BNFL Sellafield: The Future for Discharges

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INTRODUCTION

Political, public and other stakeholder interest in relation to radioactive discharges continues to increase in Western Europe. For example, the 'Sintra Statement' (1) of the Oslo Paris Commission (OSPAR) provides a ministerial commitment to reduce discharges, by the year 2020, of artificial radionuclides to levels where their concentrations in the marine environment, above historic levels, are close to zero.

Since the 1970s, BNFL has secured major reductions in discharges from its Sellafield site in the UK. This has partly been achieved by changes in operational practice, but more by virtue of a substantial programme of waste management and effluent treatment plants which have progressively come into operation over the past 15 years. Doses to members of the marine critical group have reduced from about 2 millisieverts per year in the early 1980s to about 0.1 millisievert per year at the present time (with about half of the current doses attributable to historical discharges in the 1970s, principally plutonium, americium and caesium). Similarly, doses to critical groups resulting from aerial discharges have reduced approximately five-fold to about 0.1 millisievert.

This paper discusses key decisions/factors leading to these progressive and substantial reductions in radioactive discharges but, moreover, looks prospectively over the long-term future (e.g. to the year 2020). Over this period, the radiological impact of Sellafield discharges on members of the public will decline further – this of course being with reference to current assessment methodology and critical group habit assumptions.

Reductions in the component of critical group doses attributable to historical discharges will decline slowly, as determined by the gradual dispersion of radionuclides already present in the environment and the radioactive decay of some species. Further reductions in impacts will follow the eventual cessation of older plant on the site, currently still in active operation, consequent upon the treatment of any stored liquors which have accumulated during the operation of these plants.

Newer plants on the site which have commenced operation during the 1990s or are currently under commissioning have been designed to much higher environmental standards (i.e. lower impacts). A number of facilities which will come into active operation over the period 2000-2005 will give rise similarly to extremely low impacts as a consequence of routine emissions. The paper discusses the future radiological impact of the site.

HISTORY OF THE SELLAFIELD SITE

The Sellafield site on the Cumbrian coast is the largest nuclear complex in the UK. The primary activities currently undertaken at Sellafield are reprocessing of Magnox and oxide fuels, manufacture of mixed oxide fuels (using the products from reprocessing), the conditioning of radioactive wastes for safe long-term storage or disposal, clean up of historic facilities and the operation of the Calder Hall nuclear power station. Whilst the earliest operations at the site were undertaken largely for military purposes, from the late 1950s Sellafield has mainly served the UK and overseas civil nuclear power programmes.

ORIGIN OF DISCHARGES FROM SELLAFIELD

a) LIQUID DISCHARGES

During reprocessing operations, some effluents containing a small fraction of the radioactivity originally present in the fuel, are discharged to sea via pipelines which extend some two miles off the coast adjacent to the site. The main sources of such effluents are :-

- *Pond purges* of ponds built to store irradiated Magnox and oxide fuel prior to reprocessing, to allow shorter lived isotopes to decay. The older facilities are now undergoing Post Operational Clean Out (POCO) prior to decommissioning. Purges from the Magnox storage ponds are routed through the Site Ion Exchange Effluent Plant (SIXEP). Oxide fuel, which has stainless steel/zircaloy cladding, does not corrode significantly in water and the pond water does not require treatment.
- *Low active effluents* considered to be higher, or potentially higher, in alpha activity are treated in the Enhanced Actinide Removal Plant (EARP). Other waste streams are routed to the Segregated Effluent Treatment Plant (SETP) where they are neutralised and screened prior to discharge to the marine environment.
- Any remaining effluents which may contain trace levels of activity (e.g. rainwater run-off, cooling water, borehole water, laundry waste and stream condensates) are collected, sampled and pumped to sea via the

marine pipeline.

- *Medium Active Concentrate* (MAC) streams are produced by reducing the volume of some of the effluents arising from Magnox reprocessing operations, and these are accumulated in tanks on site. Storage allows the activity associated with short-lived isotopes to decay. In the past these effluents were not treated further but discharged to sea following several years storage. This practice was discontinued in the early 1980s, and the liquors have remained in storage on site until EARP was commissioned in 1994. These effluents are now being treated in EARP.
- *Salt Evaporator Concentrate* (SEC) arises from solvent washing operations in the Magnox and THORP reprocessing plants and are concentrated by the Salt Evaporator, which commenced operation in 1985. As with MAC, arisings of SEC are decay-stored on site, prior to treatment in EARP.
- *Solvents* such as tri-butyl phosphate and odourless kerosene which are used in reprocessing operations and gradually lost by dissolution, or entrainment into monitoring tanks. These stored solvents will be treated in the Solvent Treatment Plant (STP) once commissioning work is complete.

Radioactive discharges from the Sellafield site to the marine environment have been consistently below annual discharge limits set by UK regulatory bodies and have been reduced dramatically since their peak in the mid 1970s (Figures 1a and 1b). These reductions in discharges have been effected by decommissioning older facilities and replacing them with more stringently designed and engineered plants, and by the introduction of specific waste treatment plants such as EARP and SIXEP. The accumulation of Medium Active Concentrates pending further treatment has also reduced discharges to sea in recent years.

Figure 1a : Historic liquid discharges from the Sellafield site (alpha discharges)

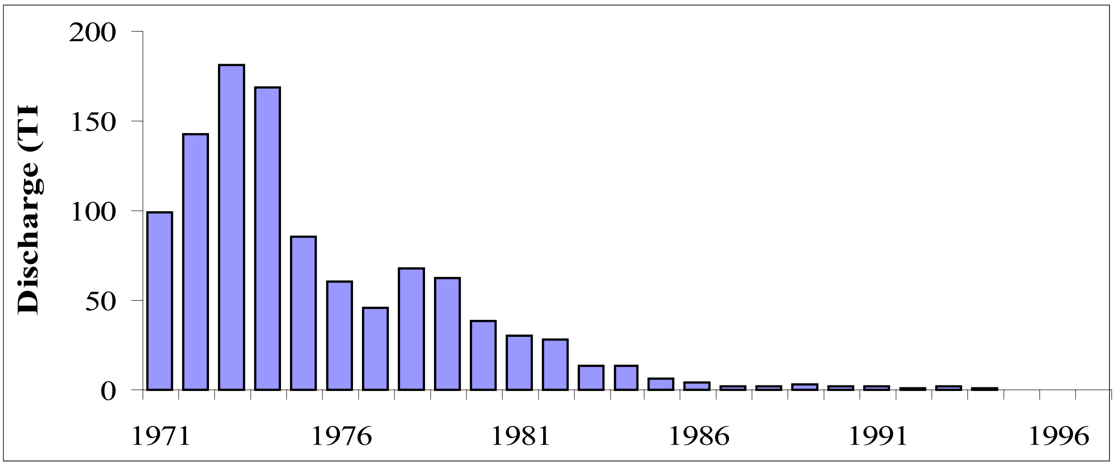
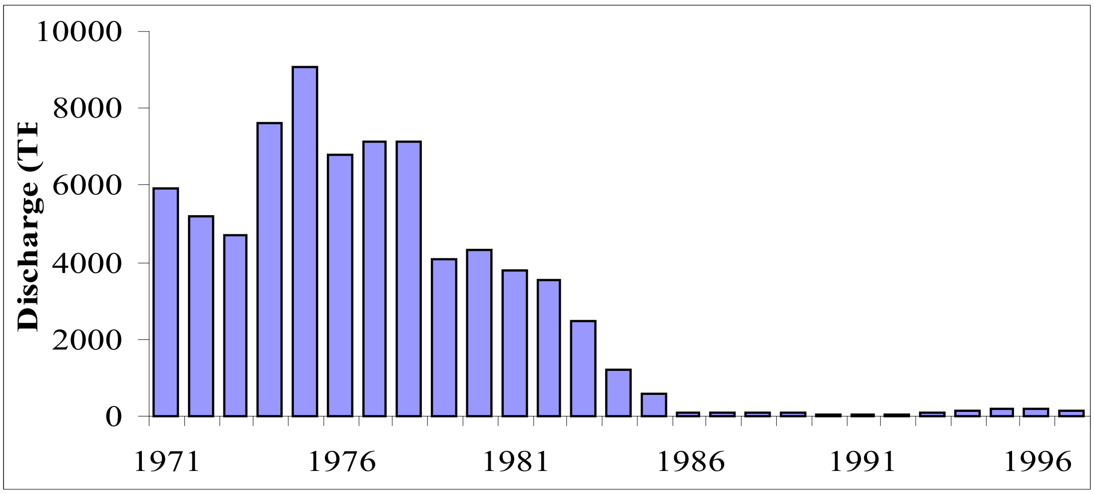


Figure 1b : Historic liquid discharges from the Sellafield site (beta activity)



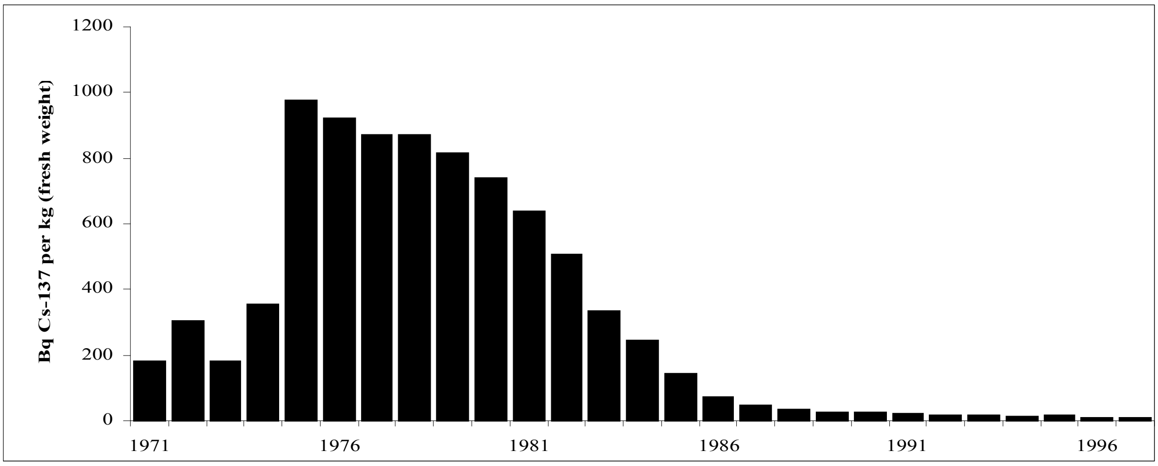
Monitoring by both BNFL and the Ministry of Agriculture, Fisheries and Food (MAFF) gives a clear indication of those radionuclides in liquid discharges from Sellafield which have the largest environmental impact on dose uptake by the critical groups. The relative dose contributions vary depending on the pathway but, based on current discharge levels, the radionuclides of primary significance are Tc-99, Ru-106, Sr-90, Cs-137, C-14 and Co-60. Of these, Tc-99 and Sr-90 arise mainly in the MAC processed through EARP. Small amounts of Sr-90 are also processed through SETP and SIXEP.

The main source of C-14 discharge to sea arises from Magnox fuel reprocessing, with the remainder mostly from treatment of liquid concentrates in EARP. Small amounts of Ru-106 and Cs-137 are discharged to the marine environment following storage and treatment of liquid concentrates (SEC) and other routine arisings in SIXEP, EARP and SETP. Pond storage of LWR fuel gives rise to discharges of Co-60. In addition to these radionuclides, the actinides (primarily Pu-alpha and Am-241) continue to contribute a significant fraction of the total dose to the critical group, largely as a result of historic discharges.

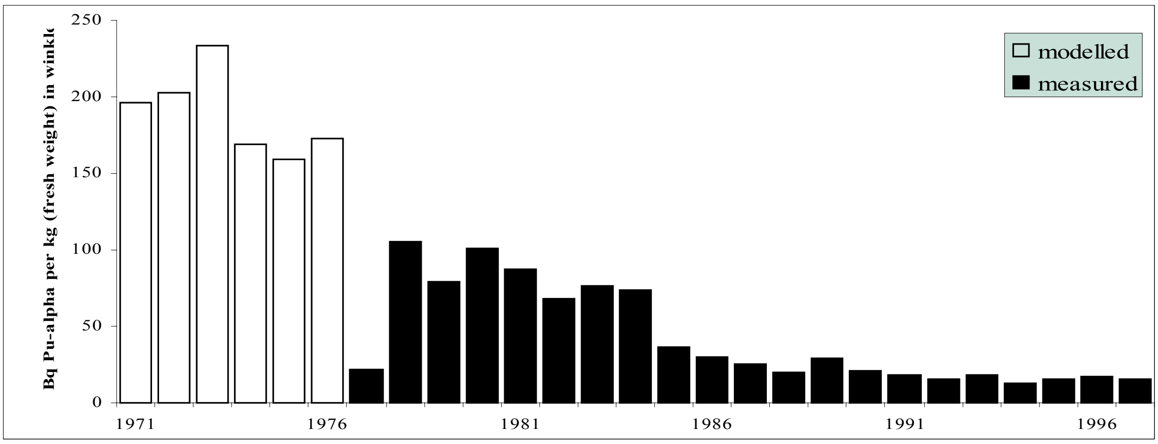
Concentrations of Cs-137 in fish (cod and plaice) and Pu-alpha in winkles from the coast and coastal waters around Sellafield are summarised in Figures 2a and 2b. These are good environmental indicators. It can be seen that concentrations have declined since the peak in the mid-1970s, approximately in line with reductions in discharges. This decline is predicted to continue as a result of decay and gradual dispersion of the historic discharges.

Figure 2 : Concentrations of Cs-137 and Pu-alpha in biota from the vicinity of Sellafield

a) Cs-137 in cod and plaice



b) Pu-alpha in winkles

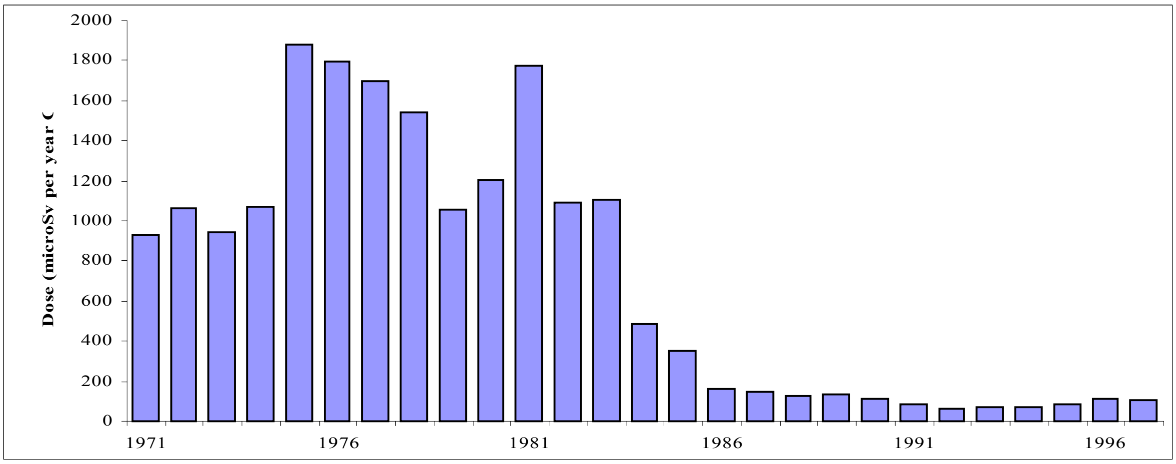


Over the years, the principal pathways of interest have varied but the pathway giving rise to the highest historic doses (and the highest current doses closest to Sellafield) arises from consumption of fish and shellfish. From 1978 a separate group consuming winkles was identified.

These pathways have always been presented in combination. When predicting doses into the future, habits averaged over previous years provide a suitable point for comparison.

The dose to the fish/shellfish consumers rose to a peak in the mid-1970s around 2 millisieverts per year (Figure 3). By 1985, when the ICRP announced that the principal limit for dose to the public should be 1 millisievert per year (2), measures introduced by BNFL to reduce its discharges had reduced the peak dose to less than 0.5 millisievert per year. Over the past decade, doses have continued to fall slowly, largely as a result of previously discharged material continuing to decay. Current peak dose estimates in the vicinity of Sellafield are around 0.1 millisievert per year, of which more than half derives from historic discharges.

Figure 3 : Critical group dose to seafood consumers near Sellafield



Doses to seafood consumers (and other critical groups) decline with distance from Sellafield. The impact of Sellafield discharges at the eastern seaboard of Eire has been estimated by the Radiological Protection Institute of Ireland to be less than 0.002 millisievert per year to the identified group of high rate seafood consumers (3). This is very much lower than any recognised dose limit.

b) AERIAL DISCHARGES

Radioactive effluents are discharged to atmosphere from several authorised stacks on the Sellafield site. These discharges consist principally of ventilation air from the process plants and Calder Hall nuclear power station. The radioactive content comprises noble gases (e.g. Ar-41 and Kr-85), other gases and vapours (e.g. H-3, I-129 and C-14) and suspended particulates. Major release points are, where appropriate, fitted with abatement equipment, such as high efficiency particulate filters or scrubbers, to reduce the quantity of radioactivity discharged, and are monitored continuously.

Discharges of radioactivity to the atmosphere also take place from Approved Places, which comprise numerous minor stacks and other release points. The latter discharges are largely associated with the resuspension of small amounts of radioactivity from open fuel storage ponds and building ventilation systems.

Discharges to atmosphere generally have a higher impact per unit release on the terrestrial environment than corresponding liquid discharges have on the marine environment. Consequently, as a matter of establishing best practicable environmental options, discharges to atmosphere are normally numerically small by comparison to marine discharges. Thus, of all H-3 discharged from Sellafield, only about 5% is discharged to air. Although there are exceptions to this (e.g. roughly one third of Ru-106 and C-14 is discharged via the stacks) as a general rule aerial discharges deposited to land and run-off to coastal waters do not add appreciably to the total inventory in the marine environment.

Two gases which require separate consideration are Ar-41 and Kr-85. These are inert noble gases, discharged exclusively via the stacks to the atmosphere. They do not react with rainwater and deposition to ground is very low. Their impact on man derives almost entirely from external exposure, with no impact via the marine environment. Discharges of Ar-41 have remained fairly constant being directly related to operation of the Calder Hall reactors. Discharges of Kr-85 have increased due to commissioning and operation of the second reprocessing plant, THORP, however the contribution of this isotope to critical group dose is small.

Figures 4a and 4b illustrate best estimate discharge profiles for particulate total alpha and beta aerial discharges from Sellafield. These profiles show a substantial reduction since the peak discharges in the early 1970s.

Doses to the terrestrial critical group dose due to airborne releases of radioactivity from Sellafield are typically less than 0.1millisievert per year. This figure includes exposure due to consumption of local produce and also the contribution due to external exposure to Ar-41 discharged from the reactors at Calder Hall and also, to a much lesser extent, Kr-85 discharged from the reprocessing plants. It is difficult to reconstruct the dose record for aerial discharges due to changes in sampling, reporting practices and critical group pathways, but it is estimated that current critical group doses have decreased approximately five-fold since those associated with the peak discharges of the early 1970s.

Figure 4a : Historic aerial discharges from the Sellafield site (total alpha discharges)
(NB. data for 1980 - 1987 are modelled figures only)

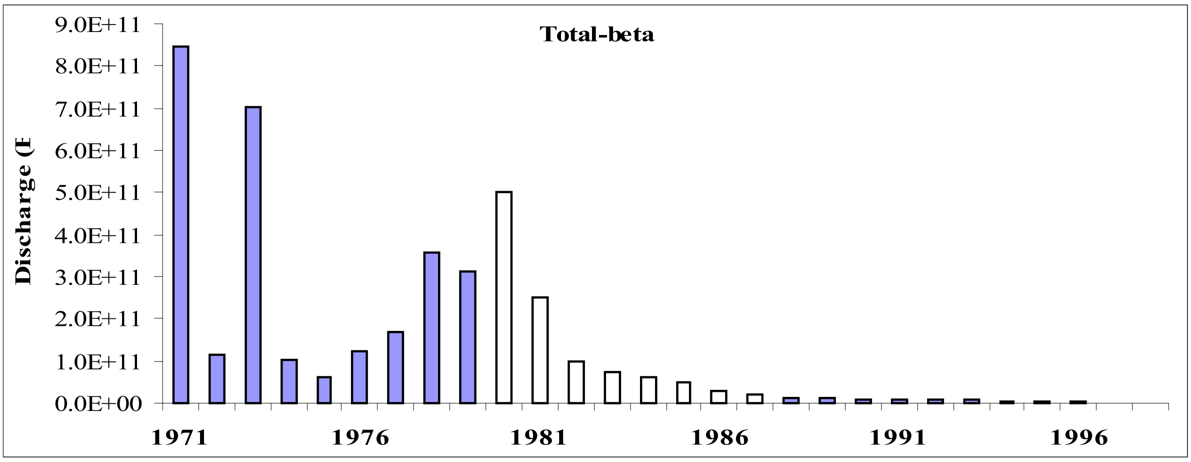
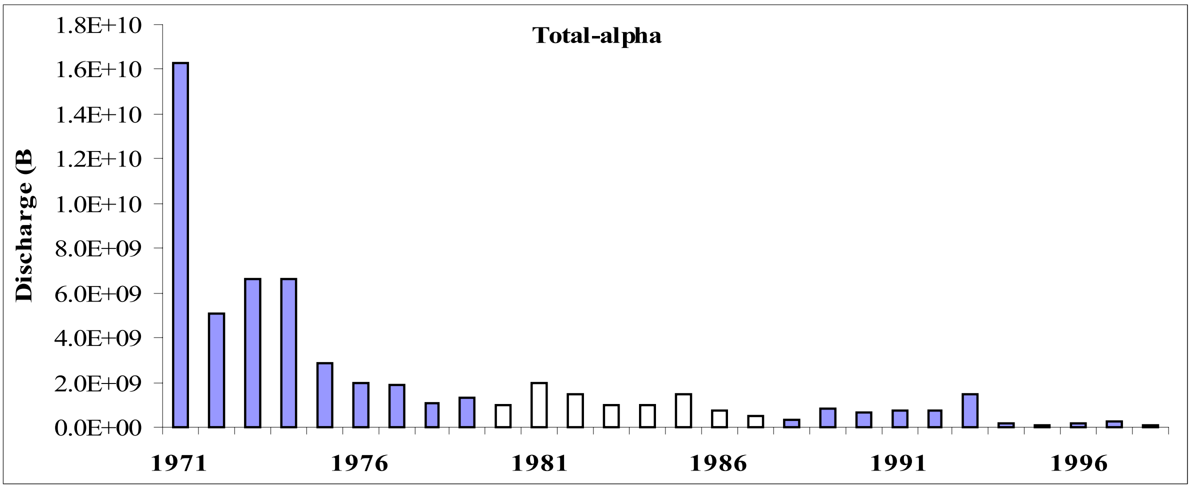


Figure 4b : Historic aerial discharges from the Sellafield site (total beta discharges)
(NB. data for 1980 - 1987 are modelled figures only)



POTENTIAL FOR DISCHARGE REDUCTION

In order to meet the company's aspirations for future discharges, and the need to contribute to the UK's national strategy for addressing the requirements of the Ospar Sintra statement, the company needed to develop a vision and strategy for future discharge reduction from the Sellafield site. In developing this strategy the company endeavoured to take account of the views of a wide range of stakeholders.

An outline methodology has been developed for identifying the most important radionuclides in order to prioritise reductions. This methodology assesses the relative contribution of discharges of radionuclides to a number of criteria, including discharge magnitude (Bq), environmental concentrations, critical group and collective doses. The significance of half-life was also taken into account. Whilst acknowledging the relevance of this range of parameters, it is BNFL's view that the greatest importance should be given to critical group dose. In addition to these environmental drivers, an assessment of discharge reduction priorities also needs to take account of anticipated plant lifetimes, abatement practicalities, costs and the interaction with on-site safety issues etc.

The overall outcome of this review focussed priority for liquid effluent reduction on to Tc99, followed by C14, Sr90, Ru106 and Pu/Am. For aerial discharges the principal focus was I129, noting that discharges of Ar41 (the highest contributor to critical group dose) will cease immediately on the planned closure of the Calder Hall reactors on the site. Some other nuclides of interest are also identified in the tables below.

There are three broad options for reducing discharges :

- Use **abatement** to transfer radioactivity in gaseous or liquid form into a solid form for extended storage and, where possible for subsequent disposal. Alternatively, transfer gaseous into liquid form for immediate discharge;
- **Modify the process** in order to reduce discharge arisings at source, or enable their diversion into long term storage (e.g. as high active solid waste);
- **Stop the process/shut the plant**.

BNFL is committed to ensuring that the best practicable means are in place to limit the activity of discharges from the site and as such has an ongoing programme to review developments in technology and techniques in relation to liquid and gaseous waste streams. The following tables summarise BNFL's considerations of a number of abatement and process modifications to minimise discharges of the more significant radionuclides.

Table 1: Liquid discharges

Radionuclide	**Abatement and/or process modification**
Tc-99	• Earlier work on removal by chemical precipitation halted as final waste form not compatible with current requirements for repository disposal. • A BPEO (Best Practicable Environmental Option) study of disposal of Tc-99-bearing wastes is underway. • Research and development into a number of other post-EARP removal techniques (including chemical reduction and electrodeposition) continues. • Modification of the Magnox plant to re-route Tc-99 bearing streams from EARP to highly active storage is under investigation.
C-14	• Precipitation at Magnox is considered possible, but may not be cost-effective. This option is being reviewed as part of business strategy.
H-3	• Significant in terms of magnitude (Bq) of discharge; minimal critical group dose impact. • No abatement considered viable in near future. • Watching brief on technology developments.
Sr-90	• Initial work on removal by enhancement of the EARP process has shown promise. • Pilot scale study underway.
Pu/Am	• The EARP plant was commissioned to reduce these discharges and has been very successful in doing this. The effectiveness of this process is kept under review.
I-129	• Liquid discharges of I-129 arise mainly from scrubbing of off-gases to prevent discharge to atmosphere. Sea discharge is currently considered to be the Best Practicable Environmental Option. • Adsorption onto a solid matrix may be possible, although the resulting waste may not be compatible with current repository disposal requirements.
Cs-137	• As for Sr-90, enhancements to the EARP process show promise for reducing emissions.

Table 2: Aerial discharges

Radionuclide	Abatement and/or process modification
Ar-41	• Not considered feasible because Ar-41 is an 'inert' gas and very large volumes of air are involved.
C-14	• An additional scrubber is under construction to deal with a presently untreated discharge from the Magnox highly active waste plants. This will re-route aerial discharges to the liquid effluent stream. • Incremental performance improvements on existing scrubbers on the Magnox and THORP plants may be possible.
Kr-85	• Research on possible processes is ongoing but currently known candidate technologies are not considered viable at the necessary scale on technical, engineering and safety grounds.
I-129	• The new scrubber referred to in relation to C-14 will also abate I-129 discharges to some extent. • The feasibility of a new type of filter for more general application is being assessed. • Process adjustments to improve abatement in THORP are being considered. • Adsorption onto a solid matrix may be feasible but waste is not currently compatible with current repository disposal requirements.
H-3	• Some incremental improvements which will increase abatement of tritium released in the form of tritiated water (HTO) are being pursued. • There are currently no cost-effective viable technologies which could abate discharges in the form of tritium gas (HT or T_2).

It is important to take timescales into account in consideration of abatement options. BNFL's experience is that new plant, or substantial modifications to existing plant, takes at least 5 - 8 years to implement given technical development, planning permission, regulatory acceptance etc.. In some cases, discharge reductions may be effected by planned closure of plants/processes before new abatement could be introduced. Nevertheless, BNFL is committed to achieving continuing reductions in discharges over and above those resulting from planned shutdown of existing facilities.

A number of new clean-up plants are due to be commissioned during the first decade of this century. Some of these operations are outlined below :-

- Solvent Treatment Plant. STP will destroy the solvents currently stored on site by incineration, producing an aqueous residue containing the bulk of the radioactivity. This will go to EARP for further treatment prior to discharge. STP is ready to commence commissioning.
- Sellafield Drypac Plant. SDP will dry and compact Magnox sludge (currently stored in silos since the mid 1960s) prior to encapsulation. It is scheduled to commence active commissioning in 2002.
- Box Encapsulation Plant. BEP will encapsulate retrieved waste from the Dry Storage Silos, Magnox storage ponds, decanning facilities, pile storage pond and oversize material from the Magnox storage silos. BEP is scheduled to commence active commissioning in 2003.

The above facilities are primarily intended to treat stored wastes and thus improve the overall safety of radioactive waste management. Some increases in discharges will occur as such wastes are worked through, although their impact on man and the environment will be insignificant.

FUTURE DECISIONS

Future discharges are clearly dependent on (but not directly related to) the commercial operations undertaken at Sellafield. In order to assess the need for further discharge reductions, and to comply with OSPAR, it is necessary to consider future business and plant operation scenarios.

Indicative discharge profiles for the principal radionuclides for a number of potential operating scenarios have been compiled. These included the bounding options of stopping reprocessing now and a 'full potential' case in which the lifetimes of both reprocessing plants were extended into the middle of the third decade of this century. Stopping reprocessing now is not practicable due to the inventory of Magnox fuel currently in reactor cores or storage ponds which currently relies on Magnox reprocessing for medium to long-term management as there is no other proven long-term option. At the other end of the scale, the extension of Magnox reactor and Magnox reprocessing lifetimes to the mid-2020s was not considered to be acceptable without substantial abatement, the cost of which in itself may render the Magnox business uneconomic. The impact of discharges from THORP reprocessing is considerably less than from Magnox reprocessing and therefore is less affected by the same argument.

The potential future operating strategy for the UK Magnox reactors, Magnox reprocessing and THORP reprocessing therefore lies between these two extremes. The optimised final form will ideally maximise the Company's business potential but will also be influenced by external pressures and priorities for discharge reductions. This must, however, be balanced by competing factors such as cost, employment and occupational safety. It should also be remembered that there is no evidence of any harm to man or the environment at the current levels of discharges.

Indicative profiles of critical group doses resulting from the discharges associated with such an aspirational operating strategy are illustrated in Figures 5 and 6. Note that these profiles are illustrative and exclude doses due to historical discharges and those due to decommissioning activities. The former contributes approximately an additional 50 microsieverts to the marine critical group dose; the latter is considered to be very small during the next few decades.

These aspirational profiles are based on the most likely upper business case and do not take account of any of the potential abatement options discussed earlier in this paper. In particular it is noted that the dominant contribution to liquid discharge critical group dose is Tc-99, for which extensive work is in progress to develop appropriate abatement – although no proven process has yet been identified. For aerial discharges the dominant long term contribution arises from I-129, but in this case there is strong evidence that the assessment models significantly over-predict the dose compared to actual environmental measurements. Work is in hand to ensure that forward predictions of dose are more realistic as well as to address the options for I-129 discharge reduction.

Figure 5 : Contribution by radionuclide to critical group dose from liquid discharges for an aspirational business scenario

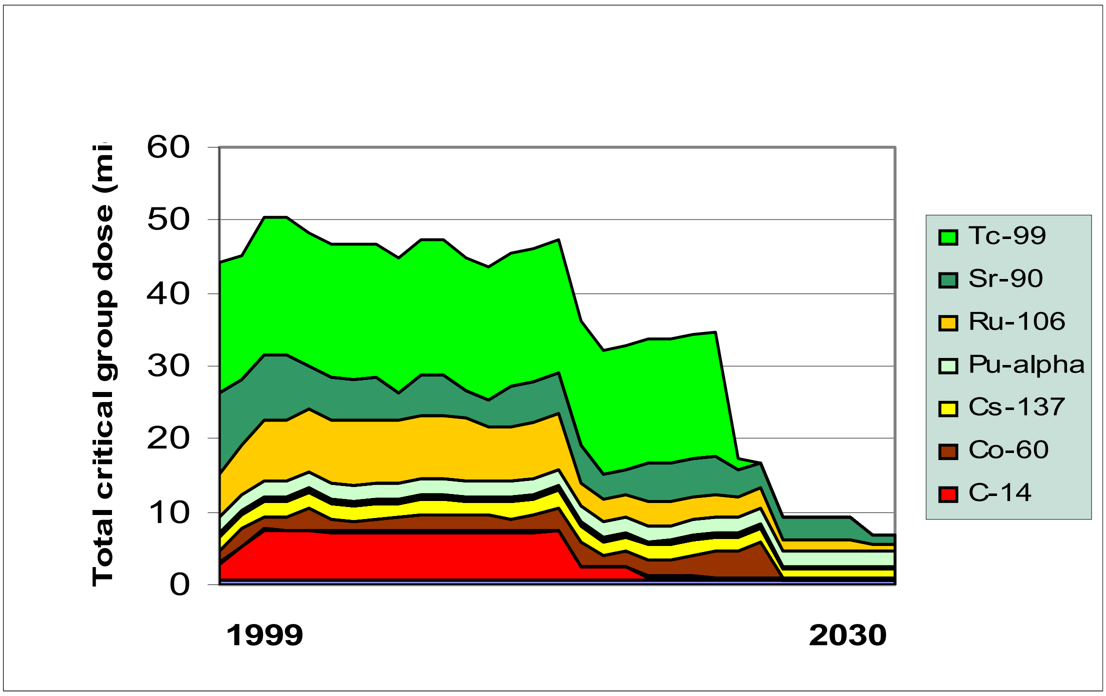
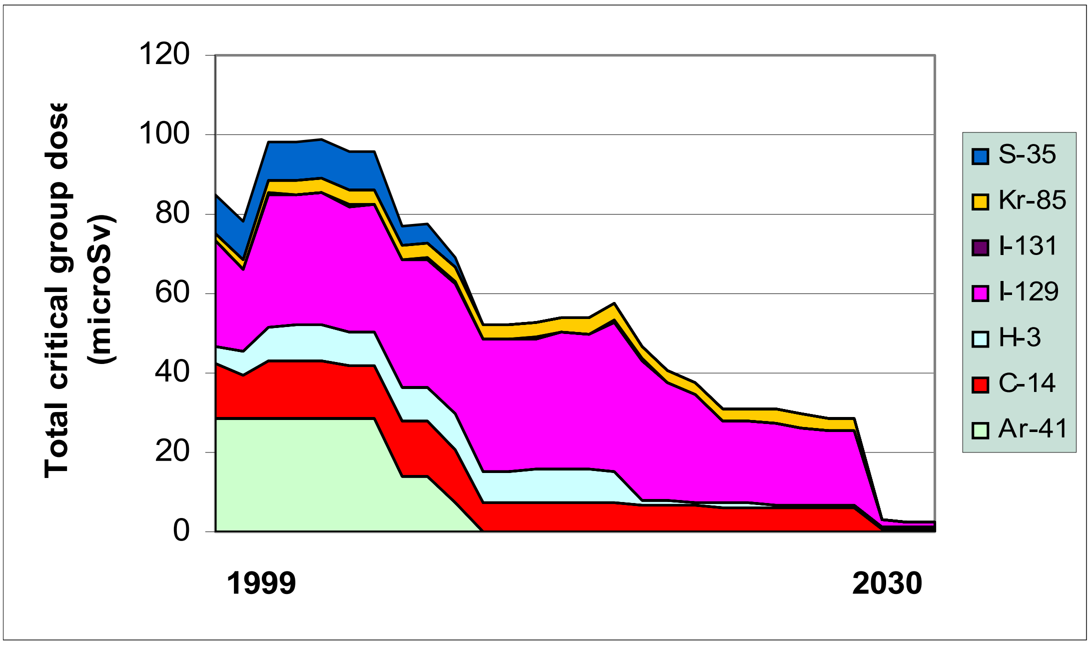


Figure 6 : Contribution by radionuclide to critical group dose from aerial discharges for an aspirational business scenario



This year, a National Strategy for discharges is being developed by the UK Department of Environment, Transport and the Regions. This will be heavily influenced by the OSPAR-Sintra agreement. Due to the current lack of guidance on OSPAR requirements, BNFL and many other organisations are of the opinion that internationally recognised 'harm' thresholds should be developed below which no further significant costly action would be necessary as the risks would be accepted as negligible. Current thinking is that this level may be of the order of 0.03 millisieverts, which is of the order of 1% of the dose to a member of the UK public arising from natural background radiation. Application of this 'threshold' value to Figures 5 and 6 above suggests that BNFL should consider some further reductions in the assessed discharges in order to meet the likely National Strategy and OSPAR requirements.

As stated above, the above figures highlight Tc-99 (liquid) and I-129 (aerial) as the key radionuclides on which to focus reduction measures, assuming that BNFL's future operating strategy is similar to the aspirational case for which indicative discharges have been illustrated. The only abatement taken into consideration in the above figures is the new scrubber for aerial discharges of C-14 and I-129 mentioned in Table 2. BNFL is, however, progressing work in both of these areas as detailed in Tables 1 and 2, which have the potential to effect significant reductions in discharges of these, and other, isotopes. The availability of final disposal routes for any solid waste products could, however, have a significant bearing on selection of any abatement schemes. For these key nuclides of interest which have long half lives, i.e. I-129, Tc-99 and (to some extent) C-14, there needs to be a genuine debate and assessment to identify what is the Best Practicable Environmental Option for the long term management of these nuclides. For example, in the case of I-129 the current philosophy of all reprocessing plants is to seek to route as much of this substance as possible to liquid discharge since this gives the lowest critical group dose and very little collective dose within the 500 year period which is the principal reference frame. If this I-129 were to be extracted for encapsulation into solid waste then the current UK Nirex safety criteria would not allow acceptance of this waste stream into the anticipated national repository since it would infringe the long term critical group risk target. There is thus a strong case for arguing that sea discharge is the best option and that a policy of discharge reduction for these nuclides may indeed be inappropriate.

CONCLUSIONS

Radioactive discharges have an increasingly high political and public profile both in the UK and in Europe as a whole. Inevitably pressure is being placed on nuclear operators to further reduce discharges which are already at levels which give doses which are very low compared to natural background and which have negligible impact on man and the environment. The benefits of implementing such reductions is increasingly being outweighed by considerations of cost, feasibility and occupational safety.

Discharges from BNFL's Sellafield site have been continuously and progressively reduced since the mid-1970s, a trend which will continue into the future. Subject to technical and economic feasibility, BNFL is however committed to reducing the impact of the site's discharges to 'near-zero' levels (less than 30 microsieverts or around 1% of natural background) by 2020 to comply with the anticipated requirements of the National Strategy and the OSPAR-Sintra statement.

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1. Sintra Statement of the Ministerial Meeting of the OSPAR Commission, dated 23 July 1998.
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3. RPII (1998). *Radioactivity Monitoring of the Irish Marine Environment 1996 and 1997.* Radiological Protection Institute of Ireland, Dublin.