten below those accepted for occupational exposure." This recommendation was clarified in 1956,³ when it was stated that it did not refer to the entire population but to "persons who might be exposed unknowingly in the neighbourhood of a plant or source of radiation." It was further stated that "under the conditions at present envisaged, the regions in which the 10% level might be reached would contain a very small fraction of the population and, therefore, the average organ doses per individual of the whole population would be very much lower than 10% of the maximum permissible organ doses for occupational exposure." It is clear that the permissible levels should be lower for persons exposed continuously in the neighbourhood of a plant or source of radiation than for those who are exposed occupationally, since the former group may include children and might apply to lifelong exposure rather than during the period of working life. It is likely, moreover, that those occupationally exposed would be under detailed health surveillance and that the amounts of radiation received by each individual would be known. However, the I.C.R.P. recommendations are estimated on the basis of prolonged exposure, and the levels permissible for transient intake may be higher than those recommended by the Commission for continuous intake.

The main effects requiring assessment are the irradiation of the thyroid gland by radioiodine, of the bone and bone marrow by radiostrontium, and of the whole body by radiocaesium. The position is simplified since (a) iodine-131 will be the major contributor to thyroid irradiation, other forms of radioiodine being negligible in comparison, and (b) strontium-90 will be of greater importance than strontium-89 in the irradiation of bone. The concentration of either iodine-131 or strontium-90 will therefore, in general, determine the suitability of food for consumption. Since fresh milk will be the main source of these isotopes and of radiocaesium, the concentrations in milk will normally provide a valid basis for control measures.

Since radioiodine is concentrated mainly in the thyroid and radiostrontium mainly in bone, these two materials do not to any serious extent cause irradiation of the same tissues. The recommended maximum intakes of them would not, therefore, be altered in the event of mixed contamination, except that when the intake included both strontium-89 and strontium-90 the levels permissible for each of these isotopes should be

reduced proportionately, since both cause irradiation of bone. Radiocaesium, however, causes irradiation of the whole body, and consequently the presence of appreciable caesium-137 contamination would involve a reduction in the permissible intakes of radioiodine and radiostrontium.

Recommendations

The following recommendations are of the maximum permissible daily intakes, attributable to an accident and in the period following it, of the four isotopes which might be of the greatest importance in determining the suitability of food for consumption—namely, iodine-131, strontium-90 and 89, and caesium-137. The values take into account the likely sequence of rise and fall of food contamination, and are expressed as those permissible at the time of maximum contamination soon after the accident. It is estimated, as described below, that these levels of intake, if continued during the likely course of the contamination, would deliver certain doses of radiation to the tissues most heavily irradiated. These total doses are about equal to the *annual* doses regarded as the maximum permissible ones for these tissues by the I.C.R.P. for those occupationally exposed to radiation. Thus the maximum intakes of iodine-131 proposed for various ages correspond to a total thyroid irradiation of 25 rad, as compared with a maximum annual value of 30 rad during occupational exposure; the intakes for strontium-89 and strontium-90 correspond to a total of 15 rad and an annual rate of 1.5 rad per year respectively, at sites of highest concentration in bone, as compared with an occupational rate of 15 rad per year in bone; and the caesium-137 intake gives a total dose of 10 rad to the whole body, which is less than the maximum annual occupational value of 12 rad for whole-body external irradiation, although greater than the average annual value of 5 rad appropriate to a prolonged continuing exposure.

The recommendations are intended to apply to accidental contamination causing significant exposure of numbers of people small compared with one-fiftieth of the whole population of the United Kingdom, and the Committee has taken into consideration that it is possible but unlikely that the same persons might be significantly exposed to a second accidental release of radioactive material. The following account is intended to summarize and illustrate, rather than to give in detail, the information reviewed by the Committee and the recommended precautions in the event of accident.

Radioiodine.—The recommended maximum permissible initial daily intakes for iodine-131 are 60 m μ c per day up to age 6 months, rising to 110 m μ c per day at age 3 years, 300 m μ c per day at age 10 years, and 1,300 m μ c per day at ages over 20. These values assume that the amounts of iodine-131 in the food and in the thyroid decrease at a rate no faster than that due to radioactive decay. Irrespective of the rate of decrease, the maximum permissible total intakes of iodine-131 attributable to the accident would be 650 m μ c, 1,200 m μ c, 3,400 m μ c, and 15,000 m μ c for the ages given above.

Radiostrontium.—For the strontium isotopes the recommended maximum permissible daily intakes are 2 m μ c per day for strontium-90 and 200 m μ c per day for strontium-89, at any age. When the intake includes both isotopes the levels of each should be reduced accordingly.

Radiocaesium.—In the case of caesium-137 the recommended maximum permissible daily intakes are 60 m μ c per day at birth, rising to 150 m μ c per day at age 6 months and 1,150 m μ c per day at ages over 20. These values assume that the amounts of caesium-137 in the food and in the body decrease at rates such that the effective half periods are 10 weeks and 20 weeks respectively. The corresponding maximum permissible total intakes are 6 μ c, 15 μ c, and 115 μ c.

Comments on the Recommendations

Iodine-131

The Committee has considered that the maximum intake of radioactive iodine should be such that the mean radiation dose to the thyroid gland would not exceed 25 rad. The recommended intakes will depend upon the thyroid size and iodine uptake from food at different ages. The mass of the gland was taken to be 1.8 g. from birth to 6 months, 3.4 g. at age 3 years, 9.2 g. at age 10 years, and 25 g. in the adult,^{4,5} the uptake falling from 50% in childhood to 30% in adult life.^{6,7}

For the calculation of emergency levels of the daily intake of iodine-131, fresh milk is regarded as the most important source of the isotope. If pastures are contaminated with iodine-131 and no loss of the isotope occurs from the herbage except by radioactive decay, the iodine-131 content of milk from the cows grazed on these pastures will reach a maximum value about three days after the contamination and, after the first week, fall with the half period of iodine-131. For children fed on liquid milk only, the maximum thyroid irradiation would be likely to occur at an age of about 6 months, since the thyroid size increases very little from birth until this age, whereas the milk intake may increase with body weight until this age. The maximum permissible intake of 60 m μ c per day corresponds to a peak iodine-131 concentration in milk of 0.065 μ c per litre, assuming a milk intake of 0.9 litre per day at the age of 6 months. This maximum intake would correspond to a total ingestion of 0.65 μ c, which, with 50% uptake into the 1.8-g. gland and prolonged retention, would give a total mean dose of 25 rad to the gland. The values proposed at different ages correspond to the same total mean dose.

It may be noted that the limit of 0.065 μ c per litre could be raised considerably provided that young children were fed on dried milk, or liquid milk, from uncontaminated sources. An initial concentration of 0.3 μ c per litre would permit normal intakes for children over the age of 3 years (assuming a milk intake of 0.3 litre per day at this age).

Radioactive Strontium

The bone-seeking radioactive isotopes will have a very non-uniform distribution in the skeleton unless the intake is over a long period of time. A basic problem in estimating maximum permissible levels for emergency exposure is whether the calculations should be based on mean radiation dose in the skeleton or local dose at sites of maximum concentration. In the absence of a definite answer to this question, the calculations have been made on the assumption that a certain radiation dose or dose-rate is not to be exceeded at any site of isotope concentration in the bone. If future work shows that mean skeletal dose, and not

this local dose, is the significant criterion it will be possible to increase the values of dietary intake that have been proposed.

A second difficulty arises in that one of the strontium isotopes, strontium-90, has a long half-life (28 years) while the other, strontium-89, has a much shorter half-life (53 days). It would not be reasonable to adopt the same criterion for both isotopes. It was considered, therefore, that for the long-lived strontium-90 the maximum permissible value for emergency exposure should be calculated on a basis of the maximum yearly dose-rate at a site of concentration, while for the short-lived strontium-89 the criterion should be the maximum total radiation dose delivered at any such site. The Committee recommended that in the case of strontium-90 the maximum permissible local dose-rate in mineral bone should be 1.5 rad per year and in the case of strontium-89 the maximum permissible local dose should be 15 rad. Both maximum and mean doses to the bone marrow will be substantially less than those to mineral bone.⁸

Level for Strontium-90.—New bone deposited during the growing period in children will be formed from circulating calcium, which will be derived largely from the current dietary intake contaminated with radio-strontium, but partly also from less contaminated calcium released from older bone during remoulding processes. Moreover, it has been shown that, after the ingestion of a diet containing both strontium and calcium, the ratio of strontium to calcium deposited in bone is about one-quarter of that in the diet. This change in the ratio results from differences in the absorption and excretion of the two elements.^{9 10}

If the diet contains 2 m μ c of strontium-90 associated with a normal calcium intake of 1 g. daily, the strontium-90 concentration at sites of new bone formation will therefore not exceed one-quarter of this dietary ratio, or 0.5 m μ c per g. of calcium. The dose rate in bone at this concentration is rather less than 1.5 rad per year.

Level for Strontium-89.—The level of dietary contamination of strontium-89 which will give a total dose not exceeding a given value at any local deposit can be calculated by integrating the dose rate over time, using 53 days as the half-life. The value for the concentration of strontium-89 in bone which will give a total dose not exceeding 15 rad at the site of the deposit is 50 m μ c of strontium-89 per gramme of calcium, corresponding to a daily dietary intake of 200 m μ c.

Duration of Intake.—The shorter the duration of intake the greater will be the fraction of the skeleton that is spared irradiation and the smaller will be the size of the deposits of contaminated bone. The calculations have assumed that the deposits have dimensions at least comparable to the range of the beta rays emitted, and if the dimensions are less, values of dose and dose-rate may be substantially lower than those calculated above. Therefore, for intakes limited to short periods—for example, weeks—it may well be that the maximum permissible levels of dietary contamination with strontium-90 and strontium-89 could be raised considerably above the values stated. However, more data on certain aspects of the metabolism of calcium and strontium in bone are required before any higher figures can be recommended.

Prolonging the duration of intake (so long as the daily intake of isotope does not increase) will not affect the

maximum local dose-rate calculated for strontium-90. In the case of strontium-89 the maximum total dose at any site is also unlikely to be increased by prolonged intake, since the half-life of this isotope is short compared to its turnover time in bone.

Caesium-137

The Committee considered that the maximum intake of radioactive caesium should be such that the mean radiation dose to the whole body would not in the most unfavourable case exceed 10 rad.

Since fresh milk would be the most important source of radiocaesium, young children, because of their high intake relative to their body mass, would be those at greatest risk. From the way in which caesium enters milk it can be assumed that the contamination of milk would decrease rapidly, and a value of 10 weeks has been taken for its half-period. The evidence following the Windscale accident¹¹ suggests that this would be an upper limit for the half-value period of radiocaesium in milk. In consequence of this and of the value assumed for the half-period in the body, it may prove that the recommended maximum values for the initial daily intake are unduly low and might safely be higher.

The initial daily intakes which would produce a dose of 10 rad to the whole body are 60 m μ c at birth, 150 m μ c at 6 months, and 1,150 m μ c in the adult, using the following assumptions: (1) the mass of the body is taken to be 3.7 kg. at birth, 8.8 kg. at the age of 6 months, and 70 kg. in the adult; (2) uptake is assumed to be 100% in each case; and (3) a value of 20 weeks is taken for the half-period of caesium in the body^{12 13} although some evidence suggests that this value may be unduly high. The corresponding total intakes are 6 μ c, 15 μ c, and 115 μ c. The maximum initial concentration in milk for children at birth and aged 6 months is about 150 m μ c per litre in either case.

Limitation of the concentration of this particular radioactive material in food supplies to levels permissible for infants and children would mean that adults would receive doses of whole-body radiation which are much smaller than 10 rad.

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