ASSESSMENT OF PUBLIC DOSES DUE TO DISCHARGES FROM URANIUM FUEL FABRICATION AT SPRINGFIELDS WORKS, BNFL, UK

A. H. Fishwick and R. M. Wilson
British Nuclear Fuels plc, Fuel Division
Springfields Works

ABSTRACT

The paper describes legally authorized limits for discharges of liquid radioactive waste to the River Ribble, flowing near to Springfields Works. It then goes on to demonstrate that actual discharges are only a small fraction of these limits. The environmental monitoring programs, to determine the effects of these discharges, are described in detail, leading to quantification of the environmental impact to the most exposed group and also to other, less-exposed groups. Finally, these exposures are set in the context of UK limits, and international and UK guidelines, for public dose exposure. They are shown to be significantly below all these values.

INTRODUCTION

BNFL Fuel Division's manufacturing plant is located at Springfields in the Fylde area of the county of Lancashire in north-west England.

The plant has the following feedstocks:

- Uranium Ore Concentrates (UOCs);
- Enriched Uranium Hexafluoride (UF_6);
- Reactor Depleted Uranium Trioxide (from the UK Magnox program) (MDU).

UOC is processed to UF_6 or to U metal for Magnox reactors. Enriched UF_6 is processed into UO_2 fuels for UK AGR reactors or for lightwater reactors.

MDU is processed to UF_6 for re-enrichment and subsequent use in UK AGR reactors.

Intermediate products are manufactured as well as finished fuels.

LIQUID WASTES

Liquid radioactive wastes are discharged from the Site by pipeline to the tidal waters of the River Ribble's estuary which opens into the eastern Irish Sea some 30 miles north-west of Manchester. These discharges are made under the terms of an Authorization issued under the Radioactive Substances Act, 1960 by her Majesty's Inspectorate of Pollution and the Ministry of Agriculture, Fisheries and Food - the UK Government departments with responsibility for administering the Radioactive Substances Act with respect to Nuclear Licensed Sites in England and Wales.

The authorization, in common with other authorizations issued throughout the UK, contains numerical discharge limits on discharges, as well as other conditions. The numerical limits are given in Table I.

The actual discharges are a small fraction of the authorized limit as Table II shows, using the 1991 discharge data as a typical example.

The vast majority of the radioactivity in the liquid waste arises as a result of the solvent extraction purification of UOCs. The raffinate from this process is neutralized with lime before being added to other liquid waste streams prior to discharge, which is on a continuous basis.

The principal radionuclides are ^{232}Th and its daughters, ^{230}Th, ^{234}Th and ^{234m}Pa. The first two are residual impurities from the Ore Concentration process, with the levels being dependent on the source of the UOC and the concentration process used - solvent extraction resulting in markedly lower levels than ion exchange. The last two are short lived daughters of ^{238}U which rapidly grow back into secular equilibrium after concentration and hence levels are independent of the concentration process.

QUANTIFICATION OF THE RISK TO THE POPULATION FROM DISCHARGES

In the UK, risk is not evaluated with the exception of the disposal of solid radioactive wastes. The actual evaluations carried out are Critical Group and Collective doses, which are a stage of actual risk evaluation.

Collective dose is simply quantified by using tables of Collective dose per unit quantity of radioisotope discharged which are calculated by the UK National Radiological Protection Board (NRPB) (1).

Critical Group dose quantification involves the identification of routes of dose uptake to man followed by habit surveys and measurements of the environmental effects of the discharges or the modelling of the effects of discharges.

Critical Group and Collective doses and the data leading to their quantification, as determined by the Site Operator, are critically reviewed by the Authorizing Departments when they require an Authorization to be reviewed - typically every three or four years. The Environmental Protection Act, 1990 amended the Radioactive Substances Act, 1960 with the effect that the submissions by Operators are placed on a Public Register and are available to members of the public on request and that the Authorizing Departments must consult potentially interested parties such as local government and pressure groups during a period of public consultation.

QUANTIFICATION OF CRITICAL GROUP DOSE

The two steps in this process are the identification of potential pathways for dose uptake to man and the carrying out of environmental monitoring. The identification of pathways is done by Habit Surveys. In England and Wales, the Ministry of Agriculture, Fisheries and Food undertake Habit Surveys, although Site Operators are quite at liberty to undertake their own Habit Surveys as well.

Habit Surveys carried out in the Ribble Estuary have identified the following pathways which are listed in order of importance.

Other pathways currently under investigation include the consumption of samphire (a saltmarsh plant) and wildfowl -

TABLE I
Numerical Authorized Discharge Limits

	Discharge Limits TBq		
	Pre October 1991 Per Quarter	After October 1991 Per Quarter	Per Year
Thorium-230	not specified	not specified	2
Thorium-232	not specified	not specified	0.2
Uranium	not specified	not specified	0.15
Neptunium-237	not specified	not specified	0.04
Technetium-99	not specified	not specified	0.6
Total alpha	3.3	1.5	4
Total beta	110	80	240

TABLE II
Actual Discharge Levels, 1991

Radionuclide(s)	Annual Limit (TBq)	Actual, 1991 (TBq)	Percent of Limit
Thorium-230	2	0.11	5.5
Thorium-232	0.2	0.0012	0.6
Uranium	0.15	0.053	35
Neptunium-237	0.04	0.0003	0.75
Technetium-99	0.6	0.05	8.3
Total alpha	4	0.17	4.3
Total beta	240	38	16

TABLE III
Critical and Sub-critical Groups and Principal Dose Uptake Pathways

Boat Dwellers	External Dose (gamma)
Fishermen (Rod and Line)	External Dose (β + gamma)
Shellfish Consumers	Internal Dose
Wildfowlers	External Dose (β + gamma)
Consumers of meat from beasts grazing on saltmarsh	Internal Dose
Net Fishermen	External Dose (β)

the Ribble Estuary is a nationally important overwintering site for many species of wildfowl.

The environmental monitoring is carried out by a combination of statutory monitoring and voluntary monitoring. The statutory program is another of the requirements of the discharge authorization whereby monitoring is specified at selected locations, and defined frequencies, so as to allow a comprehensive assessment of public dose uptake to be made. For illustrative purposes, the gamma dose rates at the specified locations, for 1991, are given in Table IV.

The BNFL voluntary program is much more extensive than this, covering many more locations from the estuary of the River Ribble to its tidal limit. The tidal action of the river results in small, but measurable, increases in dose rate above background from the estuary mouth up to some 15 miles

TABLE IV
Mean Gamma Dose Rates, 1991

Location	Mean Gamma Dose Rate (MicroSieverts Per Hour)
Lytham	0.10
Freckleton	0.11
BNFL outfall	0.13
460 meter upstream of outfall	0.10
Savick Brook	0.08
Sand Lagoon	0.06
Penwortham Bridge	0.14
River Douglas, Becconsall	0.11
Hesketh Outmarsh	0.12
Natural Background	0.087

upstream. The boat dwellers are located generally near to the estuary mouth, wildfowlers use marshlands in the same general area and rod and line fishermen tend to use the river closer to its tidal limit.

In the case of gamma pathways, dose uptake is the product of the annual mean gamma doserate and the annual occupancy. In the case of boat dwellers, MAFF calculate an effective occupancy which takes account of the shielding afforded by the hull of the boat and the water covering the mud banks at high tide.

The Ribble estuary is not only affected by discharges from Springfields but also those from Sellafield. To apportion the dose between the two sources, data from routine radiochemical analyses of mud samples taken from the estuary are used. The basic model used is that described by Hunt (2) which is an exponential depth model. This has had to be modified as the model assumes an exponential decrease in radionuclide concentration with depth, the rate of decrease being determined by a combination of sedimentation rate and halflife. The most dominant radionuclide is ^{137}Cs. The results of core samples taken at boat dweller locations in the estuary show that the levels of ^{137}Cs rise to 3 to 4 times the current surface concentration at a depth of 300 to 350 mm. With halflife of ^{137}Cs being relatively long, an almost uniform concentration would be expected. The variation of concentration with depth reflects the substantial reduction in ^{137}Cs discharges from Sellafield brought about by the introduction of the SIXEP plant. This plant, the Sellafield Site Ion Exchange Effluent Treatment Plant, uses the ion-exchange technique to bring about a reduction in caesium, and some other radionuclides, in Sellafield liquid effluent and has been in operation since 1985. ^{134}Cs with its much shorter halflife would be expected to show a marked decrease in concentration with depth but actually has a fairly even distribution, again, a consequence of higher past discharges from Sellafield, pre SIXEP.

In addition to these effects, the original model is applicable to semi-infinite plane sources such as the extensive areas of saltmarsh where the model was validated. The boat dweller locations in the Ribble are narrow, slanted sources. Although there are compensation factors for this type of source geometry, a different approach was taken. The original model predicts doserates; since the aim was not to predict doserates but to apportion components of it, radionuclide concentrations were put into the model and the summation of the components was compared directly to the measured doserates. The contribution from each radionuclide was termed the Dose Contribution Index (DCI):

$$DCI_r = A_r \bullet E_r \bullet (S/\lambda_r) \bullet R_r \bullet K$$

Where

A_r =	concentration of radionuclide (Bq kg^{-1})
E_r =	effective gamma energy of radionuclide (Mev Bq^{-1})
S =	sedimentation rate (m a^{-1})
λ_r =	radioactive decay constant (a^{-1})
R_r =	a reduction factor (dimensionless)
K =	1 x 10^4 (arbitrary constant)

(S/λ_r) is known as the relaxation depth and is the depth where the concentration is e^{-1} of the surface concentration.

MAFF recommend that a doserate of 0.087 μGy h^{-1} is subtracted from measured doserates to account for natural background in muddy estuaries. The Thorium radionuclides are naturally occurring and thus the measured concentrations have to compensate for this. Measured values from samples taken in the estuary of the River Wyre were used. The River Wyre flows into the eastern Irish Sea approximately 24 km (15 miles) north of the River Ribble and is not affected by Springfields discharges. In addition to this, the ^{232}Th decay chain was not in secular equilibrium and split into four components.

The individual DCIs were summed and equated to the excess doserate:

$$\Sigma\, DCI_{artificial} = (\text{measured doserate} - 0.087)$$

Hence the contribution to Critical Group dose from the Thorium radionuclides which are not discharged from Sellafield can be simply determined:

$$Doserate_{Springfields} = \Sigma\, DCI_{Thorium} / \Sigma\, DCI_{Artificial} \times \text{excess doserate}$$

To try to validate this approach, some very simple in situ spectroscopy was carried out. One very noticeable difference was the contribution from ^{234}Th. The model indicates that the contribution from ^{234}Th should be about the same as that from ^{234m}Pa which ^{234}Th supports (^{234m}Pa has a halflife of 1.18 minutes and its concentration is expected to be the same as ^{234}Th) however the contribution from ^{234}Th was found to be about one tenth of that expected. ^{234m}Pa's effective gamma is made up of relatively low abundances of quite high energy emissions whereas the contribution from ^{234}Th is made up of relatively abundant but low energy (< 100 keV) gamma emissions. It is likely that the ^{234}Th's emissions are much more heavily attenuated than those from ^{234m}Pa - a problem not unknown to radiochemists.

This approach indicates that about 85% of dose in outer estuary areas where the boat dwellers and wildfowlers are located, is due to Sellafield discharges whereas in the upper estuary areas, where rod and line fishermen are to be found, the split is approximately 50:50.

Wildfowlers and rod and line fishermen can also be affected by another, more unusual, route of Effective Dose Equivalent (EDE) uptake. One of the short lived daughters of ^{238}U which is discharged from Springfields is ^{234m}Pa which emits a high energy beta with a maximum energy of 2.2 MeV. Beta radiation with such energy is capable of penetrating clothing and the skin of the scrotum and partially irradiating the testes, thus leading to a contribution to EDE (Effective Dose Equivalent).

The first step in interpreting ß doserates measured in the estuary was to determine the effect of absorption by clothing. This was done by carrying out a series of measurements through varying thicknesses of a low Z absorber (paper) using uranium as a source of ^{234m}Pa. An absorption graph was drawn up which allowed the effects of varying thicknesses of clothing to be evaluated. The same graph was also used to account for absorption by the skin of the scrotum and the tunica vaginalis which overlie the testes. ICRP Reference Man data was used for the thicknesses of these tissues (3). Clothing thicknesses were as advised by MAFF following a habit survey.

Penetration into the testes was calculated using a standard ß absorption equation and modelling the testes as spheres of unity density with one half of the surface being irradiated. A subsequent, more sophisticated approach by Hunt (4) modelled the testes as oval spheroids using MIRD Phantom data and obtained a very similar answer.

The main problem with assessing EDE by this route is in interpreting the doserate data. The actual attitude of the body with respect to the mud banks is important, ie whether the person is stood up, seated on a lightweight stool, seated on a tacklebox or sat on the mud - the latter being very unlikely due to the soft nature of the mud. Some fishermen sit on the river banks or stand actually in the water rather than on the mud.

Past routine quarterly monitoring data had indicated that there could be quite significant temporal and spatial changes to the levels of ^{234m}Pa and in 1992 a program of monthly monitoring was instituted which confirmed this and will need to be continued to allow confirmation of the dose assessment.

The handling of nets by commercial fishermen also gives a potential route for dose uptake although recent monitoring has failed to detect any significant contamination.

The same methodology as for rod and line fishermen was also applied to wildfowlers.

Beta dose to the lens of the eye has also been evaluated but does not give rise to any EDE as ICRP considers that only deterministic effects arise from this route of exposure.

When the methodology of ICRP 60 is adapted, there will be an additional source of Committed Effective Dose (CED) via ß irradiation of the skin. Hunt (4) has carried out some assessment of the effect of this with large degrees of pessimism but nevertheless, the indications are that this could become a noticeable source of CED, particularly for wildfowlers who tend to get involved with intimate contact with mud. Again, good quality monitoring and Habit data is needed to carry out realistic dose assessments.

Evaluation of doses to cockle consumers is quite straightforward, with samples of cockles being prepared as for culinary purposes and then being analyzed. The combination of radionuclide concentrations and consumption rates (again advised by MAFF) gives intakes and then simple dose per unit intake conversions (5) can be used.

The evaluation of doses from the consumption of meat from sheep and cattle which graze saltmarshes is a little more complex. This route is assessed by taking samples of grass which are then analyzed. Grass to muscle transfer factors and grass consumption rates recommended by NRPB (6) combined with beast grazing time on the marshes give radionuclide concentrations in muscle. Meat consumption rates given by NRPB (7) give intakes of radionuclides by man which are then simply converted to doses by use of dose per unit conversions.

It is of note that the external dose pathways are most affected by ^{232}Th plus its daughters (gamma) and the short lived daughters of ^{238}U (^{234}Th and ^{234m}Pa) (beta + gamma) whereas the internal dose pathways are most affected by ^{230}Th.

The principal doses amongst those discussed above are summarized in Table V, which also expresses dose as a fraction of the current UK limit and gives estimates of more minor pathway doses to these groups.

CONCLUSION

Risk to the public in the UK from radioactive discharges is controlled by limiting dose to Critical Groups. ICRP (Ref 8) recommended a dose limit of 1 mSv per annum although the UK government has adopted an advisory value of 0.5 mSv per annum. Currently, the NRPB is carrying out a consultative process on its recommendations of the adoption of a Dose Constraint of 0.3 mSv per annum with a Dose Limit of 1 mSv per annum following the revision of dose:risk estimates made by ICRP. Dose Constraints apply to the current and potential future effects of current discharges whereas Dose Limits also include the effects of past discharges.

Assessments of Critical Group Doses in the Ribble estuary clearly show that the doses are significantly below all of the values mentioned above and hence that risks to the general public from Springfields liquid discharges are much less than those deemed as acceptable by the UK Government. All these, and other, data are published in BNFL's Annual Reports on Radioactive Discharges and Monitoring of the Environment (9).

REFERENCES

1. "The Radiological Impact of Routine Discharges During 1970-1984 and Estimated Discharges up to 1989 from the UK Civil Nuclear Power Program: Detailed Results", NRPB M143.
2. G. J. HUNT, "Sizewell Inquiry Series No 3".
3. "Report of the Task Group on Reference Man", ICRP 23.
4. G. J. HUNT, "External Dose to the Public from Beta Emitters in the Aquatic Environment near Springfields and Sellafield", Journal, Radiological Protection, 1992 Vol 12 No 4.
5. "Committed Doses to Selected Organs and Committed Effective Doses from Intakes of Radionuclides", NRPB-GS7.
6. "Calculations of the Radiological Impact of Unit Releases of Radionuclides to the Biosphere from Solid Waste Disposal Facilities", NRPB-M150.
7. "Revised Generalized Derived Limits for Radioisotopes of Strontium, Iodine, Caesium, Plutonium, Americium and Curium", NPRB-GS8.
8. "Recommendations of the International Commission on Radiological Protection", ICRP60:1990.
9. "Annual Report on Radioactive Discharges and Monitoring of the Environment", BNFL, Risley, Warrington, Cheshire, UK, 1991 (and previous years).

TABLE V
Typical Annual Doses

Group	Route of Dose Uptake	Dose μSv p.a.	Dose Limit μSv p.a.	% of Dose Limit
Boat dwellers	External Gamma Radiation	35		
	Inhalation	3.7		
	Ingestion	3.5		
Total		42.2	1,000	4.22
Shellfish Consumers	Ingestion	10.73		
Total		10.73	1,000	1.07
Wildfowler	External Gamma Rdiation	2.6		
	Inhalation	0.9		
	Ingestion	0.7		
	EDE from high energy β via gonads	0.9		
Total		5.1	1,000	0.51
Wildfowler	β dose to skin	144	50,000	0.29
	β dose to eye	29	15,000	0.2
	Penetrating β dose to gonads	29	50,000	0.06
Hypothetical 50% occupancy of estuary except for pipeline outfall	β dose to skin	4,500	50,000	9.0
Fishermen handling nets	β dose to skin	275	50,000	0.55
Fishermen at Penwortham	External Gamma Radiation	9		
	EDE from high energy β via gonads	2.4		
Total		11.4	1,000	1.14
Fishermen at Penwortham	β dose to eye	400	15,000	2.7
	Penetrating β dose to gonads	80	50,000	0.16