THE SAFE DISPOSAL OF LIQUID RADIOACTIVE WASTES FROM THE UNITED KINGDOM NUCLEAR POWER PROGRAMME: A CURRENT VIEW OF THE ENVIRONMENTAL SITUATION

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Abstract

Operational experience of the nuclear power programme in the United Kingdom has shown that the principal environmental consequences arise from the disposal of liquid radioactive waste, and relate to public health rather than to direct effects on resources. The emphasis on environmental protection programmes has thus been on the limitation of public radiation exposure. Provided that this is held within the acceptable limits as defined by ICRP, then resource considerations will be adequately. protected.

1 Introduction

The principal source of radioactive waste in the United Kingdom is the nuclear power programme; other sources of radioactive waste include a variety of research and development activities, industry and medicine, and though some use large quantities of radioactivity little becomes waste for disposal. The most important category of radioactive waste is liquid, the relative environmental impact of both gaseous and solid releases being of little significance. Another important generalization concerns the relative importance of human radiation exposure and the potential damage to environmental resources. Provided that disposals are so controlled that human exposure is within the dose limits recommended as acceptable by the International Commission on Radiological Protection[1], the potential risk to environmental resources is minor[2], reflecting the relative radiosensitivity of an animal or organism, which usually bears an inverse relationship to its evolutionary status. The emphasis in the UK has therefore been on limiting public radiation exposure whilst still maintaining a sufficiently close watch on environmental resources to ensure that they are safeguarded.

Radioactive waste is an inevitable consequence of a nuclear power programme and in its management some disposal to the environment is a practical necessity. The British approach is thus a pragmatic one, seeking the responsible utilization of environmental resources for waste disposal to an extent which will not put either the environment or public health at risk, or impose economically-crippling restrictions on the nuclear industry and thus deny the nation use of this energy source.

2 UK waste disposal policy

2.1 Radiation exposure standards

The basic objectives of UK waste disposal policy were stated in a government White Paper in 1959[3] and were embodied in legislation[4] in the following year. The first two objectives, which are both mandatory and must be met regardless of the cost, require:

(i) compliance with the ICRP-recommended dose limits for members of the public - covering somatic consequences of waste disposal, and

(ii) that exposure of the public averaged over the population of the country does not exceed 1 rem per person per 30 years - designed to safeguard against genetic effects.

The third policy objective requires that, this time taking into account cost, convenience and national importance of the subject, doses shall be kept as far below these mandatory limits as is practicable.

The first of these objectives originally referred to the most highly-known exposed individual in line with the ICRP recommendations of the day. Since then the later series of ICRP recommendations[1], endorsed by the Medical Research Council, have been adopted for use in the UK. In consequence and wherever practicable, control measures are now based on mean exposure of critical groups, though in most cases it has not proved possible to identify such groups, so that control has continued on the basis of known individual exposure.

2.2 The application of policy objectives

All radioactive waste discharges are subject to a system of prior authorization, issued by departments of central government. Authorizations are legally enforceable and specify limits on the quantity, type and rate of release of radioactivity, with further conditions, for instance relating to effluent and environmental monitoring.

In view of the mandatory nature of the first two objectives of national waste disposal policy, it is essential to know the capacity of the environment to which the waste will be released, before an authorization is issued. However, in no case has the operator of a site been allowed to discharge waste up to this limit, for, in line with the third policy objective, only disposal for which there exists a proven need is permitted, though some reasonable margin is allowed for operational flexibility and inaccuracies in forecasting waste arisings, treatment plant performance, etc. In principle, the environmental capacity may be set against either somatic or genetic dose limits, though in practice the former has generally been found to be more restrictive.

The first authorization - issued before the site is in operation - is based on an assessment of environmental capacity calculated on largely theoretical data and, because of the uncertainties in some of the assumptions made, a "safety factor" - usually 10 - is applied to the estimate of environmental capacity before it is used to decide the upper limit which can be specified in the authorization.

Once a site begins to discharge waste a system of inspection is set in being by the authorizing departments of central government, backed up by effluent and environmental monitoring. The primary aim in monitoring effluent is to check operators' statements, and whilst this is also true for environmental monitoring - the site operator must carry out sufficient monitoring to demonstrate the radiological safety of discharges in terms of public radiation exposure - the work undertaken by authorizing departments includes an element of research to provide data on which environmental capacity can be reassessed.

2. 3 The scientific evaluation of discharge limits

The system used for assessment of discharge limits is the well-known critical path approach, which aims at achieving a basic understanding of the way in which radioactivity behaves after release to the environment, in particular the routes or "pathways" through which contamination of environmental materials and human radiation exposure occurs. The first stage is a habits survey in which the characteristics or habits of the exposed population are studied - initially a qualitative identification of the pathways in a particular environment by which radioactivity is, or may conceivably be, returning to man. This is followed by a quantitative evaluation of each pathway, in the course of which it is usually found that one or perhaps two pathways will be of so much greater importance than the others that exposure through the remainder is minor and can often be ignored. These limiting situations are termed the critical pathways and it is frequently found that almost all the exposure is due to one radionuclide or a very few - the so-called critical radionuclide(s). Because of the individual characteristics of the critical radionuclide(s), which may, for instance, lead to uneven distribution within the body, a particular organ may be said to be "critical", meaning that exposure of it is greater than of others; alternatively the whole body may be uniformly irradiated, as is often the case from external sources of contamination, and the critical organ is then quoted as "total body". Within the exposed population it may also be possible to identify a small group who are at greatest risk - the "critical" group - and on which exposure estimates may be based, particularly for purposes of waste disposal control; more often this does not prove possible because of the small number of people exposed to a significant extent, and estimates are then made on the basis of the most highly exposed person found in a sample of the exposed population - the "critical individual".

Applied to the evaluation of discharge limits, the term "environmental capacity" is now in general use; the system differs according to whether assessment is being made for the first time - that is before operation of the site has begun - or is a reassessment of the consequences of a disposal which has been in operation long enough to generate measurable environmental contamination.

2. 3. 1 Pre-operation The starting point for the computational model is an assumed discharge rate - e. g. 1 Ci/day - of a mixture of specified isotopic composition. A hydraulic model of the receiving water mass is needed to provide a basis for estimating equilibrium concentrations in water for each radionuclide. In the next stage, appropriate concentration factors are used to obtain estimates of the equilibrium concentrations in the critical material(s). It is then a simple step, by way of habits survey data on consumption rates, etc., to translate these concentrations into rates of intake of radioactivity, which may be compared with the values of permissible daily intake, consistent with ICRP dose limits (derived ICRP data); an actual estimate of exposure rate which would result from discharges at the assumed rate can then be made. These steps are carried out separately for each radionuclide, and the total effect of the effluent is estimated by summation. Separate estimates are made for several body organs - often the GI Tract and Bone in addition to Total Body - as a result of which the identity of the critical organ(s) and radionuclide(s) will become apparent.

This is the procedure applied to an internal exposure pathway; the method for external pathways is very similar. Translation of contamination levels into exposure is more complex than for internal exposure and requires a dosimetry model, but the rest of the sequence is simpler because the estimate of exposure can be compared directly against ICRP-recommended dose limits.

2.3.2 During operation Once routine discharges are being made a simpler system can be used unless contamination has not reached measurable levels, in which case the pre-operational system is retained. Provided that contamination is measurable in critical materials, then a direct correlation can be deduced between this and the discharges causing it, utilizing environmental and effluent monitoring data. The relationship found is then used, in the same way as in pre-operation, to estimate the extent of public radiation exposure.

In the early phase of operation of a site, when discharges are relatively small and maybe not yet at equilibrium with respect to quantity and/or isotopic composition, it may be possible to improve on the pre-operational method of assessment by use of indicator materials. A more extensive knowledge of concentration factors is required than when there is contamination of the critical material, involving perhaps several radionuclides and the indicator and (potentially) critical materials. Whilst this is a useful variation on the normal methods it is one which has found little use in practice, for although it avoids the need for hydraulic models it is not this factor but uncertainty in effluent composition that is the major source of error in pre-operational assessment.

3 Waste disposal and its control in practice

The ultimate test of any waste disposal policy is its use in practice and in particular the successful limitation of public radiation. However, merely reducing such exposure is not an end in itself, for given unlimited financial resources any measure of waste treatment can be achieved; in a limited economy it is necessary to balance the cost against the benefit which will be reaped. In the UK the application of control measures has become a commonsense compromise between the two extremes of unnecessary discharge on the one hand and unnecessary and financially crippling restriction to nil discharges on the other - given always that public exposure is not going to exceed the mandatory limits of UK policy, the attainment of which is the first priority.

Just how this flexible policy has worked out in practice can be seen from the nuclear power programme - examples covering a range of different environments - the salient factors being summarized in Table 1. Fuller details are contained in reference[5].

3.1 Fuel element manufacture

Of the two establishments involved in fuel manufacture the larger discharges are from Springfields, Lancashire, from which disposal of low-level radioactive effluent is made by pipeline into the tidal estuary of the River Ribble. Wastes are predominantly β-active and consist of residues of uranium and its immediate daughter products, the most prominent of which is protactinium-234m. This results in contamination of the mud banks, especially in the vicinity of the pipeline outlet, and the critical pathway is one of external exposure, the most highly exposed population being workmen who maintain the river banks and attend to navigational aids. Even in extreme cases, exposure by this means is insignificant - at most a fraction of 1% of the ICRP-recommended dose limit - and the genetically-significant dose is negligible.

3.2 Nuclear power stations

With 11 sites in operation on a commercial basis, examples can be drawn from a range of types of location and three will be cited here - one discharging waste to a soft-freshwater lake (Trawsfynydd, Merioneth), one to a river estuary (Bradwell, Essex), and the third to the open sea (Dungeness, Kent). In each case the type of reactor is the same - the "Magnox" type of carbon dioxide gas-cooled, graphite-moderated unit, and the same method of waste disposal is employed - by dilution after treatment into the cooling water outflow which provides a large measure of initial dilution.

3.2.1 Trawsfynydd Discharges are made to a small lake whose capacity is small, partly because of an unusual combination of critical nuclide and material, caesium-137/-134 and trout, which reconcentrates this radioactivity to high degree. A considerable amount of treatment plant, more than at any other power station, has been installed, designed primarily to remove radiocaesium. As a result, satisfactory control has been achieved and even the most avid consumer of trout has not been subject to as much as 5% of the ICRP-recommended dose limit. In genetic terms exposure is also very low and with a small population involved it is only around 1 man-rem per year.

3.2.2 Bradwell The critical material has been the oyster throughout the 12 years during which this power station has been in operation, though the identity of the critical nuclide has changed - initially being zinc-65, a rôle now taken over by silver-110m. Tritium apart - and as elsewhere this nuclide is of negligible radiological significance - the principal nuclides in the effluent are those of radiocaesium, minimized by means of treatment plant which also removes a large proportion of the zinc-65, and which replaced plant originally designed specifically for zinc-65. Traces of caesium-137, cobalt-60 and iron-55 are also found, though none contribute significantly compared with silver-110m and zinc-65, whose combined effect is only equivalent to a few millirem per year to the largest-known consumer of oysters. The genetic impact of discharges is also trivial, less than 0.1 man-rem/year, though the relative rôles of the radionuclides are reversed, most of this exposure being from radiocaesium.

3.2.3 Dungeness, Kent This illustrates the situation where discharges generate no detectable environmental contamination, so that it is not possible to say which is the critical pathway and it would be academic even to predict one. Two are obviously of potential importance - internal exposure through consumption of fish caught in local waters close to the discharge area, and external exposure due to occupation of the local beaches - and in the presence of effluent composition radiocaesium would be most important. Sensitivity of detection of radioactivity affords one means of estimating the maximum conceivable level of public radiation exposure, from which it is clear that no individual could possibly be subject to as much as 0.1% of the ICRP-recommended dose limit, though models used to predict dispersion suggest that the true level is some orders of magnitude lower still. Genetically significant exposure is also minute - less than 0.1 man-rem per year.

3.3 Fuel reprocessing

Of the two plants involved in this operation the larger is Windscale on the Cumberland coast, discharging waste by pipeline into the Irish Sea; it also provides a wider range of exposure pathways, which emphasizes the importance of setting discharge limits individually for each site.

Three exposure pathways form the present basis for control of the major components of liquid waste, two being internal, due to consumption of foodstuffs - laverbread made from the seaweed Porphyra, and locally-caught fish - the third being external and the result of uptake of radioactivity by mud and silt.

The Porphyra/laverbread pathway has been of prime importance since plant operation began more than 20 years ago, the critical nuclide being ruthenium-106. Unlike most situations the exposed population is not local to the discharge area but some 300 miles away in South Wales, where the foodstuff is eaten. A critical group has been identified[6], so that control does not have to be exercised on the highest known rate of exposure. The remoteness of the exposed population poses further problems of monitoring and control, for during manufacture Cumberland-derived seaweed is diluted with uncontaminated seaweed from other areas. For this reason control of those components of the waste for which this pathway sets the effective limits - they include the alpha emitters and strontium-90 as well as ruthenium-106 and cerium-144 - have been related to contamination levels in locally-grown Porphyra so as to be "fail-safe". Retrospectively it is possible to calculate the received dose from analysis of the laverbread product, and in recent years the critical organ dose (the GI tract) has been found to be in the range 5 to 10% of the ICRP-recommended dose limit. This is now assessed on a daily consumption rage of 130 g of laverbread deduced for the critical group on the basis of the most recent habits assessment. In contrast, genetically-significant exposure through this pathway is very low indeed, only a few man-rems per year, a significant fraction of which comes from caesium-137 and -134, both insignificant contaminants in somatic terms.

The other important internal exposure pathway involves fish consumption, and caesium-137 and -134 are the critical nuclides - indeed the only contaminants in most of the fish caught. A large population eat it, though mean consumption rates are low. Even at the higher values of consumption rate recorded by local fishermen, exposure is only very low - a few per cent of the ICRP-recommended dose limit - total body being the critical organ. Genetically this is the most important Windscale pathway, though in absolute terms - total population gonad dose being of the order of 10^2 man-rem per year - it is of little significance, less than 0.01% of the national dose limit.

The external exposure pathway highlights another contrast in the size of exposed populations, which in this case is very small. The highest dose rates are found in a small estuary near to Windscale where mud and silt collects, contaminated by several γ-emitters but principally zirconium-95/niobium-95. Habits surveys have shown that the most highly exposed individuals are salmon fishermen, whose exposure and doses have ranged up to about 10% of the ICRP-recommended dose limit in recent years. Because of the small size of the population affected by this pathway, the total population dose is very small, not more than 1 man-rem per year.

4 Conclusions

The stringent standards set to limit disposal of radioactive waste in the United Kingdom have ensured that the consequences in terms of radiation exposure of the public are very slight; not only is such exposure within the objectives of UK policy - themselves consistent with the recommendations of the International Commission on Radiological Protection - but in all disposals radiation exposure of the public is well within the prescribed dose limits and in many instances is very much less.

References

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Table 1 Characteristics of selected disposals of liquid radioactive waste and mean radiation exposure of the public in 1970-72

Site	Pathway	Critical		Derived working limit	Exposure* (percentage of ICRP-recommended dose limit)
		Material	Nuclide		
Springfields	External	Mud	^{234m}Pa	1.25 mR h^{-1}	< 1
Trawsfynydd	Internal	Trout flesh	^{137}Cs	440 pCi. g^{-1}	3
			^{134}Cs	200 pCi. g^{-1}	1
Bradwell	Internal	Oyster flesh	^{110m}Ag	880 pCi. g^{-1}	0.2
Dungeness	Internal	Plaice flesh	^{137}Cs	175 pCi. g^{-1}	< 0.1
			^{134}Cs	80 pCi. g^{-1}	
	External	Silt	^{137}Cs ^{134}Cs	0.3 mR h^{-1}	< 0.1
Windscale	Internal	Porphyra/laverbread	^{106}Ru ^{144}Ce	170 pCi. g^{-1} (laverbread)	15
	Internal	Plaice	^{137}Cs	175 pCi. g^{-1}	2
			^{134}Cs	80 pCi. g^{-1}	
	External	Mud	$^{95}Zr/^{95}Nb$	1.7 mR h^{-1}	10

*Most highly exposed individual, except for Windscale internal exposure pathways, where critical groups form the basis of estimation.