# COLLECTIVE POPULATION RADIATION EXPOSURE FROM WASTE DISPOSAL FROM A FUEL REPROCESSING PLANT

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## 1. INTRODUCTION

The most important pathways to public radiation exposure from controlled discharges of liquid radioactive waste from the nuclear power programme in the UK are due to fuel reprocessing operations. In this respect, the predominant radionuclides which go to make up the effluent released from British Nuclear Fuels Ltd, Windscale into the Irish Sea under joint authorization of the Department of the Environment and the Ministry of Agriculture, Fisheries and Food are caesium-137 and -134. In the marine environment caesium behaves in an essentially conservative fashion and though some associates with sediment, most stays in the water and disperses from the area of discharge off the Cumbrian coast as this water moves through the Irish Sea and mixes with further distant waters, mainly those around the mainland of Scotland.

These waters support important fisheries and the consumption of fish thus provides one of the critical pathways for Windscale discharges. Because of the extent of the area through which radiocaesium of Windscale origin can be detected, the size of the fish stocks and the large population consuming them, consideration of this pathway should not be restricted to the dose to the critical group of most highly exposed people. In these circumstances, where large populations are exposed to low doses the ICRP recommends that the control procedure should take into account the integrated collective dose as well as the dose to the critical group. Assessment of collective dose is essential not only in relation to the control of the genetically effective dose but also because it forms an essential component of the optimization procedure required to meet the principle of keeping doses as low as reasonably achievable (1, 2).

## 2. THE DISTRIBUTION OF RADIOCAESIUM IN BRITISH ISLES COASTAL WATERS AND NEARBY

Radiocaesium nuclides form part of the low-level radioactive liquid waste which is discharged from Windscale into the north-east Irish Sea. After discharge the caesium mixes with the sea water which is transported through the Irish Sea in a northerly direction so that most of the radioactivity is eventually removed via the North Channel. A small amount is carried southwards, as has been shown by surveys from this laboratory during which caesium at higher than fallout levels and attributable to Windscale has been detected in the Celtic Sea and the Bristol Channel. Once out beyond the North Channel the water begins to mix with the north-east Atlantic water. However, surveys for caesium have shown that the rate of mixing is slow, with most of the water from the Irish Sea moving in a well defined path northward along the west coast of Scotland and into the North Sea (3). The hydrography of the North Sea is complex; caesium entering from the north-west is found at varying concentrations throughout much of it and can still be detected in the water flowing out into the Norwegian Sea. Details of concentration are reported elsewhere (3, 4). On the present evidence dilution factors in the Irish Sea relative to the immediate vicinity of the release point are about 20 to 30 to the North Channel and

10 to 20 to Anglesey. Between the North Channel and Cape Wrath there is a dilution of about 5 to 10 and a further small dilution between there and the northern North Sea. However, due to variations in the rate of release of radiocaesium from Windscale and to short-term variation in the pattern of water movement, these factors are likely to change especially at the greater distances from Windscale. The times of transit between the points referred to are long, for example about 0.5-1 year from the Cumbrian coast to the North Channel and a similar time scale to Cape Wrath. These times are comparable to the radioactive half life of caesium-134 and the concentrations of this radionuclide at distance are therefore being reduced significantly by radioactive decay.

## 3. THE CALCULATION OF COLLECTIVE DOSE

The formal definition of collective dose rate is

$$S = \int_0^{\infty} H \, N_H(H) \, dH$$

where $N_H(H)$ is the population spectrum in dose rate and $N_H(H)\,dH$ the number of individuals receiving a dose in the range H to H + dH. A more directly applicable formulation is given by the summation

$$S = \Sigma_j H_j N_j$$

where $H_j$ is the per caput dose rate in population group j of size $N_j$. When applied to internal irradiation from the consumption of fish containing radioactivity $H = k W_j C_j$, where $W_j$ is the mean consumption rate of population j and $C_j$ the mean concentration in their intake of fish. The constant of proportionality, k, relates the rate of intake of each radionuclide to dose and may be obtained from ICRP II (5). $W_j$ may be replaced by $Q_j/N_j$ where $Q_j$ is the total catch of fish consumed by population $N_j$ and the above equation reduces to

$$S = \Sigma k \, Q_j \, C_j \, .$$

The collective dose for any given population may be computed therefore by using the statistics on fish landings compiled by ICES (6) together with the measurements of radioactivity in fish samples. For the present purposes data on fish landings have been corrected to take account of the non-edible fraction such as bone and viscera. This probably leads to an overestimate of the amounts consumed because no allowance has been made for other wastage. On the other hand, no allowance has been made for the contribution to the human diet from the more tenuous routes which begin with "industrial fish" stocks which are used to produce fish meal and provide feedstock for cattle, pigs and poultry, etc.

In view of the size of the area over which caesium from Windscale is detectable the calculation of collective dose might at first sight seem to require the measurement of radiocaesium in a large number of samples of fish. Whilst in practice the fish stocks are surveyed as comprehensively as possible with special attention to those responsible for most of the dose, it is possible to make reasonable estimates of the concentration in fish from a knowledge of the concentrations of radiocaesium in water and the concentration factors for the nuclide between fish and water. This approach has been used to supplement the direct measurements on fish and especially to take account of the contributions from fish stocks which are difficult of access such as some of the landings made by other countries.

## 4. RESULTS AND DISCUSSION

The Western European shelf waters in which Windscale-derived radiocaesium can be detected have been fished by a number of European countries in addition to the UK, notably the Republic of Ireland, France, Belgium, the Netherlands, Denmark, West Germany, Norway and the USSR. The more distant waters around Scotland, the North and Norwegian Seas are also fished by a number of different countries.

Collective doses from radiocaesium in 1974 and 1975 have been calculated separately for the UK and for other Western European nations, notably those listed above. The results are shown in Table 1. Most of the dose is due to caesium-137 but account has also been taken of the contribution of caesium-134. Also shown is the average per capita dose rate for the countries concerned and these have been related to the population dose limit adopted by the UK (7) for the control of radiation exposure from waste disposal operations. This limit was set on mainly genetic considerations at 1 rem per person in 30 years, that is equivalent to 33 m rem per person per year, and is used rather than any current ICRP limit. The only relevant advice from the Commission is a higher overall limit of 5 rem per generation but this is not specific to waste disposal.

| Population (and size) | Collective dose rate, man rem/yr | | Mean per caput dose | | | |
|---|---|---|---|---|---|---|
| | | | m rem/person/yr | | % of UK max. | |
| | 1974 | 1975 | 1974 | 1975 | 1974 | 1975 |
| UK ($5.5 \times 10^7$) | $4.8 \times 10^3$ | $8.3 \times 10^3$ | 0.09 | 0.15 | 0.24 | 0.45 |
| Other W European nations ($1.4 \times 10^8$) | $3.8 \times 10^3$ | $5.7 \times 10^3$ | 0.03 | 0.04 | 0.08 | 0.12 |

TABLE 1 Collective dose rates of Windscale radiocaesium discharges through the fish consumption pathway, 1974-75

The difference in collective doses between 1974 and 1975 is mainly due to an increase in the discharge rate of radiocaesium from Windscale during 1974. Due to the time it takes for caesium to reach the more distant water masses and the time lag in it working its way through the food chain to the fish eaten by man, little effect of this increased discharge was seen in 1974. The full effect of the higher rate of discharge in the distant waters such as the North and Norwegian Seas has even yet to be seen. However, because the contribution to total collective dose from these areas is small, the total collective dose may not increase even when the higher rate of discharge does eventually reflect in these more distant waters. By that time it is expected that measures which have been taken to reduce discharges will be taking effect with the result that the rate of fall in the contribution to total dose from the Irish Sea stocks will be greater than the rate of increase of that from the more distant areas.

In addition to providing the means of quantifying the genetically effective dose from this discharge of radiocaesium and of demonstrating compliance with national policy objectives on average population dose, assessment of the integrated population dose is needed in order to demonstrate that the philosophy of keeping doses "as low as is reasonably achievable" is being honoured. An essential piece of information when coming to a scientifically based decision concerning the reduction of discharges is how far reduction is cost-effective and therefore justified on radiological/economic grounds; furthermore, it provides a logical basis for choice of the best means of achieving any desired reduction. Decisions to reduce the rate of discharge are bound to cost money; they are likely also to result in higher doses being received by the people who will operate the effluent treatment equipment and handle the caesium reconcentrated from the effluent. Before embarking on a programme to reduce discharges it should be ascertained that the costs of so doing (including those associated with the integrated dose to the operators) are not out of proportion to the savings in the detrimental cost associated with not discharging the waste.

The detrimental cost of discharging may be calculated by assuming a linear relationship between dose and effect as recommended by ICRP. This permits an estimate to be made of the total damage in terms of radiation-induced deaths attributable to the discharge in the exposed population. The total damage may be translated into financial terms by considering how much it is deemed that society is prepared to pay in order to avoid death. This last figure is not an easy one to arrive at, involving as it does the quantification of pain, suffering and life itself but is necessary to provide a sound scientific/economic basis for a waste mangement policy. Shepherd and Hetherington (2) have discussed the question of the cost appropriate to the prevention of one man rem of exposure to the general public and deduced a figure of £50 per man rem. When applied to the discharge of radiocaesium from Windscale during 1975, for example, when the total collective dose was about $1.4 \times 10^4$ man rem the total detrimental cost was approaching £1 M. This figure provides a context in which the cost of methods of effluent treatment and caesium extraction facilities may be viewed. Any treatment process whose discounted capital plus annual running costs significantly exceed this amount would be difficult to justify economically whereas any measure costing significantly less would merit further investigation to see how its costs compared with the detrimental cost savings from its use.

## REFERENCES

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