# Best Practicable Environmental Option Study for Management of Radioactive Waste Arisings from the Dounreay Site Restoration Plan

Issue 1.0

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# Contents

**A3 Tables**

Note that some Tables are included in the main text but Tables presented in A3 format have been attached and indexed following the Appendices.

# Project Team

This study has been carried out by a UKAEA Project Team listed below, who have experience and expertise in the areas of radioactive waste management, regulatory compliance, health and safety, nuclear decommissioning and the conduct of BPEO studies. The non-UKAEA team members bring the same range of experience and expertise but from elsewhere within the nuclear industry and the field of environmental consultancy. This informed, broad based approach is believed to the most appropriate for a study of this complexity.

***Project Team***[1]

| | |
|---|---|
| Graham Crittenden | UKAEA Dounreay (Safety and Environment Group)<br>UKAEA Project Manager |
| Mark Dutton | NNC Ltd |
| James Gunn | UKAEA Dounreay (Decommissioning Group) |
| Marion Hill | Enviros Consulting Ltd |
| Juliet Long | UKAEA (Corporate Safety, Health and Environment Group) |
| David Lord | UKAEA Dounreay (Safety and Environment Group) |
| Katrina Lourie | UKAEA Dounreay (Waste Management Group) |
| Roy Manning | UKAEA (Planning, Performance and Engineering Division) |
| Bill Miller | Enviros Consulting Ltd |
| Bob Morley | BNFL Sellafield (Environment, Health, Safety and Quality) |
| Mark Raffle | UKAEA Dounreay (Waste Management Group) |
| Paul Robinson | UKAEA Dounreay (Safety and Environment Group) |
| Lorna Stevens | Entec Ltd |
| Colin Stewart | UKAEA Dounreay (Safety and Environment Group) |
| Mike Tait | UKAEA Dounreay (Waste Management Group) |

There has been no public consultation or public involvement in the course of this study and therefore the conclusions are, at this stage, those of the Project Team as endorsed by UKAEA. UKAEA recognise and support the views on BPEO consultation expressed in the 12th report of the Royal Commission on Environmental Pollution, and public views on the management of Dounreay Site Restoration Plan (DSRP) radioactive waste management will be sought as part of UKAEA's DSRP public participation strategy.

[1] The affiliations of team member shown are those at the beginning of the project.

# Abbreviations and acronyms

| | |
|---|---|
| ADU | Ammonium Diuranate |
| AECP | Atomic Energy Code of Practice |
| BATNEEC | Best Available Technology Not Entailing Excessive Cost |
| BPEO | Best Practicable Environmental Option |
| BPM | Best Practicable Means |
| BSL | Basic Safety Limit |
| BSO | Basic Safety Objective |
| CHILW | Contact Handleable Intermediate Level Waste |
| DEFRA | Department of the Environment, Food and Rural Affairs |
| DCP | Dounreay Cementation Plant |
| DFR | Dounreay Fast Reactor |
| DRWI | Dounreay Radioactive Waste Inventory |
| DSRP | Dounreay Site Restoration Plan |
| DVP | Dounreay Vitrification Plant |
| HAL | High Active Liquor |
| HEPA | High Efficiency Particulate in Air |
| HEU | Highly Enriched Uranium |
| HLW | High Level Waste |
| HSE | Health and Safety Executive |
| HVAC | Heating, Ventilating and Air-Conditioning |
| IAEA | International Atomic Energy Agency |
| ICRP | International Commission on Radiological Protection |
| ILW | Intermediate Level Waste |
| IPC | Integrated Pollution Control |
| LLL | Low Level Liquid |
| LLLETP | Low Level Liquid Effluent Treatment Plant |
| LLW | Low Level Waste |
| MAL | Medium Active Liquor |
| MTR | Materials Testing Reactor |
| NII | Nuclear Installations Inspectorate |
| NRPB | National Radiological Protection Board |
| PCM | Plutonium Contaminated Material |
| PFR | Prototype Fast Reactor |
| POCO | Post-Operational Clean Out |
| R&D | Research and Development |
| SEPA | Scottish Environmental Protection Agency |
| RCEP | Royal Commission on Environmental Pollution |
| RHILW | Remote Handleable Intermediate Level Waste |
| RSA | Radioactive Substances Act |
| UK | United Kingdom |
| UKAEA | United Kingdom Atomic Energy Authority |
| VLRM | Very Low Level Radioactive Material |
| WVP | Windscale Vitrification Plant |

# Executive Summary

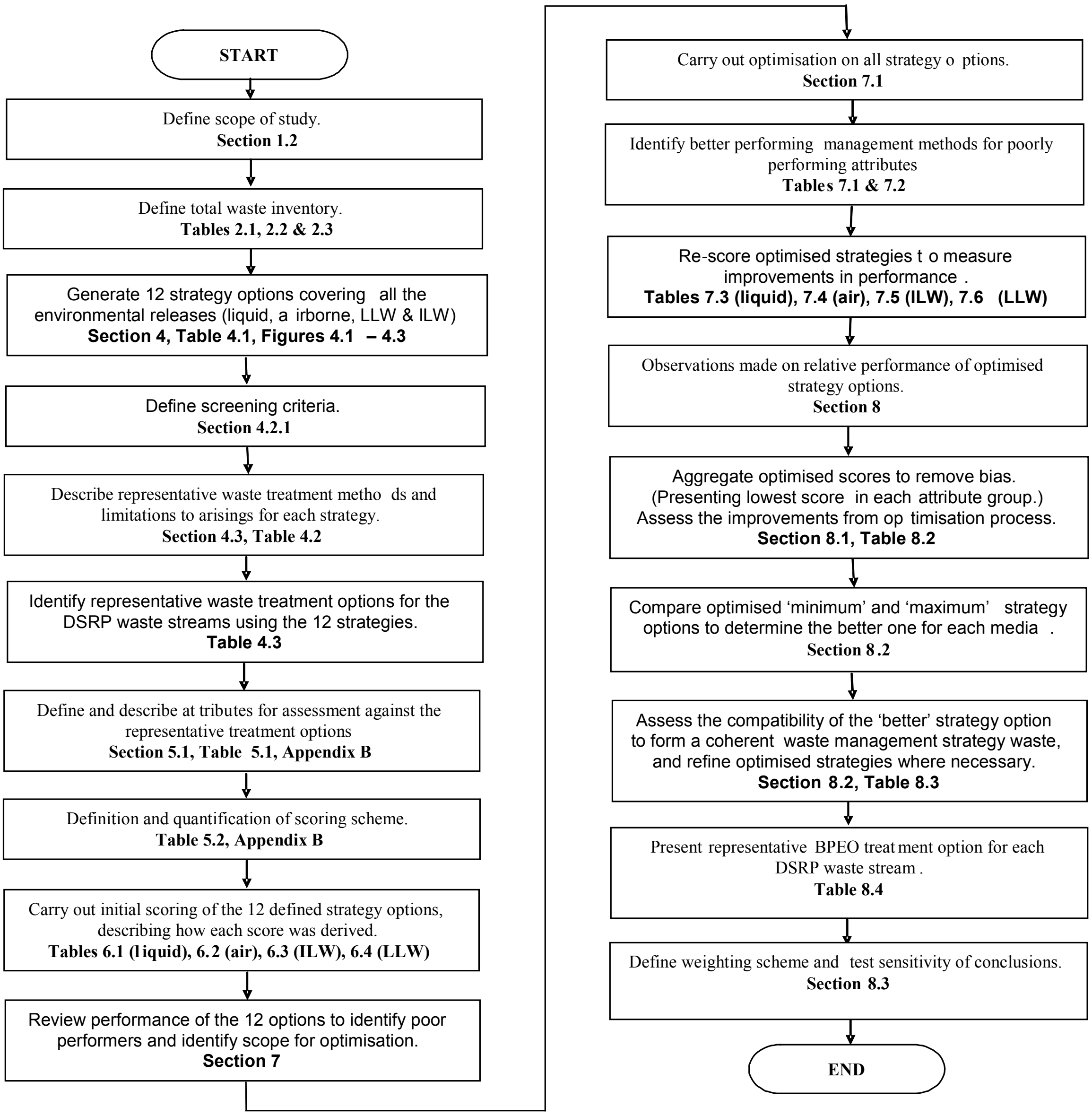
For more than 40 years, the United Kingdom Atomic Energy Authority (UKAEA) has undertaken research into nuclear energy production at its site at Dounreay in northern Scotland. This research programme has now ended and the site is being decommissioned in accordance with the Dounreay Site Restoration Plan (DSRP) which sets out a programme of decommissioning, clean-up and waste management for the site which is expected to last some 50 to 60 years. The overall objective of the DSRP is to make the site available for alternative use or to achieve a permanently safe condition that requires minimal institutional care. This will be done in a way that progressively minimises the hazards on the site, within an overall framework that ensures the safety of workers and the public, and protects the environment.

The implementation of the DSRP will require the management of a large number of solid, liquid and gaseous radioactive and non-radioactive waste streams with a broad range of physical, chemical and radiological characteristics. The DSRP approach is to deal first with those radioactive waste streams that present major hazards. Some of these waste streams are ‘legacy’ wastes, meaning they are left over from routine operations previously performed on the site over the last few decades, but the majority of the waste streams will be ‘decommissioning’ wastes, meaning they will be generated during site restoration (e.g. from the demolition of radiologically contaminated buildings).

This report sets out a Best Practicable Environmental Options (BPEO) assessment which had the objective of aiding in the development of a coherent strategy for managing the many different radioactive waste streams that will arise during the restoration of the Dounreay site and its surroundings, that is environmentally sound, safe, technically viable and provides value for money to the UK taxpayer. A route map of the BPEO assessment is shown overleaf, with references to the appropriate sections, tables and figures within the main text. This study does not address the issue of how the Dounreay site is to be decommissioned and is, therefore, set within the framework and timescales defined in the DSRP.

To make the BPEO manageable, the 268 radioactive waste streams identified in the Dounreay Radioactive Waste Inventory (DRWI) were rationalised to group together waste streams with similar physical, chemical and radiological characteristics. In addition, information from other sources has been used to define certain liquid and gaseous waste streams not included in DRWI that are of interest to the study. In all, 36 separate radioactive waste streams were identified for this study that represent, collectively, all of the different radioactive wastes that either exist today or are expected to arise at Dounreay in the future, during the course of the DSRP.

***Flowchart of BPEO methodology applied in this project, with references to relevant sections of text, tables and figures.***



A BPEO is a formalised system for evaluating issues that may have environmental implications and for determining appropriate options to address those issues. A BPEO usually involves the key stages of:

- generating a comprehensive list of possible options that potentially could be implemented to address the waste management issue at hand;
- rejecting ('screening') those options that clearly are neither technically feasible nor legal (e.g. they contravene national or international law), whilst those that would require extensive development are retained but are scored low when the maturity of the technology is addressed[2];
- evaluating ('scoring') the remaining options against a set of attributes that relate to the key safety, technological, environmental, socio-economic and financial characteristics that are thought to be important for making the decision and which can be used to discriminate between the different options; and
- on this basis identifying the 'best' option.

This BPEO study was performed in a series of workshops by a team of experts that included representatives from the Safety and Environment; Decommissioning; Waste Management; and Corporate Safety, Health and Environmental Groups and the Planning, Performance and Engineering Division of UKAEA, and consultants from BNFL, Entec, Enviros Consulting and NNC. The conclusions reached at the workshops, and the reasons for them, were reported by Enviros Consulting and NNC and reviewed by the rest of the Project Team.

In this study, the major environmental issues in radioactive waste management for the Dounreay site were taken to be:

- the level of liquid radioactive discharges to the environment;
- the level of airborne radioactive discharges to the atmosphere;
- the quantities of solid intermediate-level radioactive waste (ILW) requiring long-term management[3]; and
- the quantities of solid low-level radioactive waste (LLW) requiring long-term management.

[2] The use of screening was limited in this BPEO because the options considered were 'strategies' comprised of a number of different treatment methods for the various waste streams, rather than individual processes. It was considered preferable to carry these through to scoring to demonstrate precisely why certain options would be unacceptable.

[3] For the sake of conciseness, included in this category are the high active liquors (HALs) which, if they were to be immobilised, may be classed as either solid ILW or solid high level waste (HLW) depending on the immobilisation method used and the waste classification scheme applied.

Three broad strategy options have been defined for each issue, so as to cover the full spectrum of possibilities and all the relevant trade-offs. These are:

- strategies that generate minimum discharges and solid waste volumes;
- strategies that generate maximum discharges and solid waste volumes; and
- strategies that fall between these end-points (i.e. strategies that generate intermediate discharges and solid waste volumes).

The maximum and minimum strategy options reflect the likely extremes that are achievable using available technology or technology that may become available in the next two decades or so. Many possible intermediate strategies exist between these two extremes and, therefore, a single ***representative*** intermediate option was identified for each issue, for the purposes of illustration. Thus, in total, the following 12 strategy options were defined.

| **Strategy Option Number and Name** | | **Key Features of Strategy Option** |
|---|---|---|
| $Liq_{Min}$ | Minimum Liquid Discharges | Effluent arisings minimised by choice of process (including recycling), maximum treatment of effluents prior to discharge to sea.<br>Thus, in this strategy, only dry abatement techniques are used for gaseous discharges and dry decontamination techniques are used for solid waste. All low level liquid arisings are evaporated and all other liquid arisings are processed to form solid waste. |
| $Liq_{Max}$ | Maximum Liquid Discharges | No steps taken to minimise arisings, minimum treatment prior to discharge to sea.<br>In this strategy, wet scrubbing is used to abate gaseous discharges, wet decontamination techniques are used on solid waste and all of the liquid arisings are discharged directly to sea without any processing. |
| $Liq_{Inter}$ | Intermediate Liquid Discharges | Some minimisation of arisings, intermediate treatment prior to discharge to sea. |
| $Atm_{Min}$ | Minimum Atmospheric Discharges | Effluent arisings minimised by choice of process, maximum treatment of effluents prior to discharge to air.<br>In this strategy, processes that generate significant quantities of airborne activity, such as vitrification, dry decontamination and high pressure water jetting are excluded, and the currently available techniques that are most effective in removing each type of radionuclide from gaseous discharges are included. |
| $Atm_{Max}$ | Maximum Atmospheric Discharges | No steps taken to minimise arisings, minimum treatment prior to discharge to air.<br>In this strategy, there is no restriction on processes that generate significant quantities of airborne activity and there is no removal of activity from gaseous discharges. |
| $Atm_{Inter}$ | Intermediate Atmospheric Discharges | Some minimisation of arisings, intermediate treatment prior to discharge to air. |

| Strategy Option Number and Name | | Key Features of Strategy Option |
|---|---|---|
| $ILW_{Min}$ | Minimum Quantities of Solid ILW | Arisings of primary and secondary wastes minimised, treatment/conditioning methods chosen to minimise waste volumes.<br>In this strategy, all abatement techniques of liquid and gaseous waste that generate ILW are excluded and all practical segregation of ILW from other wastes and all practical decontamination and volume reduction of ILW is carried out. |
| $ILW_{Max}$ | Maximum Quantities of Solid ILW | No particular steps taken to minimise arisings of primary or secondary wastes, treatment/conditioning methods chosen with no particular reference to reducing waste volumes.<br>In this strategy, all abatement techniques of liquid and gaseous waste that generate ILW are included and there is no segregation of ILW from other wastes and no or volume reduction of ILW is carried out. |
| $ILW_{Inter}$ | Intermediate Quantities of Solid ILW | Some steps taken to minimise arisings, some account taken of waste volumes in choosing treatment/conditioning methods. |
| $LLW_{Min}$ | Minimum Quantities of Solid LLW | Arisings of primary and secondary wastes minimised, treatment/conditioning methods chosen to minimise waste volumes.<br>In this strategy, all abatement techniques of liquid and gaseous waste that generate LLW are excluded, there is no decontamination of ILW, the LLW in the existing disposal pits is left in situ and all practical segregation of LLW from inactive wastes and all practical decontamination and volume reduction of LLW is carried out. |
| $LLW_{Max}$ | Maximum Quantities of Solid LLW | No particular steps taken to minimise arisings of primary or secondary wastes, treatment/conditioning methods chosen with no particular reference to waste volumes.<br>In this strategy, all abatement techniques of liquid and gaseous waste that generate LLW are included, ILW is decontaminated to form LLW as far as practical, the remaining ILW is diluted and packaged as LLW where possible, the LLW in the existing disposal pits is removed and treated and segregation, decontamination and volume reduction of LLW is carried out. |
| $LLW_{Inter}$ | Intermediate Quantities of Solid LLW | Some steps taken to minimise arisings, some account taken of waste volumes in choosing treatment/conditioning methods. |

From the above, it will be seen that the 12 basic strategy options were defined in terms of a ***representative*** management method for each of the 36 separate waste streams. These representative management methods were chosen from the likely alternative technologies and operational procedures that could practicably be applied to each waste stream, and were intended to be consistent with the overall objectives of each strategy option. Thus, for example, in $Liq_{Min}$, all the low level liquid waste is evaporated in a central evaporator before discharge regardless of its activity and the medium active liquors (MALs) are cemented directly with no discharge to the sea, as opposed the passing them through an ion exchange plant and discharging the treated liquor. In the case of $Liq_{Max}$, all liquid arisings, including the high active liquors (HALs), are discharged to sea. These representative management methods are not intended to be prescriptive but rather to indicate the likely general approach to waste management that could be adopted in each strategy option. Thus, the evaluation of each of the 12 strategies indicated the extent to which the basic strategy would represent the BPEO and, for which waste streams, it is unacceptable.

Having defined the 12 strategy options, these were then evaluated and scored against 32 sub-attributes that were organised into the following 6 attribute groups, using a set of pre-determined calibration schemes for the scoring:

- Group 1 Health and safety
- Group 2 Environmental impacts
- Group 3 Technical performance
- Group 4 Socio-economic considerations
- Group 5 Environmental objectives
- Group 6 Financial cost

The evaluation and scoring exercise illustrated a number of limitations in the environmental and technical performance of some of the strategy options that arose because of specific representative management methods chosen for the treatment of some individual waste streams. For example:

- the direct discharge to sea of the HALs and MALs results in doses to members of the public that would be above the statutory limit, an unacceptable reduction in seawater quality and violates the Government commitment in the OSPAR Convention to progressively reduce discharges into the sea;
- the lack of any abatement of gaseous discharges leads to an intolerable risk to members of the public and an unacceptable reduction in air quality following;
- the lack of control on the volumes of solid ILW and LLW generated (in particularly the creation of large volumes of LLW by dilution of ILW) violates the principle of minimising waste volumes and result in very high costs for storage and disposal.

Using the information from the evaluation and scoring exercise, the maximum and minimum strategy options were then optimised by identifying better performing representative management methods for those cases where poor performance was identified. This created 8 new ‘optimised’ strategy options for liquid and airborne discharges, and solid ILW and LLW volumes. The original intermediate strategy options were not optimised because the eight new strategies are themselves intermediate strategies and to optimise the original intermediate strategies would not reveal the extent to which minimising or maximising discharges or waste volumes is the BPEO.

Thus, an optimised strategy, $Liq_{MinOpt}$, was developed from $Liq_{Min}$, by replacing the central evaporation of all low level liquid waste (because of the associated very large energy consumption and cost) with local treatment by smaller evaporators or ion exchange plants. $Liq_{MinOpt}$ retains liquid decontamination of solid wastes, where this is the only practical way of reducing their volume, and the low discharge approach for the other waste streams. Likewise, an optimising strategy, $Liq_{MaxOpt}$, was developed from $Liq_{Max}$, by replacing direct discharge to sea of HALs, MALs and some other liquid waste streams (because of the associated very high doses to the public) with cementation so that the resulting doses were below the constraint of 300 μSv $yr^{-1}$. $Liq_{MaxOpt}$ retains the minimum processing option and direct discharge for the waste streams with very small amounts of activity.

Similarly, optimised strategies were developed for $Atm_{Min}$ and $Atm_{Max}$, $ILW_{Min}$ and $ILW_{Max}$, and $LLW_{Min}$ and $ILW_{Max}$.

The resulting 8 optimised strategy options were then re-scored to measure the improvement in performance that accrued through optimisation. The average and lowest scores for the attribute groups awarded to the optimised strategy options are indicated in the following table, together with their respective totals.

| | **Liq Min Opt** | **Liq Max Opt** | **Atm Min Opt** | **Atm Max Opt** | **ILW Min Opt** | **ILW Max Opt** | **LLW Min Opt** | **LLW Max Opt** |
|---|---|---|---|---|---|---|---|---|
| *Average scores:* | | | | | | | | |
| Group 1: Human health | 3.9 | 3.6 | 4.0 | 3.6 | 3.3 | 4.1 | 3.4 | 3.6 |
| Group 2: Environmental impact | 4.5 | 4.3 | 4.4 | 4.3 | 4.4 | 4.6 | 4.1 | 4.5 |
| Group 3: Technical issues | 4.8 | 4.5 | 4.5 | 4.0 | 4.5 | 4.8 | 4.5 | 4.5 |
| Group 4: Socio-economic issues | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Group 5: Environmental objectives | 4.2 | 4.2 | 4.4 | 3.4 | 4.2 | 4.4 | 4.2 | 4.4 |
| Group 6: Cost | 2.0 | 5.0 | 5.0 | 3.0 | 3.0 | 3.0 | 5.0 | 2.0 |
| ***Total*** | ***22.4*** | ***24.6*** | ***25.3*** | ***21.3*** | ***22.4*** | ***23.9*** | ***24.2*** | ***22.0*** |
| *Lowest scores:* | | | | | | | | |
| Group 1: Human health | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Group 2: Environmental impact | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 |
| Group 3: Technical issues | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| Group 4: Socio-economic issues | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Group 5: Environmental objectives | 2 | 3 | 3 | 3 | 4 | 3 | 4 | 3 |
| Group 6: Cost | 2 | 5 | 5 | 3 | 3 | 3 | 5 | 2 |
| ***Total*** | ***17*** | ***21*** | ***21*** | ***18*** | ***20*** | ***20*** | ***22*** | ***18*** |

It can be seen that the scores for all 8 optimised strategy options are broadly similar but there are some important differences.

From the point of view of determining which optimised strategy options perform best, it was considered that the lowest scores for the attribute groups (the lower half of the table above) were the most appropriate to use. This is because using the lowest scores is a conservative approach that avoids masking any particularly poor performance against specific sub-attributes, which may otherwise occur through averaging.

Nonetheless, the BPEO was not chosen simply on the basis of the highest score. The scores were, instead, used to inform the decision making process by directing the evaluation to the comparative performance of all the optimised strategy options against the various attributes used. Thus, the 4 pairs of optimised strategies were compared and analysed to determine the optimised strategy options for liquid and airborne discharges, and the volumes of solid ILW and LLW waste that perform better.

In the case of $Liq_{MinOpt}$ and $Liq_{MaxOpt}$, which focus on liquid discharges, $Liq_{MinOpt}$ scores less well overall because, as shown in the table above, the direct cementing of waste streams with no dewatering, such as the MALs, and the lack of decontamination of ILW metals means that it only scores 2 against the 'Environmental objective' attribute group, which includes waste minimisation. The additional waste created also means that it scores less well on the 'Cost' attribute group. Thus, of these two, $Liq_{MaxOpt}$ is the preferred option. This preference is consistent with the average scores in the above table.

In the case of $Atm_{MinOpt}$ and $Atm_{MaxOpt}$, which focus on atmospheric discharges, $Atm_{MaxOpt}$ scores less well against the attribute groups 'Technical issues' and 'Cost'. This is because this strategy includes the vitrification of the HALs and ADU floc which results in a score of 3 against for the 'Technical issues' attribute group because vitrification is both less flexible and more expensive than cementation. If these waste streams were cemented instead of vitrified, the score for $Atm_{MaxOpt}$ against 'Technical issues' would rise from 3 to 4 and the score for the 'Cost' would rise from 3 to 5 giving the scores in the table below (for $Atm_{MaxOpt}$*).

| | Liq Min Opt | Liq Max Opt | Atm Min Opt | Atm Max Opt* | ILW Min Opt* | ILW Max Opt | LLW Min Opt | LLW Max Opt |
|---|---|---|---|---|---|---|---|---|
| *Average scores:* | | | | | | | | |
| Group 1: Human health | 3.9 | 3.6 | 4.0 | 3.6 | 3.3 | 4.0 | 3.4 | 3.6 |
| Group 2: Environmental impact | 4.5 | 4.3 | 4.4 | 4.3 | 4.4 | 4.6 | 4.1 | 4.5 |
| Group 3: Technical issues | 4.8 | 4.5 | 4.5 | 4.5 | 4.5 | 4.8 | 4.5 | 4.5 |
| Group 4: Socio-economic issues | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Group 5: Environmental objectives | 4.2 | 4.2 | 4.4 | 3.4 | 4.2 | 4.4 | 4.2 | 4.4 |
| Group 6: Cost | 2.0 | 5.0 | 5.0 | 5.0 | 5.0 | 3.0 | 5.0 | 2.0 |
| ***Total*** | ***22.4*** | ***24.6*** | ***25.3*** | ***23.6*** | ***24.4*** | ***23.8*** | ***24.2*** | ***22.0*** |
| *Lowest scores:* | | | | | | | | |
| Group 1: Human health | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Group 2: Environmental impact | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 |
| Group 3: Technical issues | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

| | Liq Min Opt | Liq Max Opt | Atm Min Opt | Atm Max Opt* | ILW Min Opt* | ILW Max Opt | LLW Min Opt | LLW Max Opt |
|---|---|---|---|---|---|---|---|---|
| Group 4: Socio-economic issues | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Group 5: Environmental objectives | 2 | 3 | 3 | 3 | 4 | 3 | 4 | 3 |
| Group 6: Cost | 2 | 5 | 5 | 5 | 5 | 3 | 5 | 2 |
| ***Total*** | ***17*** | ***21*** | ***21*** | ***21*** | ***22*** | ***20*** | ***22*** | ***18*** |

In this case, the lowest scores can not distinguish between the options of $Atm_{MinOpt}$ and $Atm_{MaxOpt}$*. Looking at the average scores, however, $Atm_{MinOpt}$ scores better because the scores reflect the reduced discharges associated with the abatement of tritium, Carbon-14 and Iodine-129. This is achieved, however, at a high cost relative to the small reduction in the individual or societal doses that are achieved and, thus, in the opinion of the Project Team, $Atm_{MaxOpt}$* is the preferred option. This conclusion is supported by the BPEO studies that have been carried out by BNFL for their gaseous discharges from Sellafield.

In the case of $ILW_{MinOpt}$ and $ILW_{MaxOpt}$, which focus on the volumes of solid ILW, $ILW_{MinOpt}$ scores the lower against 'Environmental impact' because it does not abate aerial discharges of tritium or Iodine-129; the higher against 'Environmental objectives' because it minimises the volume of solid ILW that is produced; and the lower against 'Cost' because it includes the higher cost of vitrifying the HALs, compared to the cementation options that is assumed in $ILW_{MaxOpt}$. If the vitrification of the HALs in $ILW_{MinOpt}$ is replaced by cementation, then the score for 'Cost' would rise from 3 to 5, giving the scores in the table above (for $ILW_{MinOpt}$*). In view of the desirability of minimising solid waste arisings, with its associated cost savings, and the grossly disproportionate costs of abating aerial discharges of tritium or Iodine-129, $ILW_{MinOpt}$* which includes cementation of the HALs is the preferred strategy option. This conclusion is consistent with the averaged scores above.

In the case of $LLW_{MinOpt}$ and $LLW_{MaxOpt}$, which focus on the volumes of solid LLW, $LLW_{MinOpt}$ scores the highest. The largest differences in the attribute group scores are for 'Cost' in which $LLW_{MinOpt}$ scores higher because this option benefits from the anticipated cost savings associated with the free release of some contaminated metals, the reuse of some contaminated concrete and building materials, leaving the pit waste in-situ and encapsulating contaminated soils in-situ. As there is no difference in the scores for the environmental attributes, $LLW_{MinOpt}$ is the preferred strategy option because it provides the same level of protection of the environment for no additional cost. This conclusion is supported by the averaged scores above.

It was, therefore, concluded that the preferred optimised strategy options were:

- $Liq_{MaxOpt}$ for liquid discharges;

- $Atm_{MaxOpt}$*, which includes cementation of the HALs and the ADU floc, for airborne discharges;
- $ILW_{MinOpt}$*, which includes cementation of the HALs, for solid ILW volumes; and
- $LLW_{MinOpt}$ for solid LLW volumes.

These preferred optimised strategy options were then amalgamated to form a single coherent waste management strategy on the basis of their discharges and solid waste volumes that is considered to be the BPEO for the DSRP wastes. This was achieved by combining the representative treatment methods for liquid wastes from $Liq_{MaxOpt}$, with the representative treatment methods for airborne wastes from $Atm_{MaxOpt}$*, the representative treatment methods for solid ILW from $ILW_{MinOpt}$* and the representative treatment methods for solid LLW from $LLW_{MinOpt}$. This identified BPEO thus includes the key elements of the four preferred strategy options, so that it:

- does not require the abatement of liquid and airborne discharges using disproportionately expensive novel technologies to capture hard-to-scrub species such as tritium, Krypton-85 and Iodine-129;
- minimises the volumes of solid ILW and LLW, wherever practicable, by decontaminating, compacting, incinerating or segregating the majority of solid waste materials; and
- does not cause serious detriment to human health and the wider environment.

This representative treatment methods identified for each of the waste streams implied by this BPEO are defined in the following table.

| **Waste** | | **Representative treatment method** |
|---|---|---|
| **No.** | **Description** | |
| Airborne Wastes ($Atm_{MaxOpt}$*): | | |
| A1 | Particulates from active process and building ventilation | Current practice for the treatment of particulates from the ventilation of active processes and buildings, which is based on the use of HEPAs, where appropriate. |
| A2 | Particulates from treating contaminated ground | Where contaminated ground is remediated, allowing the direct release to the atmosphere of particulates from soils etc. This means no deliberate measures are taken to capture dust from treating contaminated ground, except for more active areas e.g. active drains. |
| A3 | H-3 | Allowing direct discharge of tritium. There are minimal health and safety implications, and environmental consequences from direct discharge and it would involve a grossly disproportionate cost to treat. This decision is supported by BNFL's gaseous waste stream BPEO studies. |

| Waste No. | Description | Representative treatment method |
|---|---|---|
| A4 | C-14 | Allowing direct discharge of C-14. There are minimal health and safety implications, and environmental consequences from direct discharge and it would involve a grossly disproportionate cost to treat. This decision is supported by BNFL's gaseous waste stream BPEO studies. |
| A5 | Kr-85 | Allowing direct discharge of Kr-85. There are minimal health and safety implications, and environmental consequences from direct discharge and it would involve a grossly disproportionate cost to treat. Future arisings are expected to be small because of the limited fuel material processing which is planned. This decision is supported by BNFL's gaseous waste stream BPEO studies. |
| A6 | Iodines | Allowing direct discharge of iodines. There are minimal health and safety implications, and environmental consequences from direct discharge and it would involve a grossly disproportionate cost to treat. This decision is supported by BNFL's gaseous waste stream BPEO studies. Future arisings are expected to be small because of the limited fuel material processing which is planned. This decision may need to be revised if there are future plans to vitrify the PFR raffinate because this would lead to enhanced iodine release. |
| Liquid Wastes ($Liq_{MaxOpt}$): | | |
| L1 | Low level liquid | Allowing direct discharge of low-level liquids. There are minimal health and safety implications, and environmental consequences from direct discharge via the LLLETP (which has the primary role of controlling the pH of the discharged liquids). In order to ensure that this would still be consistent with the environmental objective of progressively reducing discharges and achieving 'near to zero' by 2020 as required by the OSPAR Convention. BPM studies for individual waste streams will be performed. |
| L2 | MALs | |
| L2.1 | MALs from decommissioning | Cement decommissioning MALs. Their activity is too high for direct discharge and cementation was considered the most appropriate immobilisation method evaluated in this study. The MALs may require some appropriate treatment before cementation and this should be addressed in a BPM study. |
| L2.2 | Legacy MALs | Cement legacy MALs from the PFR and plant washing tank. Their activity is too high for direct discharge and cementation was considered the most appropriate immobilisation method evaluated in this study. The MALs may require some appropriate treatment before cementation and this should be addressed in a BPM study. |
| L3 | DFR raffinate | Cement DFR raffinate. Their activity is too high for direct discharge and cementation was considered the most appropriate immobilisation method evaluated in this study. The raffinate may require some appropriate treatment before cementation and this should be addressed in a BPM study. |

| Waste No. | Description | Representative treatment method |
|---|---|---|
| L4 | PFR raffinate | Cement PFR raffinate. Their activity is too high for direct discharge, and cementation was considered the most appropriate immobilisation method evaluated in this study, particularly in relation to the comparative cost of vitrification. It is recognised that there is an ongoing study to evaluate options for the management of PFR raffinate in greater detail. Note: this study has now confirmed the cementation option. |
| L5 | Solvents and oils | Either direct solidification of the solvents and oils, or incineration with cementation of any solid waste. In either case, the activity will be contained in a cement matrix. Their activity is too high for direct discharge and there would be significant non-radiological environmental consequences from their release to the marine environment. The incineration of washed solvent with scrubbing of the off-gas was the preferred option of a separate BPEO study for solvent disposal at Dounreay. |
| L6 | Flocs and sludges | |
| L6.1 | Ammonium diuranate | Cement the floc and direct discharge of the supernate. The activity of the floc is too high for direct discharge and cementation was considered the most appropriate immobilisation method evaluated in this study. There are minimal health and safety implications, and environmental consequences from the direct discharge of the supernate, which has an activity level equivalent to low level liquid. It is recognised that there is an ongoing study to evaluate options for the management of ADU floc in greater detail. |
| L6.2 | LLLETP sludge | Dissolve and direct discharge of the LLLETP sludge. This treatment was not optimised in this study because the likely health and safety, environmental and cost implications were below the threshold levels adopted in optimisation. It would, however, be common sense to minimise all arisings and treat in a similar manner to other sludges. This would be consistent with the environmental objective of progressively reducing discharges and achieving ‘near to zero’ by 2020 as required by the OSPAR Convention |
| L6.3 | Shaft and Silo sludge | Cement both Shaft and Silo sludges. Their activity is too high for direct discharge and their physical characteristics are inappropriate (e.g. contains insoluble solid components). Cementation was considered the most appropriate immobilisation method evaluated in this study. The sludges may require some appropriate treatment before cementation and this should be addressed in a BPM study. |
| L6.4 | Fuel storage pond sludges | Cement fuel storage pond sludges. Their activity is too high for direct discharge and their physical characteristics are inappropriate (e.g. contains insoluble solid components). Cementation was considered the most appropriate immobilisation method evaluated in this study. The sludges may require some appropriate treatment before cementation and this should be addressed in a BPM study. |
| Solid LLW Wastes ($LLW_{MinOpt}$): | | |

| Waste No. | Description | Representative treatment method |
|---|---|---|
| S1 | LLW | |
| S1.1 | General metals | Segregate and decontaminate LLW metals to achieve free release in so far as practicable. Otherwise grout and package. |
| S1.2 | Tritiated metals (note secondary circuit only) | Smelt tritiated metals to achieve free release creates lowest volume of LLW for storage or disposal from this waste stream. This treatment was not optimised in this study because the likely health and safety, environmental and cost implications were below the threshold levels adopted in optimisation. No consideration was made of the volume of metal which may require treatment. Smelting may not prove cost effective if only small volumes require treatment. A waste stream specific BPEO/BPM study is recommended to address this issue. |
| S1.3 | Concrete and building materials | Segregate and decontaminate LLW concrete and building materials to achieve free release in so far as practicable. Otherwise grout and package. |
| S1.4 | Cellulosic materials | Incinerate LLW cellulosic materials followed by cementation of the ash creates lowest volume of LLW for storage or disposal from this waste stream. This treatment was not optimised in this study because the likely health and safety, environmental and cost implications were below the threshold levels adopted in optimisation. Incineration may not prove cost effective if only small volumes require treatment. A waste stream specific BPEO/BPM study is recommended to address this issue. |
| S1.5 | Non-cellulosic compactables | Segregate and decontaminate non-cellulosic, compactable materials to achieve free release in so far as practicable. Otherwise grout and package. |
| S1.6 | Pits wastes | Do not empty the Pits to retrieve wastes creates lowest volume of LLW for storage or disposal from this waste stream. There are minimal health and safety implications, and environmental consequences from not retrieving, and it would involve a high cost to do so. This cost and the dose to the workers were identified as key issues in the BPEO for LLW at Dounreay, which was supported by assessments that indicate that even if coastal erosion breached the facility, there would be an insignificant radiological risk to the public at this time. However, the loss of control of the waste was seen as contrary to the environmental objective of contain and control. |
| S1.7 | Bulk non-compactables, non-combustible | Segregate and decontaminate bulk non-compactable, non-combustible materials to achieve free release in so far as practicable. Otherwise grout and package. |

| Waste No. | Description | Representative treatment method |
|---|---|---|
| S1.8 | Soils | Leave contaminated soils in-situ and do not treat, except for more active areas e.g. active drains. This creates lowest volume of LLW for storage or disposal from this waste stream. There are minimal health and safety implications, and environmental consequences from not treating soils. To be addressed further in site end-points study which is underway. |
| Solid ILW Wastes ($ILW_{MinOpt}$*): | | |
| S2 | CHILW, inc. PCM | Segregate and decontaminate CHILW materials to LLW classification in so far as practicable. Otherwise supercompact, grout and package. |
| S3 | Shaft and silo RHILW | Segregate and decontaminate Shaft and Silo RHILW materials to LLW classification in so far as practicable. Otherwise supercompact, grout and package. |
| S4 | RHILW in Stores | Segregate and decontaminate RHILW materials in stores to LLW classification in so far as practicable. Otherwise supercompact, grout and package. |
| S5 | Boron carbide | Release tritium by washing or dissolving the boron carbide and direct discharge of the washing liquid. This creates lowest volume of ILW for storage or disposal from this waste stream. This treatment was not optimised in this study because the likely health and safety, environmental and cost implications were below the threshold levels adopted in optimisation. Alternatives are to treat as other ILW or decay store to achieve LLW classification. A waste stream specific BPEO/BPM study is recommended to address this issue. |
| S6 | Decommissioning ILW | |
| S6.1 | Metals (including those with surface contamination) | Segregate and decontaminate ILW metals materials to LLW classification in so far as practicable, which will not be possible for activated steels. Otherwise cut, package and grout. |
| S6.2 | Graphite | Incinerate graphite followed by cementation of the ash creates lowest volume of ILW for storage or disposal from this waste stream. This treatment was not optimised in this study because the likely health and safety, environmental and cost implications were below the threshold levels adopted in optimisation. Incineration may not prove cost effective if only small volumes require treatment. A waste stream specific BPEO/BPM study is recommended to address this issue. |
| S6.3 | Concrete and rock | Segregate and decontaminate concrete and rock to LLW classification in so far as practicable. Otherwise grout and package. |

The radioactive waste management strategy defined above is not intended to prescribe in detail how each waste stream should be treated on site at Dounreay. Rather it suggests ***representative*** approaches to treating individual waste streams that are consistent with an overall strategy to site waste management that balances gaseous and liquid discharges, with the generation of solid waste volumes. Therefore, when deciding how an individual waste stream is to be treated, a different treatment method may be chosen to the representative treatment identified but it should, ideally, have similar (or better) consequences for liquid and gaseous discharges, and solid waste volumes, to those of the representative treatment method.

UKAEA Dounreay have produced waste strategy documents that have utilised the output from this study.

A sensitivity study was performed to examine the robustness of the above conclusion to the importance that is attached to each group of attributes, using a weighting scheme developed by the Project Team, but the application of weightings did not change the overall conclusions. It is thus concluded that the BPEO described in the above table is robust at a strategic level for the development of a coherent waste management strategy for the DSRP wastes. Nonetheless, it is recognised that a number of waste stream specific BPEO or BPM studies are required to address issues at a more detailed level than was possible in this assessment.

There has been no public consultation or public involvement in the course of this study and therefore, the conclusions are, at this stage, those of the Project Team as endorsed by UKAEA.  UKAEA recognise and support the views on BPEO consultation expressed in the 12th report of the Royal Commission on Environmental Pollution, and public views on the management of DSRP radioactive wastes are being sought as part of UKAEA’s, DSRP public participation strategy.

# 1 Introduction

## 1.1 Background

Since 1958, the United Kingdom Atomic Energy Authority (UKAEA) has operated three experimental test reactors at its site at Dounreay in northern Scotland, as an integral part of the UK's research programme into fast breeder reactor development. In 2000, UKAEA published the Dounreay Site Restoration Plan (DSRP) which sets out a programme of decommissioning[4], clean-up and waste management for the site [UKAEA, 2000]. The overall objective of the DSRP is to make the site available for alternative use or to achieve a permanently safe condition that requires minimal institutional care. This is to be done in a way that progressively minimises the hazards on the site, within an overall framework that ensures the safety of workers and the public, and protects the environment.

The DSRP sets out the steps designed to decommission the site in some 50 to 60 years. Whilst it represents current understanding of the issues to be addressed it is intended to be a living document which will be reviewed and developed in the light of experience. Although the DSRP covers a timescale of 50 to 60 years it is expected that all major radiological hazards will have been removed within the first 25 to 30 years. By then all fuels should have been either processed or conditioned for storage and intermediate and high level wastes packaged in a form suitable for long-term storage and/or ultimate disposal in a national repository.

The DSRP is consistent with UKAEA's overall decommissioning and radioactive waste management policy which accords with Government policy as set out in Cm 2919 'Review of Radioactive Waste Policy' [Secretary of State for the Environment, 1995]. It is to:

- restore UKAEA sites so that they may be made available for unrestricted alternative use or to a permanently safe condition that requires minimal institutional care;
- carry out Stage 1 decommissioning as soon as and as far as reasonably practicable following closure of a facility;
- schedule further decommissioning work to reduce the hazards presented by the facility in a progressive and systematic way taking account of:

[4] Decommissioning is the set of actions taken at the end of a nuclear facility's operational life to take it permanently out of service. The ultimate aim of decommissioning is to make the site available for other purposes. It includes actions to systematically and progressively reduce the level of hazard on a site and it may include the physical dismantling of the facilities. It is not necessarily a single step process and may involve stages spread over a number of years [HSE, 2001a].

  - the potential hazards posed to the public, workers and the environment,
  - the availability of waste routes and of experienced personnel, the time required to plan the work and if necessary develop decommissioning techniques and equipment, and time dependent safety and environmental risks (e.g. recognising the benefits or otherwise from radioactive decay);
  - the financial implications of proceeding on different timescales, subject to safety and environmental considerations, taking account of changes in the real value over time of costs and benefits, time dependent financial risks, the impact on support and infrastructure costs and the time value of money which is currently reflected in a 6% real discount rate (defined by HM Treasury).
- ensure that wastes are not created unnecessarily and are characterised and segregated at source, subject to consideration of cost and dose to workers;
- make proper use of available authorised waste disposal routes;
- provide adequate storage capacity of an appropriate standard for existing and expected arisings of wastes for which there is currently no disposal route;
- condition and package radioactive wastes in compliance with agreed national standards and on timescales consistent with safety, environmental, dose uptake and value for money considerations; and
- retain knowledge and records of redundant radioactive facilities and wastes.

Implementation of the DSRP will require the management of a large number of solid, liquid and gaseous waste streams with a broad range of physical, chemical and radiological characteristics. The DSRP approach is to deal first with those waste streams that present major hazards. Some of these waste streams are ‘operational’ wastes that are currently arising mainly from care and maintenance operations prior to decommissioning. Other waste streams are ‘legacy’ wastes, meaning they are left over from routine operations previously performed on the site over the last few decades. The majority of the waste streams by volume will, however, be ‘decommissioning’ wastes, meaning they will be generated during the site restoration programme (e.g. from the demolition of radiologically contaminated buildings).

It is a requirement of UKAEA’s Radioactive Substances Act (RSA) Certificate of Authorisation for the disposal of radioactive waste at the Dounreay site that decisions on waste management are supported by a Best Practicable Environmental Option (BPEO) study to be submitted to the Scottish Environment Protection Agency (SEPA).

A BPEO is a formalised system for evaluating issues that may have environmental implications and for determining appropriate options to address those issues (see

Section 3 and Appendix A). To date, this requirement has been fulfilled by conducting individual BPEO studies for specific plants and processes with implications for radioactive discharges and solid waste generation. SEPA now require a strategic BPEO study that addresses the combined management of all the wastes that will have to be dealt with over the lifetime of the DSRP. In addition, this report forms part of UKAEA's programme to develop a coherent strategy for managing the many different DSRP waste streams, that is safe, environmentally sound, technically viable and provides value for money to the UK taxpayer.

Although the DSRP sets out the overall approach to decommissioning the Dounreay site and addresses the basic elements of the radioactive waste management strategy, this strategy will need to be developed further during the implementation of the DSRP, so as to meet the needs of UKAEA, the Department of Trade and Industry (DTI), SEPA and the Nuclear Installations Inspectorate (NII, which is a component of the Health and Safety Executive, HSE) [HSE, 2001a, HSE, 2001b]. The DSRP is a 'living document', in the sense that it will be reviewed regularly and revised if necessary. The radioactive waste management strategy will similarly be reviewed and revised if necessary.

## 1.2 Objectives and scope

The overall objective of this BPEO study is to provide a foundation for further development of an overall strategy for the management of the wastes to be dealt with during the restoration of the Dounreay site and its surroundings. It aims to do this by identifying the BPEO for a waste management strategy, where the BPEO is the strategy that *'provides the most benefit or least damage to the environment as a whole, at acceptable cost, in the long term as well as in the short term'* [RCEP,1988].

As indicated above, the '*DSRP wastes BPEO'* study reported in this document is intended to provide technical and environmental input to the development of a coherent DSRP waste management strategy. This study is intended to help to provide a clear framework within which proposals for managing particular wastes and for carrying out particular processes can be judged.

In addition, this study will help to identify those wastes and processes for which individual BPEO and Best Practicable Means (BPM) studies need to be carried out.

This study will also be used by UKAEA to support the new application for its RSA authorisations.

UKAEA has stated that the objectives of radioactive waste management during site restoration are:

- to ensure that wastes are not created unnecessarily; and
- to treat, condition, store and dispose of wastes that already exist, or that will be created, in ways that protect the public, workers and the environment, while achieving value for money for the UK tax payer.

The same objectives apply to any wastes associated with restoration of the environment around the Dounreay site. These objectives are consistent with current Government policy and regulatory guidance.

It is recognised that policy for managing solid radioactive wastes in the UK is under review and that the outcome will not be known for sometime [DEFRA, 2001]. It would not be appropriate for this BPEO study to prejudge what the outcome of this review may be. Accordingly, the study does not deal with the selection of long-term management methods for solid radioactive wastes (e.g. indefinite storage, geological disposal etc). The focus of the project is restricted to the steps that lead up to long-term waste management and that are within UKAEA's control.

In accordance with recommendations for best practice in BPEO studies, this study aims to identify and assess a wide range of strategy options [RCEP, 1988]. It is not limited to options that have already been considered by UKAEA to some extent, nor to options that have already been judged to be potentially acceptable to regulators, Government departments, UKAEA or other groups of stakeholders. In line with the overall objectives of the DSRP, it is UKAEA's intention to open this decision making process to public consultation.

# 2 Radioactive Wastes Considered in the Study

This study addresses most of the solid, liquid and airborne radioactive wastes that are expected to arise during the DSRP. These include radioactive materials whose treatment will give rise to wastes or that may themselves become wastes, and both primary and secondary wastes are included.

In the context of this report, the term ‘radioactive wastes’ has the same meaning as in the RSA. It means all wastes with activity concentrations above those in Schedule 1 of the RSA and includes those containing radionuclides above the ubiquitous background[5] unrelated to operations on the Dounreay site. Sources of radioactive wastes at Dounreay include:

- ***Operations:*** mainly care and maintenance operations prior to decommissioning, but also some operations to fulfil current commercial contracts; operational wastes are arising now and wastes from care and maintenance operations will continue to arise for several decades.
- ***Legacy wastes and materials:*** these are defined here to be wastes and materials that arose from previous operations on the Dounreay site. They include wastes that exist now but that require further treatment or conditioning, and materials that are yet to be treated. Treatment and conditioning of legacy wastes and materials may give rise to secondary wastes that have to be managed.
- ***Decommissioning:*** these include wastes generated from post-operational clean out (POCO) of active plants, dismantling of plants and buildings, remediation of contaminated land etc; most decommissioning wastes have yet to be generated.

For the purposes of this BPEO study, operational and legacy wastes are considered together, since they both relate to waste streams arising from operations at the site and, therefore, may sometimes be treated using the same management methods. The main difference between these two sources relates to the timing of their arisings. Where this difference may have implications for waste management operations, a distinction is drawn, but otherwise not.

These sources of activity, give rise to waste streams in solid, liquid and airborne forms:

- ***Solid wastes:*** the more active solid wastes and materials include what is currently termed ‘intermediate level waste’ (ILW). The less active solid wastes include those currently termed by UKAEA Dounreay ‘low level waste’ (LLW) and ‘very low level radioactive material’ (VLRM), and wastes that are less active than VLRM.

[5] This background includes global fallout from the nuclear weapons tests of the 1950s and 1960s, and activity from the Chernobyl accident.

- ***Liquid wastes:*** the more active liquid wastes and materials on the Dounreay site include so-called ‘high active liquors’ (HALs), ‘medium active liquors’ (MALs) and small amounts of dissolved fuel materials. The less active liquid wastes include low level liquid (LLL) effluents generated by various plants.
- ***Airborne wastes:*** these are gases and particulates, with various levels of activity that arise from ventilation of active buildings, process discharges and from other locations (e.g. contaminated land). Many of the gaseous species are currently included in solid and liquid materials (e.g. tritium in tritiated metals).

## 2.1 Wastes and Other Materials Excluded from the Study

This study does not re-examine management options for specific legacy wastes or materials that are already being treated or conditioned, such as Material Test Reactor (MTR) raffinate, or that are about to be treated or conditioned in plant that has been built or, is in construction, such as alkali metals from the PFR and DFR reactors.

This study also does not re-examine management options for the Dounreay fuel materials inventory for which a BPEO study [UKAEA 2001] has already been carried out. The management of these Dounreay fuel materials inventory will, however, give rise to secondary wastes and these are included in this study. Of particular note are the gaseous radionuclide Kr-85 and the iodines, both of which may arise from treatment of fuels by any process. Other secondary waste streams are likely be relatively minor in volume and activity, however, compared with the legacy wastes and decommissioning waste inventories that will arise from DSRP.

Similarly, the study does not address waste and other materials which will be returned to UKAEA customers, although the types of secondary wastes generated by processing of these materials are considered.

Options and strategies for managing non-radioactive wastes in general are also not included but the impacts of managing any non-radioactive wastes that will arise during the management of radioactive wastes are considered.

## 2.2 The Dounreay Radioactive Waste Inventory and the DSRP wastes

### 2.2.1 DSRP waste stream materials

UKAEA maintains the Dounreay Radioactive Waste Inventory (DRWI) which contains details of the majority of the legacy (including operational) and decommissioning waste streams that will arise during the DSRP. The DRWI is revised annually and the version used to support this study is the 2001 DRWI [Barton, 2001]. The DRWI records raw waste arisings for 268 separate waste streams, which cover most of the solid wastes and some of the liquid wastes that this study needs to address. The DRWI does not, however, explicitly record arisings of many of the gaseous wastes and a number of the liquid wastes, and their discharges, that are of interest to this study.

To make the BPEO manageable, the 268 classified waste streams from DRWI have been rationalised to group together waste streams with similar physical, chemical and radiological characteristics. In addition, information from other sources has been used to define those liquid and gaseous waste streams not included in DRWI that are of interest to the study. In all, 36 separate DSRP waste streams were defined for consideration: these are listed in Table 2.1.

**Table 2.1:** Waste streams considered in the study.

| Waste stream | Waste description |
|---|---|
| ***Airborne wastes*** | |
| A1 | Particulates from active process and building ventilation |
| A2 | Particulates from treating contaminated ground |
| A3 | H-3 (tritium) |
| A4 | C-14 (carbon-14) |
| A5 | Kr-85 (krypton-85) |
| A6 | Iodines |
| ***Liquid wastes*** | |
| L1 | Low level liquid |
| L2 | MALs |
| L2.1 | MALs from decommissioning |
| L2.2 | Legacy MALs |
| L3 | DFR raffinate |
| L4 | PFR raffinate |
| L5 | Solvents and oils |
| L6 | Flocs and sludges |
| L6.1 | ADU floc |
| L6.2 | LLLETP sludge |
| L6.3 | Shaft and Silo sludge |
| L6.4 | Fuel storage pond sludges |
| ***Solid wastes*** | |
| S1 | LLW |
| S1.1 | General metals |
| S1.2 | Tritiated metals |
| S1.3 | Concrete and building materials |
| S1.4 | Cellulosic materials |
| S1.5 | Non-cellulosic compactables |
| S1.6 | Pits wastes |

| Waste stream | Waste description |
|---|---|
| S1.7 | Bulk non-compactables, non-combustible |
| S1.8 | Soils |
| S2 | CHILW, including PCM |
| S3 | Shaft and Silo RHILW |
| S4 | RHILW in stores |
| S5 | Boron carbide |
| S6 | Decommissioning ILW |
| S6.1 | Metals (including surface contamination) |
| S6.2 | Graphite |
| S6.3 | Concrete and rock |

### 2.2.2 DSRP activity inventories

The total alpha and beta/gamma activities in waste stocks on 1 April 2001 recorded in DRWI for solids and liquids were $6.71 \times 10^3$ TBq and $3.30 \times 10^5$ TBq respectively. Figure 2.1 shows the relative contributions of HLW, RHILW, CHILW and LLW (which includes VLRM) to the alpha activity in waste stocks on 1 April 2001, while Figure 2.2 shows the corresponding information for beta/gamma activity.

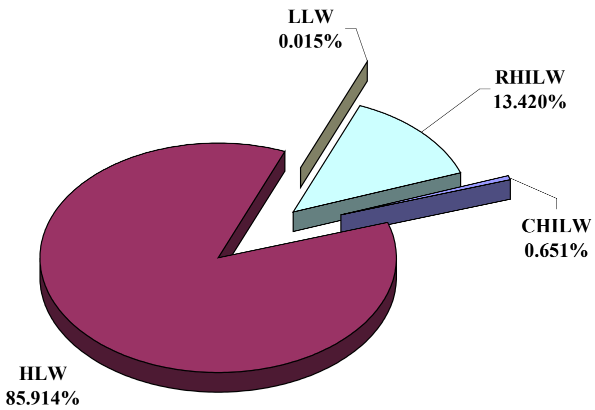



**Figure 2.1:** Proportions of alpha activity by waste type. From Barton [2001].

It can be seen that most of the alpha activity is contained in HLW. The total activity in RHILW is lower, while the activity content of CHILW and LLW is much lower still. Over 95% of the activity in HLW is from beta/gamma emitting nuclides.

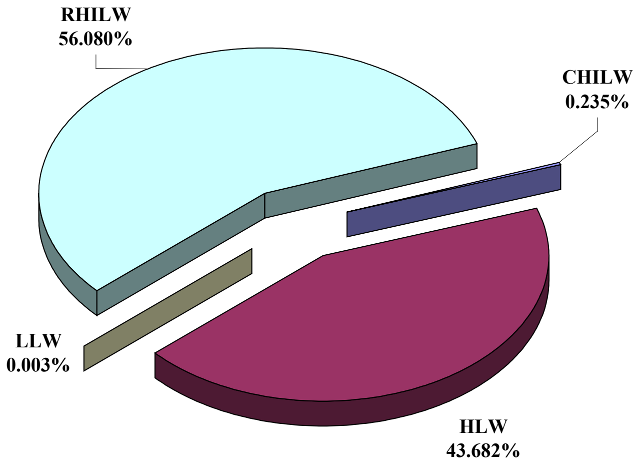



**Figure 2.2:** Proportions of beta/gamma activity by waste type. From Barton [2001].

Once the additional waste streams that will arise due to decommissioning during the DSRP are considered, the total alpha and beta/gamma activities considered in this BPEO study rise to $7.2 \times 10^3$ TBq and $5.6 \times 10^5$ TBq respectively. The different waste streams will be generated and treated over different periods of time throughout the DSRP and, therefore, these totals do not reflect the total activity of the untreated wastes at any particular point in time.

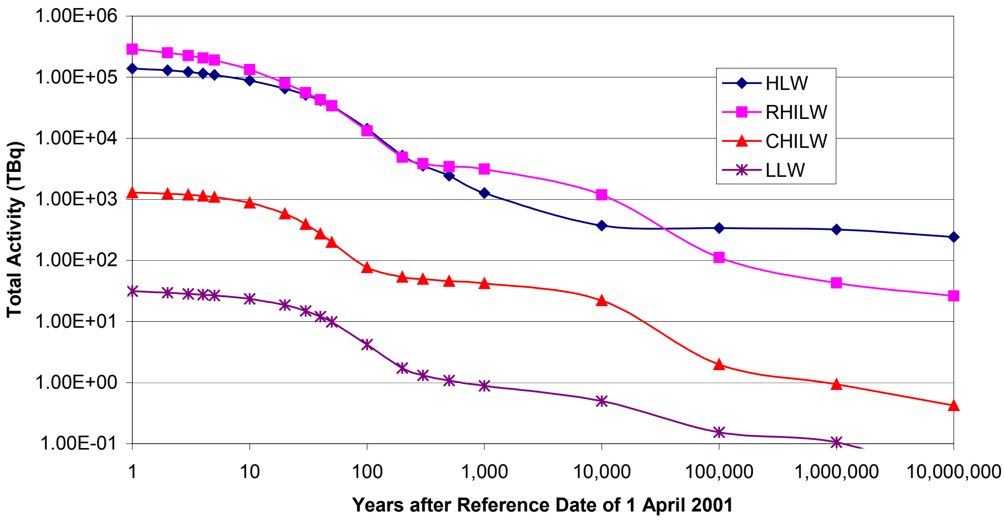



**Figure 2.3:** Total activity of HLW, RHILW, CHILW and LLW as a function of time. From Barton [2001].

To overcome this, the total activity of accumulated wastes after the reference date of 1 April 2001 is calculated taking into account the radioactive decay of each waste stream. Figure 2.3 illustrates how the total activities of HLW, RHILW, CHILW and LLW change with time after 1 April 2001. Note that this is the total activity in current stocks and all future arisings.

Total activities fall in a manner that reflects the decay of the major radionuclide species. The activity of RHILW is similar to that of HLW due to the much larger volume of RHILW. The activity of HLW falls off more quickly than RHILW because of the lower quantities of uranium, which, with its daughter products is the major contributor to total activities after about 1,000,000 years.

The total DSRP inventory considered in this report can also be considered in terms of the proportion in different states, and this is shown in Table 2.2.

**Table 2.2:** DSRP waste inventory by state.

| State | Alpha (TBq) | Beta/gamma (TBq) | Total (TBq) | Percentage of total activity |
|---|---|---|---|---|
| Airborne | see text | see text | $4x10^3$ | 0.1 |
| Liquid | $5.2x10^3$ | $1.4x10^5$ | $1.4x10^5$ | 25.2 |
| Solid | $2.0x10^3$ | $4.2x10^5$ | $4.2x10^5$ | 74.7 |

The majority of the activity associated with airborne waste streams arises from gaseous species (H-3, C-14 etc.) which are currently included in solid and liquid materials (e.g. contained within tritiated metals). The inventory of these gaseous species is approximately $4x10^3$ TBq and is mostly in the form of tritium. These gaseous species would be liberated if certain management methods were adopted to treat the solid and liquid waste streams they were associated with (e.g. heating or smelting tritiated metals). Only then could these gaseous species waste streams be separately identified and treated within an overall waste management strategy.

The most significant waste streams, in terms of activity, considered in this study are indicated in Table 2.3. The two most significant waste streams are the PFR raffinate (L4) and the RHILW Metals (S6.1). The PFR raffinate is the first cycle liquid waste generated by the reprocessing of PFR core fuel. The metals are derived from decommissioning of reactors, plants and buildings. The dominant beta/gamma emitting radionuclide in the metals is Co-60.

**Table 2.3:** Most significant DSRP waste streams by inventory.

| Waste stream | | Alpha (TBq) | Beta/ gamma (TBq) | Total (TBq) | Percentage of total activity |
|---|---|---|---|---|---|
| L3 | DFR raffinate | 12 | $5.4x10^3$ | $5.4x10^3$ | 1.0 |
| L4 | PFR raffinate | $5.0x10^3$ | $1.3x10^5$ | $1.3x10^5$ | 23.9<br>(= 70 % of total α) |
| L6.1 | Ammonium diuranate | $1.4x10^2$ | $1.0x10^3$ | $1.1x10^3$ | 0.2<br>(= 1.9 % of total α) |

| Waste stream | | Alpha (TBq) | Beta/ gamma (TBq) | Total (TBq) | Percentage of total activity |
|---|---|---|---|---|---|
| S2 | CHILW | 79 | $1.5x10^3$ | $1.6x10^3$ | 0.3 (= 1.1 % of total α) |
| S4 | RHILW in stores | $4.0x10^2$ | $4.2x10^4$ | $4.2x10^4$ | 7.6 |
| S5 | Boron carbide | $5.6x10^{-4}$ | $4.1x10^4$ | $4.1x10^4$ | 7.2 |
| S6.1 | RHILW metals* | $1.2x10^3$ | $3.2x10^5$ | $3.2x10^5$ | 56.7 (= 57 % of total β/γ) |
| S6.3 | Concrete and rock | 42 | $1.3x10^4$ | $1.3x10^4$ | 2.3 |

*Note that there are uncertainties associated with the activity of RHILW from reactor decommissioning and beta/gamma activity is probably over estimated.

# 3 Methodology

## 3.1 A framework for decision making

In some respects, this study is not typical of 'standard' BPEO studies which are often closely focussed on a single issue (e.g. how to manage a particular waste type or to remediate a site with one type of contaminant). Although it shares some features in common with the type of options comparison typically demanded in relation to planning regulations or statutory obligations under pollution control, the specialised nature of facilities and measures required for the management of DSRP wastes inevitably invokes broader strategic considerations. These include issues such as the extent to which existing (or future) capabilities elsewhere in the UK can be incorporated as part of the management strategy for these wastes.

The UK Government has launched a consultation exercise on all aspects of radioactive waste management in the UK [DEFRA, 2001]. In addition, the UK Government has recently published detailed plans for significant changes to current arrangements concerning the liabilities arising from Britain's civil nuclear programme. The changes, published in a White Paper [Secretary of State for Trade and Industry, 2002] include the creation of a new national body: the Liabilities Management Authority (LMA). Once established, the LMA will take on responsibility for the public sector civil nuclear liabilities currently held by BNFL and UKAEA (which include those at Dounreay).

Nonetheless, current regulatory guidance is insistent that options for dealing with certain hazardous radioactive waste streams be considered as a matter of priority. The UKAEA therefore wishes to proceed now with the identification of a management option for the DSRP wastes that is consistent with UKAEA policy and the published schedule for the DSRP. Furthermore, given the likely delay in implementing any new UK management policy for these wastes, this study is based on the premise that any chosen 'treatment' options for high-level or intermediate-level DSRP wastes should produce products that are passively safe to store pending decisions on their final disposal.

## 3.2 The BPEO Methodology

The BPEO methodology is a formalised system for evaluating issues that may have environmental implications and for determining appropriate options to address those issues. The methodology was first proposed by the Royal Commission on Environmental Pollution (RCEP) in the mid-1970s as a way to help control air pollution. The background to BPEO studies is given in Appendix A.

The methodology adopted in this BPEO study is based on the RCEP 12th report recommendations [RCEP, 1988] and draws on experience of previous BPEOs undertaken for UKAEA in relation to waste management issues at Dounreay, in particular those for the fuels materials [UKAEA 2001] and solid LLW [UKAEA 2003], as well as relevant BPEO studies undertaken by other UK organisations [Atomic Weapons Establishment 1998]. Due to the complexity of the range of waste materials addressed in this study compared to others, however, the BPEO methodology has been adapted and applied to option 'strategies' (each comprised of a number of different waste treatment methods) rather than to individual treatment methods, as would be normal when applying BPEO to the treatment of a single waste stream. The BPEO methodology, thus applied in this study, is shown schematically in Figure 3.1 and involves the following main steps:

1) ***Definition of the objectives of the BPEO study*** to provide a focus for the assessment and to help establish a basis for subsequent option evaluation by setting out the primary boundary conditions to allow the definition of the 'best' option for the management of the waste arisings from the DSRP (Section 1.2).

2) ***Generation of a comprehensive list of strategy options*** for waste management that allows for comparison between strategies that are based on discharges of liquid wastes to sea, discharges of airborne wastes to the atmosphere and immobilisation and production of wastes in solid forms (Section 4.1).

3) ***Generation of lists of technologies and operational procedures*** that potentially could be employed to manage each of the DSRP waste streams, and which address both waste arisings and waste treatment, whilst ensuring the lists are sufficiently comprehensive so that options are not limited and the outcome is not prejudged (Section 4.2).

4) ***Detailed definition of the strategy options*** for waste management by using appropriate screening criteria to identify from the lists of alternative treatment options, representative technologies to manage each waste stream that are consistent with the objectives of each strategy option, and are reasonably practical or technically feasible (Section 4.3).

5) ***Definition of a series of 'attributes'*** that relate to the key safety, environmental, technological, social and cost characteristics and consequences of each defined strategy option that are thought to be important and relevant at the level of detail being considered, and which can be used to discriminate between the different strategy options (Section 5.1).

6) ***Definition of a scoring scheme*** that allows the attributes to be applied to the different detailed strategy options in a way that allows their various technological and environmental characteristics and consequences to be compared and contrasted in a quantitative manner (Section 5.2).

7) ***Evaluation of the strategy options against the attributes***, using qualitative and quantitative information, and expert opinion where necessary, to score each

of the strategy options against every attribute using the defined scoring scheme (Section 6).

8) ***Assess, compare and optimise the strategy options*** by identifying for each one, on the basis of the scoring results, those representative waste management methods that cause low scores to be awarded and replace these with alternative waste management methods that achieve higher scores for the strategy options (Section 7).

9) ***Analyse the robustness of the optimised strategy options*** to different weighting schemes that may be applied to the scores so as to reflect the range of attitudes and value systems that may be held by different 'generic' stakeholder groups (Section 8).

10) ***Selection of the 'best' strategy option*** on the basis of the results of alternative weighting schemes applied to the optimised strategy options. It is not always possible uniquely to identify a single 'best' option and, therefore, alternatives may be presented. (Section 9).

These steps are referred to in the text throughout this report. A more detailed representation of the methodology applied in this BPEO is given in Figure 3.2 in the form of a process diagram.

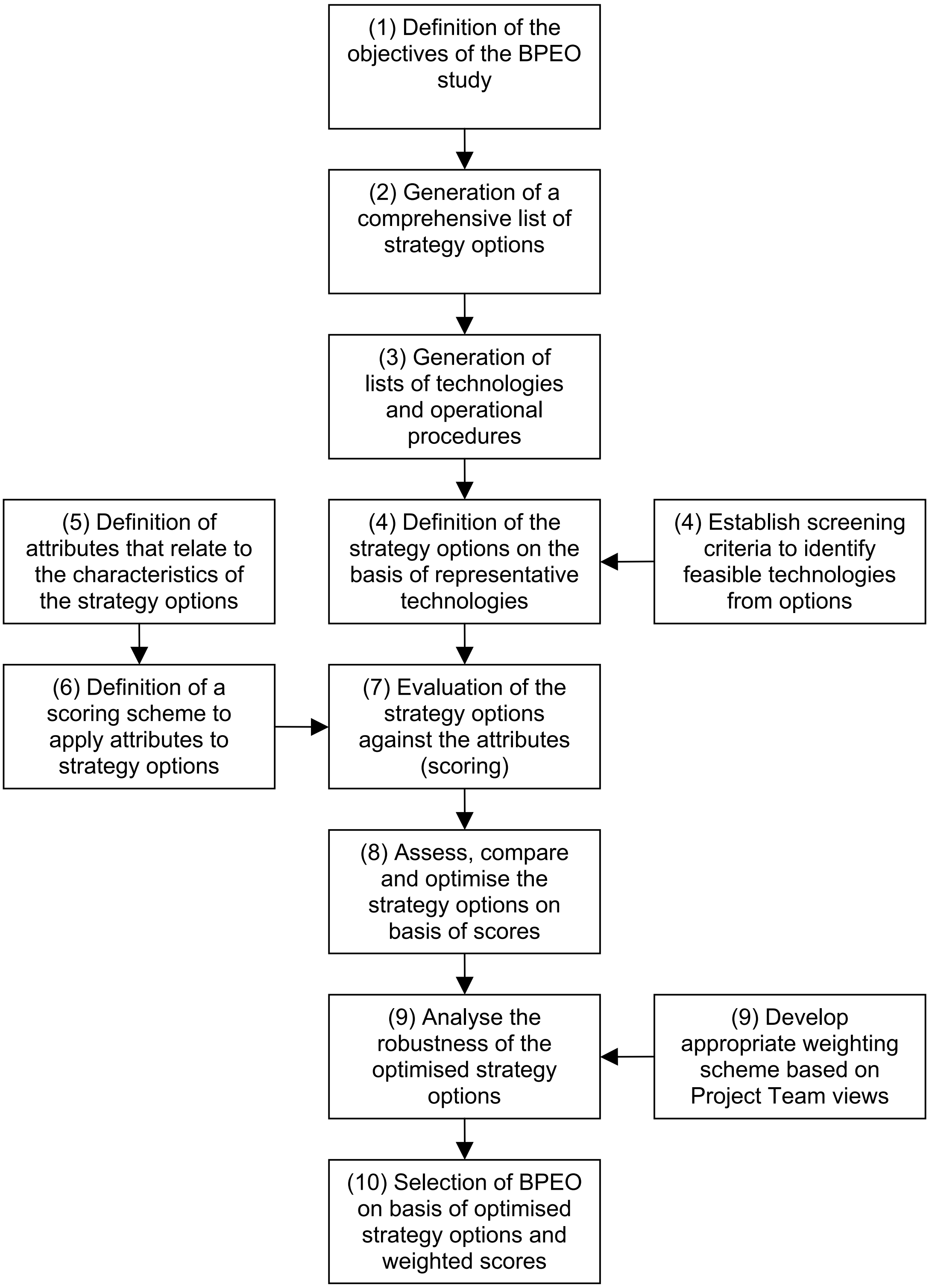



**Figure 3.1:** Schematic diagram of the BPEO methodology as applied to this study. Numbers in parentheses refer to the steps in the methodology described in the text.

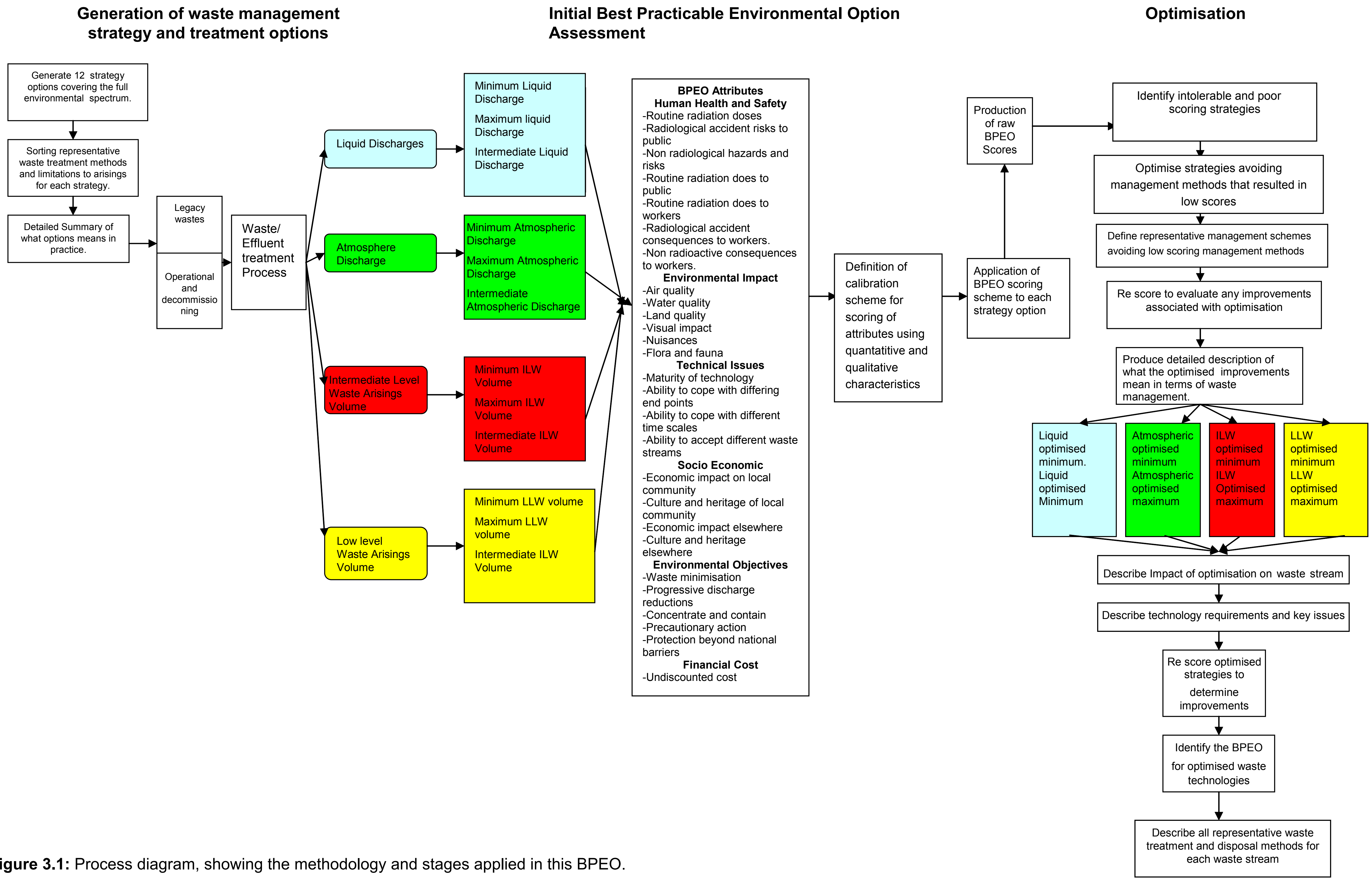



**Figure 3.1:** Process diagram, showing the methodology and stages applied in this BPEO.

# 4 Potential options for DSRP waste management

## 4.1 Generation of Strategy Options

When considering the totality of the DSRP waste streams listed in Table 2.1, various strategy options can be identified for managing them in combination, by considering the major environmental issues in radioactive waste management and taking into account the 'waste management hierarchy', which gives priority to reduction of waste arisings, re-use, and recovery and recycle [DETR, 2000]. This is Step 2 in the BPEO methodology as indicated in Figure 3.1.

For the purposes of this DSRP wastes BPEO, the major environmental issues in radioactive waste management for the Dounreay site are taken to be[6]:

- the activity of liquid discharges to the environment;
- the activity of airborne discharges to the atmosphere;
- the quantities of solid ILW requiring long-term management[7]; and
- the quantities of solid LLW requiring long-term management.

Three broad strategy options have been defined for each issue, so as to cover the full spectrum of possibilities and all the relevant trade-offs. These are (a) strategies that generate minimum discharges and solid waste volumes, (b) strategies that generate maximum discharges and solid waste volumes, and (c) strategies that fall between these end-points, i.e. strategies that generate intermediate discharges and solid waste volumes.

The maximum and minimum strategy options are clearly opposites (e.g. to maximise or to minimise liquid discharges) and reflect the likely extremes that are achievable using available technology or technology that may become available in the next two decades or so. There are many possible intermediate strategies that may be employed between the two extremes for each issue that allow for a balance between environmental

[6] Issues other than the environmental concerns of radioactive discharges and solid waste volumes are also explicitly addressed in this BPEO. These include a number of additional environmental impacts and objectives, technological concerns, socio-economic impacts etc. (see Section 5). The primary regulatory restrictions to site operations imposed by SEPA are, however, based around the issues of radioactive liquid and airborne discharges, and solid waste volumes and, for this reason, the strategy options considered in this study are developed around these themes.

[7] For the sake of conciseness, included in this category is the PFR raffinate currently held as a high active liquor which, if it were to be immobilised, may be classed as either solid ILW or solid high level waste (HLW) depending on the immobilisation method used and the waste classification scheme applied.

impacts, technical viability, cost etc. For this study, a single ***representative*** intermediate option has been identified for each issue, for the purposes of illustration only.

In total, therefore, 12 strategy options are defined, which result from applying maximum, minimum and intermediate approaches to each of the four major environmental issues listed above. These strategy options are defined in Table 4.1.

**Table 4.1:** The 12 strategy options considered in this study for the DSRP wastes.

| **Strategy Option Number and Name** | | **Key Features of Strategy Option** |
|---|---|---|
| $Liq_{Min}$ | Minimum Liquid Discharges | Liquid effluent arisings minimised by choice of process (including recycling), maximum treatment of liquid effluents prior to discharge to sea |
| $Liq_{Max}$ | Maximum Liquid Discharges | No steps taken to minimise liquid effluent arisings, minimum treatment of liquid effluents prior to discharge to sea |
| $Liq_{Inter}$ | Intermediate Liquid Discharges | Some minimisation of liquid effluent arisings, intermediate treatment prior to discharge to sea |
| $Atm_{Min}$ | Minimum Atmospheric Discharges | Gaseous effluent arisings minimised by choice of process (including recycling), maximum treatment of gaseous effluents prior to discharge to air |
| $Atm_{Max}$ | Maximum Atmospheric Discharges | No steps taken to minimise gaseous effluent arisings, minimum treatment of gaseous effluents prior to discharge to air |
| $Atm_{Inter}$ | Intermediate Atmospheric Discharges | Some minimisation of gaseous effluent arisings, intermediate treatment of gaseous effluents prior to discharge to air |
| $ILW_{Min}$ | Minimum Quantities of Solid ILW | Arisings of primary and secondary ILW are minimised, treatment/conditioning methods chosen to minimise solid ILW volumes |
| $ILW_{Max}$ | Maximum Quantities of Solid ILW | No particular steps taken to minimise arisings of primary or secondary ILW, treatment/conditioning methods chosen with no particular reference to solid ILW volumes |
| $ILW_{Inter}$ | Intermediate Quantities of Solid ILW | Some steps taken to minimise ILW arisings, some account taken of solid ILW volumes in choosing treatment/conditioning methods |
| $LLW_{Min}$ | Minimum Quantities of Solid LLW | Arisings of primary and secondary LLW minimised, treatment/conditioning methods chosen to minimise solid LLW volumes |
| $LLW_{Max}$ | Maximum Quantities of Solid LLW | No particular steps taken to minimise arisings of primary or secondary LLW, treatment/conditioning methods chosen with no particular reference to solid LLW volumes |
| $LLW_{Inter}$ | Intermediate Quantities of Solid LLW | Some steps taken to minimise LLW arisings, some account taken of solid LLW volumes in choosing treatment/conditioning methods |

Each of these strategy options takes into account management of all of the airborne, liquid and solid waste streams in Table 2.1. This is due to the potential for solid and airborne waste management methods to influence liquid waste arisings; the potential for liquid and solid waste management methods to influence airborne waste arisings;

and the potential of liquid and airborne waste management to influence solid waste arisings. Similarly, management methods for I/HLW solid wastes can influence arisings of LLW, and vice versa. Those interactions between airborne, liquid and solid waste streams that can occur due to various waste treatment processes are shown graphically in Figures 4.1 – 4.3. It is noted that solids could be treated to free release.

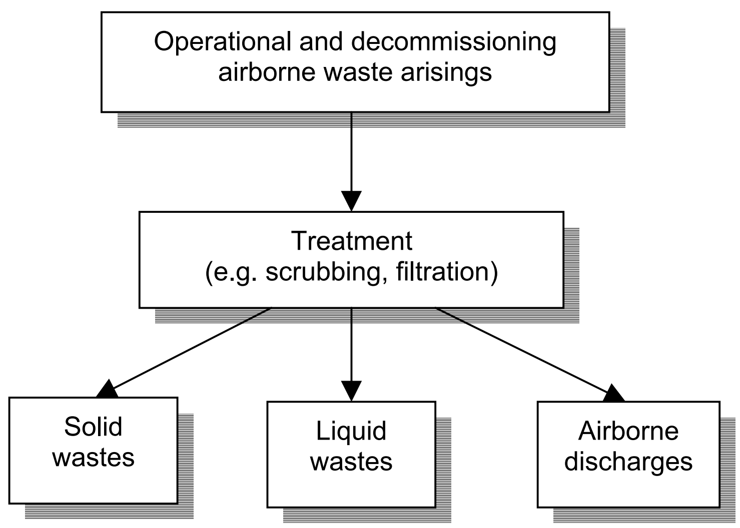



**Figure 4.1:** Airborne DSRP waste streams flows. Treatment of airborne waste streams can generate secondary solid or liquid wastes, and lead to direct airborne discharges.

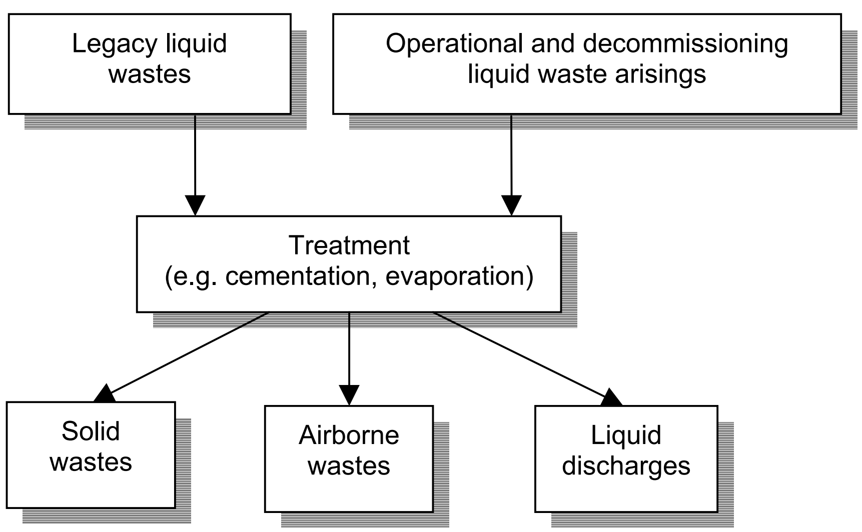



**Figure 4.2:** Liquid DSRP waste streams flows. Treatment of liquid waste streams can generate secondary solid or airborne wastes, and lead to direct liquid discharges.

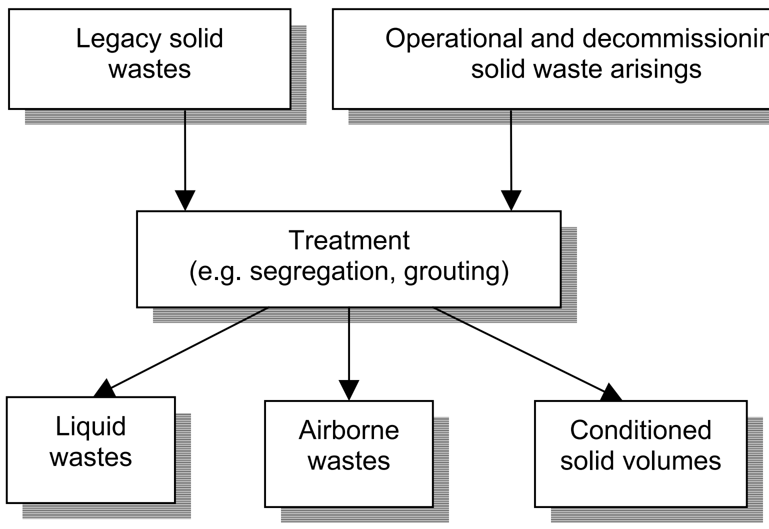



**Figure 4.3:** Solid DSRP waste streams flows. Treatment of solid waste streams can generate secondary liquid or airborne wastes, and generate volumes of conditioned solid waste.

## 4.2 Identification of Management Methods for Specific Wastes

Having identified the broad strategy options (Table 4.1) the next stage was to define, for each strategy option, representative management methods for each of the separate waste streams. This was done in two stages:

***Stage One:*** a list of options for management methods that addressed limitation of arisings and technologies for treatment was first generated for each DSRP waste stream. This is Step 3 in the BPEO methodology as indicated in Figure 3.1. These potential technologies and operational procedures are listed in the 'Options for Management Methods' columns in Table 4.2.

These lists of management methods were not necessarily intended to be fully comprehensive of all possible options available to treat each waste stream but were intended to be sufficiently broad so that they covered 'typical' or 'industry standard' treatments, as well as alternative treatments that allowed discrimination between the objectives of the 12 strategy options: i.e. options that allowed different levels of airborne and liquid discharges, and generated different volumes of ILW and LLW. Where individual BPEO or BPM studies had previously been undertaken for specific waste streams (e.g. PFR raffinate), these were used to inform the choice of management methods considered.

***Stage Two:*** for each strategy option, a single ***representative*** management method was then chosen from the set of alternative technologies and operational procedures derived in Stage One for every waste stream, addressing both arisings and treatment, so that the strategy option could be defined in greater detail.

The chosen representative management methods were intended to be consistent with the overall objectives of each strategy option. Consideration was also given to the ways in which the operations that give rise to primary and secondary wastes are carried out, particularly the potential for influencing initial arisings but also the potential for re-use or recycle; and the treatment and conditioning of wastes once they have arisen. Thus, for example, for the Minimum Liquid Discharges strategy ($Liq_{Min}$), the treatment methods chosen for each waste stream are the ones that produce the least liquid waste and result in the least liquid discharges.

#### 4.2.1 Screening criteria

When identifying the representative management methods, a number of screening criteria were applied to remove from consideration any methods that are clearly not viable, so as to avoid the BPEO study being diverted away from developing practicable and achievable waste management strategies. These screening criteria were:

- ***Use of available technology:*** which limited methods only to those that make use of available technology or technology that has a reasonable prospect of being available over about the next decade or two [Fearn et al., 2002]. An example of a technology that was screened out on this basis is partitioning and transmutation. This screening criterion was not used, however, to remove from consideration management methods and technologies that have been proven at a conceptual level but which would require an element of further research and development to implement within DSRP timescales.
- ***Conditioning and packaging of solid wastes:*** which limited methods only to those that generate waste forms, and employ waste packages, that are suitable for long-term storage or disposal, or are readily reworkable. This means the technology must generate wasteforms that can either be processed or repackaged (e.g. using an overpack) if they deteriorate or otherwise prove unsuitable for disposal in any future repository [Environment Agency, 2001].
- ***National policy:*** the most recent statement of UK policy on radioactive waste is contained in Command 2919 [Secretary of State for the Environment, 1995]. This review of policy takes account of the most recent (at the time) guidance from international bodies such as ICRP and IAEA, as well as the views of official UK advisory bodies such as NRPB [1992]. This was used here to screen out options related to the import and export of radioactive waste streams. National policy on radioactive waste management is, however, under review and a recent White Paper has been published [Secretary of State for Trade and Industry, 2002].

Issues such as compliance with the UK Discharge Strategy [DEFRA, 2002] are addressed in this BPEO study through the application of attributes. This is because such an approach requires the strategy option as a whole to be assessed, rather than individual representative management methods. If a strategy option is non-compliant against a legal requirement, then it scores zero (see Section 5).

## 4.3 Definition of Strategy Options

The representative management methods chosen for each waste stream (as described above), in each of the 12 strategy options, are listed in Table 4.2. These representative management methods, when taken together for all waste streams, essentially define each strategy option, at least in terms of the major technologies required to implement them. This is Step 4 in the BPEO methodology as indicated in Figure 3.1. In this manner, these strategy options are necessarily defined at a broad level.

It needs to be stressed that the management methods identified in Table 4.2 are only intended to be ***representative***, and are not intended to determine how a particular waste or material should or will be managed. It is envisaged that the results of this BPEO study will provide input to the selection of a broad strategy for all DSRP wastes, and then BPEO (and/or BPM) studies for each group or type of wastes and materials will provide input to the more detailed selection of management methods for them.

The broad strategies defined for each of the 12 strategy options are defined in more detail in Table 4.3, on the basis of the representative technologies and management methods required to implement them. In addition to listing the key technologies, this table also describes the overall objective of each strategy option, the resulting impacts on the treatment of individual and groups of waste streams, and identifies some key issues for further consideration in the BPEO study.

For some solid and a few of the liquid wastes streams there are potential options which allow treatment on-site or off-site. For the strategic purposes of this BPEO, however, wastes are assumed to be treated on site and the end-point for their treatments is taken to be either direct discharge or storage on the Dounreay site in passively safe form, pending a decision on the subsequent long-term management method.

**Table 4.3** (over next 12 pages)**:** The overall objectives of each strategy options, together with the representative treatments and management methods identified for individual waste streams.

| $\mathbf{Liq_{Min}}$: **Minimum Liquid Discharges** |
|---|
| ***Objective:***<br>The objective of this strategy is to minimise the liquid discharges from the site arising from management of the DSRP wastes. Broadly this is achieved by minimising the use of liquids during waste treatment (e.g. adopting dry decontamination methods) and by reducing the volume discharged to the environment of liquids that do arise by using an evaporator on low level liquids and by converting other liquid wastes to solid forms (e.g. by cementation). |
| ***Impact on treatment of waste streams:***<br>Airborne waste streams either go untreated and are directly discharged to the environment (H-3, C-14 and Kr-85) or, where possible, are managed with dry treatments and filters (particulates).<br>Liquid waste streams are minimised through various methods to limit arisings, and immobilised using cement in most cases, although this may not be viable for the solvents and oils.<br>Solid waste streams generally can be handled by any treatment process except those that use liquids for decontamination. Many can be grouted without impacting on liquid discharges. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ HEPAs for active building ventilation filtration;<br>▪ range of technologies to minimise LLL arisings;<br>▪ central evaporator to treat LLL that does arise;<br>▪ robotic dismantling equipment for plant to minimise decommissioning MAL arisings;<br>▪ cementation plant for legacy MALs, DFR raffinate, oils and solvents, flocs and sludges;<br>▪ vitrification plant for PFR raffinate;<br>▪ equipment for remote sorting and segregation of solid decommissioning and legacy (Shaft, pits and silo) wastes;<br>▪ equipment for dry decontamination of solid decommissioning wastes;<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:***<br>This strategy requires working practices that minimise liquid waste arisings during decommissioning (e.g. increased recycling and hydraulic isolation of the LLW Pits). Key technology dependencies are a central evaporator capable of handling all LLL and a cementation plant that is sufficiently flexible to handle a wide range of waste streams including the MALs, DFR raffinate, and flocs and sludges.<br>Supporting R&D would be necessary to confirm the feasibility of cementing some of these waste streams, in particular the solvents and oils. Development work would be required for the robotic dismantling equipment. Dry decontamination techniques will require optimising for the specific solid decommissioning wastes that will be generated. Other techniques are routine, such as remote waste sorting and segregation, and grouting and packaging.<br>High capital and running costs will be associated with the vitrification plant, central evaporator and the cementation plant. |

| $Liq_{Max}$: Maximum Liquid Discharges |
|---|
| ***Objective:***<br>The objective of this strategy is to allow maximum discharges from the site of liquids arising from management of the DSRP wastes. Broadly this is achieved by adopting waste treatment methods that use liquids (e.g. wet decontamination methods) and by actively discharging legacy and decommissioning liquid wastes to the environment. |
| ***Impact on treatment of waste streams:***<br>Airborne waste streams are treated with wet methods (such as wet scrubbing of C-14, iodines and active building ventilation) to convert them to liquid waste streams.<br>All liquid waste streams are directly discharged to the marine environment, with only minimal pre-treatment (e.g. to dissolve flocs and sludges). No volume reduction via evaporation is required.<br>Solid decommissioning waste streams are decontaminated using liquids which are then directly discharged to the environment. Pits wastes are not retrieved. Graphite is incinerated using equipment fitted with wet scrubbers. Boron carbide is dissolved and the solution directly discharged. Tritiated metals are smelted using equipment fitted with wet scrubbers. Remaining solids are generally grouted and packaged. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ incinerator for graphite;<br>▪ smelting plant for tritiated metals;<br>▪ wet scrubbers for treating gaseous legacy wastes, and airborne wastes from ventilation, incinerator and metal smelting plants;<br>▪ plant to facilitate dissolution of flocs and sludges;<br>▪ liquid effluent collection and discharge systems;<br>▪ equipment for remote sorting and segregation of solid decommissioning and legacy (Shaft and silo) wastes;<br>▪ equipment for liquid decontamination of solid decommissioning wastes;<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:***<br>This strategy requires working practices that collect and discharge legacy liquid wastes and liquid waste arisings from decommissioning. Key technology dependencies are wet scrubber systems for gaseous waste streams, plus an incinerator with wet scrubber for graphite.<br>On site liquid effluent collection and discharge systems may require enhancing.<br>Wet decontamination techniques will require optimising for the specific solid decommissioning wastes that will be generated. Other techniques are ‘low tech’ and routine, such as remote waste sorting and segregation, and grouting and packaging.<br>High activity releases to the environment will result.<br>Capital and running costs for the various technologies are likely to be low to moderate. |

| **$Liq_{Inter}$: Intermediate Liquid Discharges** |
| --- |
| ***Objective:*** The objective of this strategy is to allow all necessary and unavoidable discharges from the site of liquids arising from management of the DSRP wastes to take place. Broadly this is achieved by adopting only those waste treatment methods that use liquids (e.g. wet decontamination methods) as are appropriate to the safe and efficient treatment of legacy and decommissioning liquid wastes. Otherwise, dry treatments are used. |
| ***Impact on treatment of waste streams:*** Airborne waste streams are managed with dry treatments and HEPA filters (particulates) where possible. H-3 undergoes only partial condensation. C-14 and iodines are treated prior to discharge. Kr-85 is discharged directly to the atmosphere.<br>Liquid waste streams are separated where necessary and subjected to pre-treatment (e.g. to dissolve flocs and sludges). Volume reduction via evaporation is employed as required. Solvents and oils are pre-washed and then incinerated using equipment fitted with standard dry scrubbers. Silo and other sludges are dewatered, with residues cemented and liquids only discharged after treatment. PFR and DFR raffinates are chemically separated and treated.<br>Solid decommissioning waste streams are decontaminated where possible using liquids, some of which are treated prior to direct discharge to the environment. Pits wastes are not retrieved. Graphite is grouted. Boron carbide is washed and the solution directly discharged. Tritiated metals are smelted using equipment fitted with condensers. Remaining solids are generally grouted and packaged. |
| ***Technology requirements:*** Key technology and plant requirements are:<br>▪ chemical separation plant for DFR and PFR raffinates;<br>▪ incinerator for solvents and oils;<br>▪ smelting plant for tritiated metals;<br>▪ plant to facilitate dissolution of flocs and sludges;<br>▪ liquid effluent collection and discharge systems;<br>▪ equipment for liquid decontamination of solid decommissioning wastes;<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:*** This strategy requires working practices that collect legacy liquid wastes and liquid waste arisings from decommissioning and discharge them where practical. Key technology dependencies include development of a chemical separation and treatment process for DFR and PFR raffinates, an incinerator for the solvents and oils, and a smelter for tritiated metals. In addition, a central evaporator will be required, as will a cementation plant for sludges.<br>Additional R&D will be necessary to develop suitable chemical separation processes for the DFR and PFR raffinates. Other techniques are routine, such as grouting and packaging.<br>Moderate capital and running costs will be associated with the central evaporator, cementation plant, incinerator and smelter. |

| $Atm_{Min}$: Minimum Airborne Discharges |
|---|
| ***Objective:***<br>The objective of this strategy is to minimise the airborne discharges from the site arising from management of the DSRP wastes. Broadly this is achieved by utilising all possible techniques during decommissioning activities and waste treatment to limit gaseous discharges and to suppress or remove airborne particulates and gases, rather than discharging them to the environment. Direct cementation and in-situ treatments are utilised wherever practicable. |
| ***Impact on treatment of waste streams:***<br>Airborne waste streams from building ventilation systems are minimised as far as possible by hermetically sealing plant, modifying flow rates and only ventilating when access is required. Vented air is treated with combinations of scrubbers (e.g. wet for C-14), filters and condensers, utilising the most efficient available techniques. Other particulates undergo in-situ encapsulation. Iodines are passed over activated charcoal before discharge to the atmosphere. Kr-85 is removed by cryogenic distillation.<br>Liquid waste streams are minimised using various methods but excluding those involving evaporation. Legacy MALs, and DFR and PFR raffinates, sludges and flocs, and solvents and oils are directly immobilised using cement. Shaft and silo sludges are cemented, having been initially frozen to reduce particulate production during retrieval.<br>Solid waste streams generally undergo minimum handling and are sealed prior to removal and grouting, in order to minimise particulate production. Pits wastes and soils undergo in-situ encapsulation. Storage of wastes, especially tritiated metals, takes place in unventilated buildings. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ efficient filtration/abatement systems for gaseous discharge points (e.g. HEPAs, and wet and dry scrubbers);<br>▪ cryogenic distillation plant for Kr-85 arisings;<br>▪ robotic dismantling equipment for solid ILW arisings from decommissioning;<br>▪ cementation plant for legacy MALs, DFR and PFR raffinates, oils and solvents, flocs and sludges;<br>▪ equipment for freezing Shaft and silo sludges, and retrieval of the frozen product; and<br>▪ equipment for remote handling and treatment of various solid wastes. |
| ***Key issues:***<br>This strategy requires working practices that minimise airborne particulates and gaseous arisings during decommissioning. Key technology dependencies are efficient filtration/abatement systems, and cementation plant(s) that are sufficiently flexible to handle a wide range of waste streams including the MALs, DFR and PFR raffinates, flocs and sludges etc.<br>Supporting R&D would be necessary to confirm the long term stability of some of these cemented waste streams, in particular the PFR raffinate and the solvents and oils. Development work would be required for the robotic dismantling equipment and to establish feasibility of freezing and retrieving Shaft and silo wastes. Other techniques are routine, such as remote waste sorting and segregation, and grouting and packaging.<br>Capital and running costs will be moderate. |

| $Atm_{Max}$: Maximum Airborne Discharges |
|---|
| ***Objective:*** |
| The objective of this strategy is to maximise the airborne discharges from the site arising from management of the DSRP wastes. Broadly this is achieved by venting all active buildings and gaseous arisings without pre-treatment and by evaporating active liquids wherever possible, or by vitrifying others without the use of abatement systems. In addition, dry decontamination processes are used preferentially, with incineration without abatement where possible. Some cementation of residues will also be necessary. |
| ***Impact on treatment of waste streams:*** |
| Airborne waste streams from building ventilation systems are maximised wherever possible by modifying flow volumes and rates, and discharging without filtration or scrubbing etc. H-3, C-14, Kr-85 and iodines are discharged directly, whilst contaminated soils are subject to simple lift and shift.<br>No significant effort is made to minimise liquid waste arisings, and low-level liquid and MALs volumes are minimised through evaporation without abatement. DFR and PFR raffinates, and flocs and sludges are vitrified without abatement. Solvents and oils, and graphite are incinerated, also without abatement.<br>Decommissioning solid waste streams generally undergo dry handling and decontamination, and are recycled where possible. Most wastes are segregated, supercompacted and grouted. Boron carbide is decontaminated by washing to release H-3, soils are simply lifted and shifted. Other wastes are treated with any suitable technique. |
| ***Technology requirements:*** |
| Key technology and plant requirements are:<br>▪ vitrification plant for DFR and PFR raffinates, oils and solvents, and flocs and sludges;<br>▪ evaporator for low level liquids, and legacy and decommissioning MALs;<br>▪ incinerator for solvents and oils, and graphite;<br>▪ smelting plant for tritiated metals;<br>▪ equipment for dry decontamination of solid decommissioning wastes;<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:*** |
| This strategy requires working practices that maximise airborne particulates and gaseous arisings during decommissioning and management of legacy wastes. Key technology dependency is a vitrification plant capable of handling a wide range of wastes including DFR and PFR raffinates, oils and solvents, and flocs and sludges.<br>Supporting R&D would be necessary to confirm the feasibility of vitrifying some of these waste streams, in particular the flocs and sludges. Dry decontamination techniques will require optimising for the specific solid decommissioning wastes that will be generated. Other techniques are routine, such as remote waste sorting and segregation, and grouting and packaging.<br>High capital and running costs will be associated with the vitrification plant and the central evaporator. |

| $Atm_{Inter}$: Intermediate Airborne Discharges |
|---|
| ***Objective:***<br>The objective of this strategy is to allow all necessary and unavoidable discharges from the site of gases and particulates arising from management of the DSRP wastes to take place. Broadly this is achieved by adopting those waste treatment methods that use filtration and particulate suppression (e.g. HEPAs) as are appropriate to the safe and efficient treatment of legacy and decommissioning wastes. |
| ***Impact on treatment of waste streams:***<br>Airborne waste streams are managed with dry treatments where possible, and discharges are abated. H-3 undergoes only partial condensation, and C-14 is dry scrubbed prior to discharge. Iodines are absorbed on silver, whilst Kr-85 undergoes liquid absorption.<br>Liquid waste streams are generally pre-treated where appropriate (e.g. to dewater and for chemical removal of activity). Solvents and oils are incinerated using equipment fitted with standard dry scrubbers. Silo and other sludges are dewatered, with residues cemented and liquids discharged. DFR and PFR raffinates are vitrified with standard abatement systems.<br>Solid decommissioning waste streams are sorted and segregated to reduce volumes, and compacted where possible prior to packaging. Boron carbide and graphite are grouted. Soils are not treated. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ efficient filtration/abatement systems for gaseous discharge points (e.g. HEPAs, and wet and dry scrubbers);<br>▪ vitrification plant for DFR and PFR raffinates;<br>▪ incinerator for solvents and oils;<br>▪ cementation plant capable of handling flocs and sludges ;<br>▪ solvent extraction plant for dissolved ADU floc;<br>▪ remote equipment for sorting and segregating solid decommissioning wastes; and<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:***<br>This strategy requires working practices that limit dispersal of particulates and discharge of gases from decommissioning where practical. Key technology dependencies include a vitrification plant for DFR and PFR raffinates, and a cementation plant for flocs and sludges.<br>Supporting R&D would be necessary to optimise the vitrification plant to the two raffinate waste streams, and to optimise solvent extraction plant for ADU floc.<br>Other techniques are routine, such as grouting and packaging.<br>High capital and running costs will be associated with the vitrification plant and its associated abatement systems, and the cementation plant. |

| $ILW_{Min}$: Minimum ILW Volumes |
|---|
| ***Objective:*** |
| The objective of this strategy is to minimise the volumes of ILW arisings across the site from management of the DSRP wastes. Broadly this is achieved by segregating and decontaminating solid waste materials wherever possible, and by discharging as many liquid wastes as possible directly to sea. Most remaining wastes and residues are cemented, grouted or vitrified. |
| ***Impact on treatment of waste streams:*** |
| Airborne waste streams from building ventilation systems are minimised by hermetically sealing active plant and buildings, reducing flow rates and only ventilating when access is required. This avoids generating contaminated HEPA filters etc. that would be added to the solid waste volumes. H-3, C-14, Kr-85 and iodines are directly discharged.<br>All methods are used to limit arisings of low-level liquid and MALs from decommissioning; those that do arise are directly discharged to sea. Legacy MALs, DFR and PFR raffinates, solvents and oils and most sludges and flocs are directly discharged to sea, with some pre-treatment as required (e.g. to dissolve ADU floc).<br>Legacy and decommissioning solid LLW volumes are treated by any method, since these cannot generate solid ILW (no likely activity concentration process).<br>Legacy and decommissioning solid ILW volumes are minimised by segregation, decontamination and compaction. Boron carbide is decontaminated by washing to remove H-3. Graphite is incinerated prior to grouting of the residue. All remaining ILW solids are grouted. |
| ***Technology requirements:*** |
| Key technology and plant requirements are:<br>▪ incinerator for graphite;<br>▪ equipment for segregation and decontamination of solid ILW wastes;<br>▪ equipment for grouting and packaging of solid ILW wastes. |
| ***Key issues:*** |
| This strategy requires working practices that minimise the generation of ILW volumes, either by treating material as, or to, LLW where possible or by directly discharging liquid and gaseous waste streams. Key technology dependency is an incinerator for graphite.<br>All methods are 'low tech' and routine, such as remote waste sorting and segregation, and grouting and packaging, and little development work will be required.<br>High activity releases to the environment will result.<br>Capital and running costs are low. |

| $ILW_{Max}$: Maximum ILW Volumes |
|---|
| ***Objective:*** The objective of this strategy is to maximise the volumes of ILW arisings across the site from management of the DSRP wastes. Broadly this is achieved by treating wastes as ILW where possible, not segregated LLW from ILW solid arisings, adopting wet decontaminating methods and cementing all liquid wastes. |
| ***Impact on treatment of waste streams:*** Increased flow rates from active plant and building ventilation systems are used to maximise particulate collection and concentration to ILW levels (although ILW HEPAs are not the norm). A multi-stage process involving catalysis and solid absorption removes H-3 as a solid phase which is cemented. Iodines are collected on activated carbon. Kr-85 is collected by zeolite separation.<br>Low-level liquid arisings are minimised using current practices, and all arisings are evaporated in a central facility and the residue cemented. All MALs, DFR and PFR raffinates, solvents and oils, and flocs and sludges are all cemented.<br>No solid legacy or decommissioning waste streams are segregated. Where possible, solid LLW volumes are decontaminated using wet techniques and the extracted activity is concentrated (e.g. on ion exchange resins) and treated as ILW. Decontaminated materials are grouted as LLW. Solid ILW volumes are directly grouted as ILW, without pre-treatment or segregation. |
| ***Technology requirements:*** Key technology and plant requirements are:<br>▪ activity capture techniques for gaseous radionuclide (catalyst and absorption for H-3, zeolite separation plant for Kr-85, activated carbon iodines);<br>▪ central evaporator for low-level liquids;<br>▪ wet decontamination systems for solid LLW volumes;<br>▪ robotic dismantling equipment for solid ILW arisings from decommissioning;<br>▪ ion exchange plant to concentrate activity from decontamination liquids;<br>▪ cementation plant for all MALs, DFR and PFR raffinates, oils and solvents, and flocs and sludges; and<br>▪ equipment for grouting and packaging of non-segregated solid decommissioning and legacy wastes. |
| ***Key issues:*** This strategy requires working practices that maximise generation of ILW, either by not segregating waste streams by activity and cementing or grouting the resulting bulk wastes, or by using decontamination processes that concentrate activity. Key technology dependencies include a cementation plant capable of handling a wide range of waste streams, wet decontamination systems for solid LLW and a central evaporator.<br>Development work would be required for the robotic dismantling equipment. Supporting R&D would be necessary to confirm the long term stability of some of these cemented waste streams, in particular the PFR raffinate and the solvents and oils, and to optimise the wet decontamination systems.<br>Large volumes of packaged solid ILW wastes will be generated.<br>Capital and running costs will be high for the cementation plant and central evaporator. |

| $ILW_{Inter}$: Intermediate ILW Volumes |
| --- |
| ***Objective:***<br>The objective of this strategy is to allow the generation of all necessary and unavoidable volumes of solid ILW arisings across the site from management of the DSRP wastes using standard techniques. Broadly this is achieved by adopting those waste treatment methods that minimise arisings where this is practicable but only where appropriate to the safe, efficient and cost effective treatment of legacy and decommissioning wastes. Where possible, solid wastes and residues are conditioned and treated as LLW. |
| ***Impact on treatment of waste streams:***<br>Normal flow rates from building ventilation systems are used to maximise particulate collection and concentration to ILW levels (although ILW HEPAs are not the norm). A catalysis and solid absorption process removes H-3 as a solid phase which is cemented. Iodines are collected on silver. Kr-85 is collected by cryogenic distillation.<br>All efforts are made to minimise low level liquid arisings, on a zone specific basis, and arisings are evaporated in local facilities and the residue cemented. MALs and ADU floc are pre-treated to remove activity and this is cemented as ILW. DFR and PFR raffinates are vitrified. Solvents and oils are incinerated, whilst remaining sludges are dewatered and cemented.<br>Legacy and decommissioning solid LLW volumes are treated by any method, since these cannot generate solid ILW (no likely activity concentration process). Legacy and decommissioning solid ILW volumes are minimised by segregation without decontamination. Boron carbide is decontaminated by washing to remove H-3. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ activity capture techniques for gaseous radionuclide (catalyst and absorption for H-3, cryogenic distillation for Kr-85, silver for iodines);<br>▪ local evaporators for low-level liquids;<br>▪ vitrification plant with standard abatement for DFR and PFR raffinates;<br>▪ incinerator for solvents and oils;<br>▪ solvent extraction systems for MALs and ADU floc;<br>▪ cementation plant for the activity removed from MALs and ADU floc, and for cementation of dewatered LLLETP, Shaft, silo and pond sludges;<br>▪ equipment for segregating, grouting and packaging solid decommissioning and legacy wastes. |
| ***Key issues:***<br>This strategy requires working practices that minimise generation of ILW only where practicable, and allows segregation of waste streams by activity where necessary and cementing or grouting of the resulting residues. Key technology dependencies include a vitrification plant for DFR and PFR raffinates, an incinerator for the solvents and oils, and a cementation plant capable of handling MALs as well as flocs and sludges.<br>Supporting R&D would be necessary to optimise the vitrification plant to the two raffinate waste streams, and to optimise solvent extraction plant for ADU floc. Other techniques are routine, such as grouting and packaging.<br>Capital and running costs will be high for the vitrification and cementation plants, and local evaporators. |

| $LLW_{Min}$: Minimum LLW Volumes |
|---|
| ***Objective:*** <br> The objective of this strategy is to minimise as far as possible the solid LLW volumes arisings across the site from management of the DSRP wastes. Broadly this is achieved by the direct discharge of as many airborne and liquid waste streams as possible, and the direct treatment of solid ILW volumes without segregation or decontamination. |
| ***Impact on treatment of waste streams:*** <br> Airborne waste streams from active plant and building ventilation systems are minimised, by hermetically sealing, reducing flow rates and only ventilating when access is required. Vented air is discharged directly without filtration, as are particulates from other sources, together with H-3, C-14, Kr-85 and iodines. <br> All efforts are made to minimise low level liquid arisings, those that do result are directly discharged to sea. All MALs are directly discharged, as are DFR and PFR raffinates together with solvents and oils. All flocs and sludges are pre-treated to dissolve solids, and then are discharged to sea, although arisings are minimised where possible, for example by isolating the LLW pits. <br> All measures are taken to minimise arisings of solid LLW volumes. The Pits wastes are not retrieved and soils are left in situ. Cellulosic solid LLW is incinerated without abatement. Tritiated metals are smelted to release H-3. The remainder of the legacy and decommissioning solid LLW volumes are segregated and decontaminated to release materials for re-use, where possible. Solid residues are compacted and grouted. <br> All legacy and decommissioning solid ILW volumes are directly treated as ILW, without using any segregation or decontamination methods. |
| ***Technology requirements:*** <br> Key technology and plant requirements are: <br> ▪ liquid waste collection, pre-treatment (e.g. dissolution) and discharge systems; <br> ▪ incinerator for cellulosic LLW volumes; <br> ▪ smelter for tritiated metals; <br> ▪ robotic dismantling equipment for solid ILW arisings from decommissioning; <br> ▪ equipment for segregating and decontaminating solid LLWs; and <br> ▪ equipment for grouting and packaging a wide range of solid decommissioning and legacy wastes. |
| ***Key issues:*** <br> This strategy requires working practices that minimise generation of LLW by treating most solid wastes as ILW and discharging as many liquids and sludges as possible. Key technology dependencies include an incinerator for cellulosic material and a smelter for tritiated metals. <br> Development work would be required for the robotic dismantling equipment. Wet decontamination techniques will require optimising for the solid LLWs. Other techniques are 'low tech' and routine, such as remote waste sorting and segregation, and grouting and packaging. <br> High activity releases to the environment will result. <br> Capital and running costs will be low to moderate for the incinerator and smelter. |

| $LLW_{Max}$: Maximum LLW Volumes |
| --- |
| ***Objective:***<br>The objective of this strategy is to maximise the solid LLW arisings across the site from management of the DSRP wastes. Broadly this is achieved by diluting as many waste streams as possible so as to reduce activity per unit volume and cementing the resulting liquids. Few wastes are segregated for free release, whilst ILW is decontaminated to LLW and grouted. |
| ***Impact on treatment of waste streams:***<br>Particulates from active plant and building ventilation systems are captured on HEPAs and these are cemented as LLW. A multi-stage process involving catalysis and solid absorption removes H-3 as a solid phase which is cemented. Iodines are collected on activated carbon. Kr-85 is collected by zeolite separation.<br>Low-level liquid arisings are minimised using current practices, and all arisings are evaporated in a central facility and the residue cemented. All MALs, DFR and PFR raffinates, solvents and oils, and flocs and sludges are diluted to achieve LLW activity concentrations, and are then cemented.<br>All legacy and decommissioning solid LLW volumes are directly treated as LLW and are grouted and packaged, without using any segregation or decontamination methods.<br>The majority of the legacy and decommissioning solid ILW volumes are segregated and decontaminated to achieve LLW, and are grouted and packaged. Boron carbide is decontaminated by washing to remove H-3. Graphite is incinerated and the residues grouted. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ activity capture techniques for gaseous radionuclide (catalyst and absorption for H-3, zeolite separation plant for Kr-85, activated carbon iodines);<br>▪ central evaporator for low-level liquids;<br>▪ wet decontamination systems for solid ILW volumes;<br>▪ cementation plant for all MALs, and diluted PFR and DFR raffinates, oils and solvents, and flocs and sludges;<br>▪ incinerator for graphite; and<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:***<br>This strategy requires working practices that maximise generation of LLW by diluting ILW liquids and decontaminating ILW solids. Key technology dependencies include a cementation plant capable of handling a wide range of waste streams, including all MALs and diluted PFR and DFR raffinates, oils and solvents, and flocs and sludges.<br>Supporting R&D would be necessary to confirm the feasibility of cementing these waste streams, in particular the diluted PFR raffinate and the solvents and oils. Other techniques are ‘low tech’ and routine, such as remote waste sorting and segregation, and grouting and packaging.<br>This strategy generates large volumes of conditioned solid LLW.<br>Capital and running costs would be high for the cementation plant and the central evaporator. |

| $LLW_{Inter}$: Intermediate LLW Volumes |
|---|
| ***Objective:***<br>The objective of this strategy is to allow the generation of all necessary and unavoidable volumes of LLW arisings across the site from management of the DSRP wastes. Broadly this is achieved by adopting those waste treatment methods that minimise arisings where this is practicable, but only where appropriate to the safe, efficient and cost effective treatment of legacy and decommissioning wastes. |
| ***Impact on treatment of waste streams:***<br>Normal flow rates from building ventilation systems are adopted to capture particulates on HEPAs and these are cemented as LLW. A catalysis and solid absorption process removes H-3 as a solid phase which is cemented. Iodines are collected on silver. Kr-85 is collected by cryogenic distillation.<br>Low-level liquid arisings are minimised using current practices, and all arisings are evaporated in local facilities and the residues cemented. All MALs, and DFR and PFR raffinates are diluted to achieve LLW activity concentrations, and are then cemented. ADU floc is pre-treated to remove activity and this is cemented as ILW. Other flocs and sludges are dewatered and cemented. Solvents and oils are incinerated with abatement.<br>Solid LLW volumes are segregated so that some achieve free release and the remainder is grouted. Pits wastes are also decontaminated. Legacy and decommissioning solid ILW volumes are directly treated as ILW, without using any segregation or decontamination methods. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ activity capture techniques for gaseous radionuclide (catalyst and absorption for H-3, cryogenic distillation for Kr-85, silver for iodines);<br>▪ local evaporator(s) for low-level liquids;<br>▪ solvent extraction plant for removal of ADU floc;<br>▪ cementation plant for all MALs, diluted PFR and DFR raffinates, and dewatered flocs and sludges;<br>▪ incinerator for solvents and oils;<br>▪ central evaporator for low level liquids; and<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:***<br>This strategy requires working practices that minimise generation of LLW only where practicable. Key technology dependencies include a cementation plant capable of handling a wide range of waste streams, including all MALs and diluted PFR and DFR raffinates, and flocs and sludges.<br>Supporting R&D would be necessary to confirm the feasibility of cementing these waste streams, in particular the diluted PFR raffinate. Other techniques are ‘low tech’ and routine, such as remote waste sorting and segregation, and grouting and packaging.<br>This strategy generates large volumes of conditioned solid LLW.<br>Capital and running costs would be high for the cementation plant and the local evaporator(s). |

# 5 Attributes and scoring schemes

## 5.1 Attributes

In this DSRP wastes BPEO study, a series of 'attributes' have been defined as the means of measuring and comparing the key safety, environmental, technological, social and cost characteristics and consequences of each of the strategy options. This is Step 5 in the BPEO methodology as indicated in Figure 3.1. Attributes are chosen to reflect a wide variety of issues of potential concern to different stakeholders. Their ability to be scored objectively was also an important factor in their selection. The initial identification of attributes draws on previous options studies for similar issues, in particular the Dounreay Fuels BPEO [UKAEA 2001] and the Dounreay LLW BPEO [UKAEA 2003], although some additional attributes are also considered here which reflect particular aspects of the wider range of waste streams that arise under the DSRP.

In common with these previous BPEO studies, the attributes are collected together in a number of separate groups that together cover a range of all relevant topics, so as not to overly emphasise one particular aspect of the problem. The attribute groups are:

- ***Health and safety:*** attributes in this group reflect the confidence that a strategy option could protect human health from both radiological and non-radiological impacts. Three separate attributes were identified in this group: public health and safety (for individuals in critical group), public health and safety (societal) and worker health and safety (for individuals). These were each further divided into a number of sub-attributes.
- ***Environmental impacts:*** two attributes are recognised in this group: physical environment, and flora and fauna to reflect the fact that there is a clear distinction in UK environmental and planning laws between the consequences of industrial and construction activities on these two elements. The physical environment attribute is further subdivided into air quality, water quality, land, visual impact, nuisances (e.g. noise and traffic) and energy usage. The flora and fauna attribute is further subdivided into preservation of habitat and preservation of species.
- ***Technical performance:*** attributes in this group address a strategy option's abilities to perform its planned function. Two separate attributes were identified in this group, namely viability and flexibility. Viability is the ease with which it can be demonstrated that a waste strategy option is technically feasible within constraints imposed by the DSRP, considering the existing maturity of technology and the necessary R&D requirement to implement a strategy option on site. Flexibility is the scope for the strategy option to be varied, if required to meet requirements for different end-points for the solid wastes (e.g. different physical

or chemical characteristics of the wasteform), possible different timescales of waste arisings or the ability to accept different waste streams if they arise.

- ***Socio-economic:*** attributes in this group address possible impacts to the local community and communities elsewhere (remote from the immediate area surrounding Dounreay and Thurso) in terms of economy, and culture and heritage.
- ***Environmental objectives:*** there is only a single attribute in this group which is itself further divided into a number of sub-attributes that measure each strategy option's consistency with the strategic environmental objectives set out in a number of guidelines and regulations. These include the minimisation of solid waste volumes, progressive reductions in future discharges, an ability to concentrate and contain contaminants, implementation of precautionary action (which also accounts for the protection of future generations) and protection beyond national borders.
- ***Financial cost:*** there is only a single attribute and one sub-attribute in this group which measures the undiscounted cost of implementing each strategy option, as measured throughout the lifetime of the DSRP but within the constraints and scope of this BPEO study. This includes the capital costs of new plant, plus operational and decommissioning costs, as well as the cost of storage on site of the volumes of solid wastes generated. Costs of final disposal are not included because the final management route after storage is beyond the scope of this BPEO study.

In total, therefore, 32 separate sub-attributes are defined within these 6 attribute groups, as listed in Table 5.1.

**Table 5.1:** The attribute groups, attributes and sub-attributes used in the study.

| Attribute Group/ Attribute | Sub-attribute |
|---|---|
| ***Human health and safety:*** | |
| 1. Public heath and safety (individuals in critical group) | 1.1 Routine radiation doses<br>1.2 Radiological accident risks<br>1.3 Non-radioactive hazards and risks |
| 2. Public health and safety (societal) | 2.1 Routine radiation doses |
| 3. Worker health and safety (individuals) | 3.1 Routine radiation doses<br>3.2 Radiological accident risks<br>3.3 Non-radioactive hazards and risks |
| ***Environmental impact:*** | |
| 4. Physical environment | 4.1 Air quality<br>4.2 Water quality |

| Attribute Group/ Attribute | Sub-attribute |
|---|---|
| | 4.3 Land<br>4.4 Visual impact<br>4.5 Nuisances (noise, traffic etc)<br>4.6 Energy usage |
| 5. Flora and fauna | 5.1 Preservation of habitat<br>5.2 Conservation of species |
| ***Technical:*** | |
| 6. Viability | 6.1 Maturity of technology |
| 7. Flexibility | 7.1 Ability to cope with various endpoints for solid wastes<br>7.2 Ability to cope with various timescales<br>7.3 Ability to accept different waste streams |
| ***Socio-economic:*** | |
| 8. Local community | 8.1 Economic impacts<br>8.2 Culture and heritage |
| 9. Elsewhere | 9.1 Economic impacts<br>9.2 Culture and heritage |
| ***Environmental objectives:*** | |
| 10. Environmental objectives | 10.1 Waste minimisation<br>10.2 Progressive discharge reductions<br>10.3 Concentrate and contain<br>10.4 Precautionary action<br>10.5 Protection beyond national borders |
| ***Financial cost:*** | |
| 11 Overall cost | 11.1 Undiscounted cost |

A number of other issues were recognised as being relevant to the performance of the strategy options (e.g. 'Complexity of plant safety systems' and 'Monitorability') and could be included as sub-attributes. Insufficient information was available, however, to allow them to be adequately scored and, consequently, they were left out of the attribute list.

## 5.2 Scoring Scheme

The method of scoring each strategy option against all of the sub-attributes adopted for this BPEO study uses a simple system, which is based on an integer scale from 0 to 5 for each sub-attribute. This is Step 6 in the BPEO methodology as indicated in Figure 3.1. To help make the scoring system consistent and to relate the numerical scores to meaningful measures of performance, 'calibration schemes' were devised for each sub-attribute. If the performance of a strategy option as judged against a sub-attribute is considered to be "intolerable" then a score of 0 is awarded[8] and this issue was then addressed in the optimisation processes (see Section 7).

If the performance of a strategy option as judged against a sub-attribute is considered to be "very good" then a score of 5 is awarded. Intermediate scores are possible and would generally equate to a range of "acceptable" performance. Some calibrated scoring schemes are defined quantitatively (e.g. for risks to human health) and others are defined qualitatively (e.g. air quality). Qualitative scoring schemes are adopted when no numerical data on performance are possible or available, for example when an evaluation is necessarily subjective. The requirements for 0 and 5 scores for each sub-attribute are explained in Table 5.2, whilst the full details of the calibration schemes are presented in Appendix B.

**Table 5.2:** Requirements for a strategy option to score 0 or 5 against each sub-attribute used in this study.

| Attribute / Sub-attribute | Requirement for intolerable performance (Score = 0) | Requirement for very good performance (Score = 5) |
|---|---|---|
| ***1. Public heath and safety (individuals in critical group):*** | | |
| 1.1 Routine radiation doses | Difficult to demonstrate doses < 1 mSv $y^{-1}$ | Easy to demonstrate doses < 10 μSv $y^{-1}$ |
| 1.2 Radiological accident risks | Difficult to demonstrate risks < $10^{-4}$ $y^{-1}$ | Easy to demonstrate risks < $10^{-6}$ $y^{-1}$ |
| 1.3 Non-radioactive hazards and risks | Difficult to demonstrate risks < $10^{-4}$ $y^{-1}$ | Easy to demonstrate risks < $10^{-6}$ $y^{-1}$ |
| ***2. Public health and safety (societal):*** | | |
| 2.1 Routine radiation doses | Difficult to demonstrate doses < 100 person Sv | Easy to demonstrate doses < 1 person Sv |
| ***3. Worker health and safety (individuals):*** | | |
| 3.1 Routine radiation doses | Difficult to demonstrate doses < 20 mSv $y^{-1}$ | Easy to demonstrate doses < 2 mSv $y^{-1}$ |
| 3.2 Radiological accident risks | Difficult to demonstrate risks < $10^{-3}$ $y^{-1}$ | Easy to demonstrate risks < $10^{-5}$ $y^{-1}$ |
| 3.3 Non-radioactive hazards and risks | Difficult to demonstrate risks < $10^{-3}$ $y^{-1}$ | Easy to demonstrate risks < $10^{-5}$ $y^{-1}$ |
| ***4. Physical environment:*** | | |
| 4.1 Air quality | Persistent objectionable substances in air in buildings off the site | No discernible reduction in air quality |
| 4.2 Water quality | Sterilisation of water resource | No discernible reduction in water quality |
| 4.3 Land | Sterilisation of substantial area of land | No discernible reduction in land quality |

[8] When referring to issues of radiological dose and risk, the term 'intolerable' means from a regulatory viewpoint, rather than from necessarily a human health impact viewpoint.

| Attribute / Sub-attribute | Requirement for intolerable performance (Score = 0) | Requirement for very good performance (Score = 5) |
|---|---|---|
| 4.4 Visual impact | Construction completely out of keeping with existing landscape | No discernible visual impact |
| 4.5 Nuisances (noise, traffic etc) | Long-term disturbance/ disruption of local life | No outward signs of the waste management scheme |
| 4.6 Energy usage | Not defined | < 1% of the current total site power usage |
| ***5. Flora and fauna:*** | | |
| 5.1 Preservation of habitat | Complete loss of natural habitat | No discernible reduction in quality of the natural habitat |
| 5.2 Conservation of species | Complete loss of local species | No discernible impact on local species |
| ***6. Viability:*** | | |
| 6.1 Maturity of technology | Unproven and not achievable with existing technology in the timescale of the DSRP. | Established approach, with good track record and applied to similar waste streams under similar circumstances to those of DSRP waste management. |
| ***7. Flexibility:*** | | |
| 7.1 Ability to cope with various endpoints for solid wastes | Entirely dependent on solid waste endpoint being pre-defined in the DSRP | Easily adaptable to cope with redefinition of solid waste endpoint during the course of the DSRP |
| 7.2 Ability to cope with various timescales | Entirely dependent on timescales being pre-defined in the DSRP | Fully flexible to cope with waste treatment and waste arisings on other timescales during the course of the DSRP |
| 7.3 Ability to accept different waste streams | Entirely dependent on waste streams being pre-defined in the DSRP | Fully flexible to cope with new or additional waste streams identified during the course of the DSRP |
| ***8. Local community:*** | | |
| 8.1 Economic impacts | Collapse of local economy | Major enhancement to the local economy |
| 8.2 Culture and heritage | Collapse of local community through depopulation | Major enhancement of local community through increased population |
| ***9. Elsewhere:*** | | |
| 9.1 Economic impacts | Collapse of economy remote from the site | Major enhancement to economy remote from the site |
| 9.2 Culture and heritage | Collapse of community through depopulation remote from the site | Major enhancement of community through increased population remote from the site |
| ***10. Environmental objectives:*** | | |
| 10.1 Waste minimisation | Volume of solid waste generated is > 10 x DSRP | Volume of solid waste generated is 0.01 x DSRP |
| 10.2 Progressive discharge reductions | No overall reduction in discharges by the end of the DSRP | Rate of discharge reduction is 3 x DSRP |

| Attribute / Sub-attribute | Requirement for intolerable performance (Score = 0) | Requirement for very good performance (Score = 5) |
|---|---|---|
| 10.3 Concentrate and contain | > 90 % of current radionuclide inventory is discharged | < 10 % of current radionuclide inventory is discharged |
| 10.4 Precautionary action | Rate of hazard reduction by immobilisation or discharge is 0.1 x DSRP | Rate of hazard reduction by immobilisation or discharge is 10 x DSRP |
| 10.5 Protection beyond national borders | Legal challenge from abroad | No implications or positive international response |
| ***11 Overall cost:*** | | |
| 11.1 Undiscounted cost | Cost relative to the DSRP > £10,000M | Cost relative to the DSRP < £601M |

# 6 Scoring of the Strategy Options Against Attributes

Scores for each strategy option against each sub-attribute, on the basis of the scoring scheme discussed in Section 5.2 and presented in detail in Appendix B, were derived using a combination of information sources. These include source materials already available, or generated as part of the study, together with expert judgment on the part of the Project Team. The latter was based on their specific knowledge of ongoing and planned operations at Dounreay and radioactive waste management schemes adopted elsewhere. This is Step 7 in the BPEO methodology as indicated in Figure 3.1. The detailed scoring process adopted the following approach:

Scoring was undertaken concurrently for the three strategy options in a consistent manner for the major environmental issues discussed in Section 3.1 (i.e. liquid discharges, airborne discharges, volumes of ILW and volumes of LLW). The reason for this was to ensure that the consequences of the minimum, maximum and intermediate approaches for these strategies could be assessed in a consistent manner with respect to each sub-attribute.

Scoring of each strategy option was carried out with regard to the chosen representative waste management technologies and operational procedures, for arisings and waste treatment, identified for it and presented in the strategy option descriptions (Table 4.3). Thus, scores were awarded on the basis of the combined characteristics and consequences of all of the various technologies that go to make up a strategy option, rather than on a single technology.

When scoring against sub-attributes which relate to quantitative characteristics of a strategy option (e.g. energy usage and undiscounted cost), for which numerical information was available, relevant values (e.g. costs) for each separate technology or plant comprising the strategy option were individually defined. These were then totalled for all technologies and plants. The score for the entire strategy was then derived on the basis of this total.

When scoring against sub-attributes which relate to qualitative characteristics of a strategy option (e.g. visual impact) or quantitative characteristics for which numerical information was unavailable (e.g. air quality), the entire strategy option was considered, bearing in mind all of its component technologies and plant, and the score estimated in a single step, relative to the relevant scoring scheme for that sub-attribute. In such cases, scoring was performed collectively by the whole Project Team (or preliminary scores were reviewed by the whole Project Team) to ensure that the widest range of expert opinion was applied to the task.

Using this approach, scores were derived for the three strategy options related to each of the four major environmental issues, and these are presented in Tables 6.1 to 6.4 (in the A3 Tables which follow the Appendices). These tables also include a commentary justifying individual scores on the basis of the scoring scheme detailed in Appendix B. To aid visual appreciation of the scores, all scores of 5 (‘very good’ performance) are coloured green, whilst all scores of 0 (‘intolerable’ performance) are coloured red. To draw attention to other low scores in each strategy option that may be addressed in the optimisation stage (Section 7), scores of 1 and 2 are coloured yellow.

It should be noted that when scoring the options against sub-attributes that relate to quantitative characteristics, it was necessary for the Project Team to apply expert judgement in several cases. For example, this was the case in assessing the risk from processes that are not addressed in the present safety cases for activities at Dounreay, estimating the increased volumes of solid waste that would result from decontamination and segregation strategies that are different from those planned for the DSRP and estimating the costs of processes that are significantly different from the strategy that has been adopted for the DSRP. These assumptions are discussed in Appendix C. In the case of costs, only the aspects of each strategy that would have a major impact on the overall cost were addressed.

# 7 Optimised Strategy Options

Having scored the strategy options against the various sub-attributes (Tables 6.1 to 6.4) (in the A3 Tables section which follows the Appendices), it was possible to assess and compare the relative performances of these strategy options in a general manner. A number of basic observations were made:

1. Strategy options $Liq_{Max}$, $Atm_{Max}$, $ILW_{Min}$, $LLW_{Min}$ and $LLW_{Max}$ all scored 0 ('intolerable' performance) against one or more of the sub-attributes. None of these strategy options could, therefore, be the BPEO for the treatment of the DSRP wastes. This is largely a consequence of the gross detrimental impacts arising from direct discharge of the PFR raffinate to the sea (in $Liq_{Max}$, $ILW_{Min}$ and $LLW_{Min}$), the vitrification of the PFR raffinate and incineration of the graphite, and solvents and oils without abatement systems (in $Atm_{Max}$), and the generation of very large volumes of LLW to be stored in $LLW_{Max}$.
2. Strategy options $Liq_{Min}$ and $ILW_{Max}$ both scored 1 ('poor' performance) against one or more of the sub-attributes. It is unlikely that these strategy options could, therefore, be the BPEO for the treatment of the DSRP wastes. This is a consequence of high energy usage from central evaporators and the generation of large volumes of solid waste.
3. Strategy option $Atm_{Min}$ is the only 'maximum/minimum' strategy option that did not score either 0 or 1 against any of the sub-attributes. This strategy option did, however, score a 2 because of the lack of maturity in the novel technologies used to treat Kr-85 and H-3.
4. None of the 'intermediate' strategy options scored either 0 or 1 against any of the sub-attributes.

These observation suggest that the BPEO for the treatment of the DSRP wastes is most likely to involve a compromise between the 'minimum' and 'maximum' treatment methods for the different waste streams, i.e. the BPEO is most likely to be an intermediate strategy. That said, although none of the 'intermediate' strategy options scored a 0 or 1, none of these would necessarily be the BPEO because there is a wide spectrum of possible intermediate strategies that could be defined, and those identified previously are only representative examples.

## 7.1 Optimisation

With these observations in mind, the next stage was to optimise the 'maximum/minimum' strategy options with the management of the wastes streams altered where they previously lead to an intolerable or poor performance. As a result, new optimised maximum strategies were defined which leant in favour of maximising discharges or waste volumes and the new optimised minimum strategies leant towards minimising discharges or waste volumes. This is Step 8 in the BPEO methodology as indicated in Figure 3.1. The existing intermediate strategy options were not optimised because this would not indicate the extent to which minimising or maximising discharges or waste volumes is the BPEO.

The generation of optimised strategy options involved two main stages:

***Stage 1:*** defining the optimised strategy options on the basis of representative management methods for the individual waste streams, avoiding any that had resulted in low scores for the maximum/minimum strategy options, and

***Stage 2:*** scoring the optimised strategy options to evaluate the improvement in performance compared to the maximum/minimum strategy options.

These stages are discussed below.

***Stage 1:*** This involved identification of better performing alternative treatment methods to replace those causing poor or gross detrimental impacts in the scoring exercise for strategy options $Liq_{Min}$, $Liq_{Max}$, $Atm_{Min}$, $Atm_{Max}$, $ILW_{Min}$, $ILW_{Max}$, $LLW_{Min}$ and $LLW_{Max}$.

These alternatives were selected from the lists given in the ‘Options for Management Methods’ columns in Table 4.2 (in the A3 Tables section which follows the Appendices). The selection of alternative treatment methods was intended still to be broadly consistent with the overall objectives of each strategy option. This approach did, however, result in a degree of compromise with regards to the ‘maximum/minimum’ strategy options. For example, the intolerable performance of $Liq_{Max}$ (Maximum Liquid Discharge) was primarily a consequence of the direct discharge of several active liquid waste streams to the sea. Any alternative treatment method for the these would necessarily mean that the strategy would no longer be fully consistent with the overall objective of $Liq_{Max}$ which is ‘maximum’ discharges. In essence, therefore, the optimisation of the ‘maximum/minimum’ strategy options means that variants of the ‘intermediate’ strategy options are developed that have a bias towards the ‘maximum’ or ‘minimum’ extremes.

When optimising strategy options $Liq_{Max}$, $ILW_{Min}$ and $LLW_{Min}$, which involve the direct discharge of several active liquids to the sea, in order to improve the scores for the key attributes of 1.1 (Routine radiation dose – individuals in critical group) and 2.1 (Routine radiation dose – societal), alternative treatment methods were identified for each liquid waste stream in turn, starting with the most active, until the remaining discharged liquids resulted in a dose that was < 300 μSv $yr^{-1}$. In effect, these strategy options were optimised for discharges, using the resulting dose as a measure of improved performance. A dose of 300 μSv $yr^{-1}$ is deemed to be the maximum acceptable dose and was, therefore, set as an optimisation ‘target’ in this instance. There was no point optimising only for the discharge of PFR raffinate (the most active liquid stream) because this would still have resulted in an unacceptable score for these dose attributes and, therefore, several additional optimisation iterations would be required.

This is illustrated by the doses for the intermediate strategies $Liq_{MaxOpt}$-i and $Liq_{MaxOpt}$-ii in Table C1.1 of Appendix C.

Similarly, when optimising each of the strategy options to improve the scores for attribute 13.1 (Undiscounted cost), alternative treatment methods were identified for all treatment methods that incurred an additional cost of £100M in excess of the cost of the DSRP, to avoid the need for repetitive iterations. The value of £100M was determined to be a sensible optimisation target given the acknowledged uncertainties in defining costs for some of the treatment methods identified in the strategy options.

Using these approaches, the strategy options $Liq_{Min}$ and $Liq_{Max}$ (associated with liquid discharges) were optimised first, followed by $Atm_{Min}$ and $Atm_{Max}$ (associated with gaseous discharges), and then the strategy options $ILW_{Min}$, $ILW_{Max}$, $LLW_{Min}$ and $LLW_{Max}$ (associated with solid waste volumes). This was so that site discharges could be explicitly addressed in relation to future RSA discharge authorisations related to management of the DSRP wastes. Whilst optimising, any changes made to the identified representative management methods in one strategy option were automatically included in the optimisation of the other strategy options where the same representative management methods occurred.

The resulting optimised strategy options are shown in Table 7.1 (in A3 Tables which follow Appendices) and are described in more detail in Table 7.2 on the following pages.

**Table 7.2** (next 8 pages)**:** The overall objectives of each optimised strategy options, together with the representative treatments and management methods identified for individual waste streams.

| **$Liq_{OptMin}$: Optimised Minimum Liquid Discharges** |
|---|
| ***Objective:***<br>The objective of this optimised strategy is to allow minimum liquid discharges from the site, without incurring excessive costs and without generating excessive volumes of solid wastes. Broadly this is achieved by sensibly minimising the use of liquids during waste treatment (e.g. by adopting a range of appropriate technologies) and by converting some liquid wastes to solid forms (e.g. by cementation). |
| ***Impact on treatment of waste streams:***<br>Airborne waste streams either go untreated and are directly discharged to the environment (H-3, C-14 and Kr-85) or, where possible, are managed with dry treatments and filters (particulates).<br>Liquid waste streams are minimised through various methods to limit arisings, and immobilised using cement in most cases, although this may not be viable for the solvents and oils. ADU floc is cemented but the floc supernate is discharged [compared to cementation of floc and supernate in $Liq_{Min}$].<br>Solid waste streams generally can be handled by any treatment process except those that use liquids for decontamination. Many can be grouted without impacting on liquid discharges. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ HEPAs for active building ventilation filtration;<br>▪ range of technologies to minimise LLL arisings;<br>▪ ion exchange system to treat LLL that does arise [replacing central evaporator];<br>▪ liquid decontamination of decommissioning systems containing MALs [replacing robotic dismantling];<br>▪ cementation plant for legacy MALs, DFR and PFR raffinate [replacing vitrification plant for PFR raffinate], oils and solvents, flocs and sludges;<br>▪ equipment for remote sorting and segregation of solid decommissioning and legacy (Shaft, pits and silo) wastes;<br>▪ equipment for dry decontamination of solid decommissioning wastes;<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:***<br>Key technology dependencies are a cementation plant that is sufficiently flexible to handle a wide range of waste streams including the MALs, DFR and PFR raffinate, and flocs and sludges.<br>Supporting R&D would be necessary to confirm the feasibility of cementing some of these waste streams, in particular the solvents and oils, and the long term stability of cemented PFR raffinate. Dry decontamination techniques will require optimising for the specific solid decommissioning wastes that will be generated. Other techniques are routine, such as remote waste sorting and segregation, and grouting and packaging.<br>Capital and running costs for the various technologies are likely to be low to moderate. |

| $Liq_{OptMax}$: Optimised Maximum Liquid Discharges |
|---|
| ***Objective:***<br>The objective of this optimised strategy is to allow maximum discharges from the site, without causing unacceptable doses to the public and workers, or excessive detrimental impacts to the environment and the local community. Broadly this is achieved by adopting waste treatment methods that use liquids (e.g. wet decontamination methods) and by actively discharging some low-level liquid wastes to the environment. |
| ***Impact on treatment of waste streams:***<br>Airborne waste streams from active building ventilation are treated by current practices [compared to wet scrubbers in $Liq_{Max}$]. C-14 and I-129 are remain treated by wet scrubbers, while 3H is treated by dehumidification.<br>Most liquid waste streams are cemented [compared to direct disposal in $Liq_{Max}$] but LLL, ADU supernate and LLLETP are still directly discharged.<br>Solid decommissioning waste streams are decontaminated using liquids which are then treated or cemented, except LLL which is still directly discharged. Pits wastes are not retrieved. Graphite is incinerated using equipment fitted with wet scrubbers. Boron carbide is dissolved and the solution directly discharged. Tritiated metals are smelted using equipment fitted with wet scrubbers. Remaining solids are generally grouted and packaged. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ incinerator for graphite [solvents and oils may also be incinerated];<br>▪ smelting plant for tritiated metals;<br>▪ wet scrubbers for I-129 and C-14;<br>▪ cementation plant for legacy MALs, DFR and PFR raffinate, oils and solvents, flocs and sludges (except LLLETP sludge);<br>▪ equipment for remote sorting and segregation of solid decommissioning and legacy (Shaft and silo) wastes;<br>▪ equipment for liquid decontamination of solid decommissioning wastes;<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:***<br>Key technology dependencies are a cementation plant that is sufficiently flexible to handle a wide range of waste streams including the MALs, DFR and PFR raffinate, and flocs and sludges.<br>Supporting R&D would be necessary to confirm the feasibility of cementing some of these waste streams, in particular the solvents and oils (if cemented), and the long term stability of cemented PFR raffinate. Wet decontamination techniques will require optimising for the specific solid decommissioning wastes that will be generated. Other techniques are 'low tech' and routine, such as remote waste sorting and segregation, and grouting and packaging.<br>Capital and running costs for the various technologies are likely to be low to moderate. |

| $Atm_{OptMin}$: Optimised Minimum Airborne Discharges |
|---|
| ***Objective:***<br>The objective of this optimised strategy is to minimise the airborne discharges from the site, without incurring excessive costs from treating hard to scrub gaseous species, whilst avoiding unacceptable doses to the public and workers, and impacts to the environment. Broadly this is achieved by utilising normal practices during decommissioning activities and waste treatment to limit gaseous discharges and to suppress or remove airborne particulates and gases, rather than discharging them to the environment. Direct cementation and in-situ treatments are utilised wherever practicable. |
| ***Impact on treatment of waste streams:***<br>Airborne waste streams are minimised by use of all practicable methods and discharges are minimised by use of HEPAs. Other particulates undergo in-situ encapsulation. Iodines are passed over activated charcoal and C-14 is treated by wet scrubbers. Kr-85 is directly discharged [compared to being treated by cryogenic distillation in $Atm_{Min}$].<br>Liquid waste streams are minimised using various methods but excluding those involving evaporation. Legacy MALs, and DFR and PFR raffinates, sludges and flocs, and solvents and oils are directly immobilised using cement, with the exception of ADU supernate which is directly discharged [compared to being directly cemented in $Atm_{Min}$]. Shaft and silo sludges are cemented, having been initially frozen to reduce particulate production during retrieval.<br>Solid waste streams generally undergo minimum handling and are sealed prior to removal and grouting, in order to minimise particulate production. Pits wastes and soils undergo in-situ encapsulation. Storage of wastes, especially tritiated metals, takes place in unventilated buildings. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ efficient filtration/abatement systems for gaseous discharge points (e.g. HEPAs, and wet and dry scrubbers);<br>▪ dehumidifier for H-3 [replacing condensation];<br>▪ liquid decontamination of decommissioning systems containing MALs [replacing robotic dismantling];<br>▪ cementation plant for legacy MALs, DFR and PFR raffinates, oils and solvents, flocs and sludges;<br>▪ equipment for freezing Shaft and silo sludges, and retrieval of the frozen product; and<br>▪ equipment for remote handling and treatment of various solid wastes. |
| ***Key issues:***<br>Key technology dependencies are efficient filtration/abatement systems, and cementation plant(s) that are sufficiently flexible to handle a wide range of waste streams including the MALs, DFR and PFR raffinates, flocs and sludges etc.<br>Supporting R&D would be necessary to confirm the long term stability of some of these cemented waste streams, in particular the PFR raffinate and the solvents and oils. Development work would be required to establish feasibility of freezing and retrieving Shaft and silo wastes. Other techniques are routine, such as remote waste sorting and segregation, and grouting and packaging.<br>Capital and running costs will be moderate. |

| $Atm_{OptMax}$: Optimised Maximum Airborne Discharges |
|---|
| ***Objective:***<br>The objective of this optimised strategy is to maximise the airborne discharges from the site, without causing unacceptable doses to the public and workers, or excessive detrimental impacts to the environment and the local community. Broadly this is achieved by applying current practices to minimise particulates from active buildings, and applying HEPAs to the ventilation system. Other gaseous waste streams and directly discharged.<br>Abatement systems are fitted to high temperature plants such as incinerators and vitrification plants [compared to no abatement in $Atm_{Max}$]. |
| ***Impact on treatment of waste streams:***<br>Airborne waste streams from building ventilation systems are treated by HEPAs. H-3, C-14, Kr-85 and iodines are discharged directly, whilst contaminated soils are subject to simple lift and shift.<br>LLL arisings are minimised and treated through ion exchange columns [compared to unabated evaporators in $Atm_{Max}$]. MALs are washed out and evaporated with abatement [compared to unabated evaporators in $Atm_{Max}$]. DFR and PFR raffinates and ADU floc are vitrified with abatement [compared to unabated vitrification in $Atm_{Max}$]. Solvents and oils, and graphite are incinerated with abatement [compared to unabated incineration in $Atm_{Max}$]. Shaft, silo and LLLETP sludges are cemented [compared to unabated vitrification in $Atm_{Max}$].<br>Decommissioning solid waste streams generally undergo dry handling and decontamination, and are recycled where possible. Most wastes are segregated, supercompacted and grouted. Boron carbide is decontaminated by washing to release H-3, soils are simply lifted and shifted. Other wastes are treated with any suitable technique. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ abated vitrification plant for DFR and PFR raffinates, and ADU floc;<br>▪ cementation plant for Shaft, silo and LLLETP sludges;<br>▪ ion exchange systems for low level liquids<br>▪ abated evaporator for legacy and decommissioning MALs;<br>▪ abated incinerator for solvents and oils, and graphite;<br>▪ abated smelting plant for tritiated metals;<br>▪ equipment for dry decontamination of solid decommissioning wastes;<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:***<br>Key technology dependencies are a vitrification plant capable of handling DFR and PFR raffinates, and ADU floc, and a cementation plant capable of handling Shaft, silo and LLLETP sludges.<br>Supporting R&D would be necessary to confirm the feasibility of vitrifying and cementing some of these waste streams, in particular the flocs and sludges. Dry decontamination techniques will require optimising for the specific solid decommissioning wastes that will be generated. Other techniques are routine, such as remote waste sorting and segregation, and grouting and packaging.<br>High capital and running costs will be associated with the vitrification plant. |

| $ILW_{OptMin}$: Optimised Minimum ILW Volumes |
| --- |
| ***Objective:***<br>The objective of this optimised strategy is to minimise the volumes of ILW arisings, without causing unacceptable doses to the public and workers, or excessive detrimental impacts to the environment and the local community or overly increasing the volume of LLW. Broadly this is achieved by segregating and decontaminating solid waste materials wherever sensible, and by cementing most liquid wastes. |
| ***Impact on treatment of waste streams:***<br>Airborne waste streams from building ventilation systems are minimised by practicable methods and discharges are reduced by use of HEPAs. Other gaseous waste streams are directly discharged.<br>All methods are used to limit arisings of low-level liquid; those that do arise are directly discharged to sea. MALs and most sludges and flocs are cemented [compared to direct discharge in $ILW_{Min}$] with the exception of ADU supernate and LLLETP sludge which are directly discharged. DFR and PFR raffinates are vitrified [compared to direct discharge in $ILW_{Min}$] and solvents and oils are incinerated [compared to direct discharge in $ILW_{Min}$].<br>Legacy and decommissioning solid ILW volumes are minimised by segregation, decontamination and compaction. Boron carbide is decontaminated by washing to remove H-3. Graphite is incinerated prior to grouting of the residue. All remaining ILW solids are grouted. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ vitrification plant for DFR and PFR raffinates;<br>▪ cementation plant for flocs and sludges;<br>▪ incinerator for graphite, and solvents and oils;<br>▪ equipment for segregation and decontamination of solid ILW wastes;<br>▪ equipment for grouting and packaging of solid ILW wastes. |
| ***Key issues:***<br>Key technology dependencies are a vitrification plant capable of handling DFR and PFR raffinates, and a cementation plant capable of handling flocs and sludges, and an incinerator for graphite, solvents and oils.<br>Other methods are ‘low tech’ and routine, such as remote waste sorting and segregation, and grouting and packaging, and little development work will be required.<br>High activity releases to the environment will result.<br>Capital and running costs are high for the vitrification plant. |

| $ILW_{OptMax}$: Optimised Maximum ILW Volumes |
|---|
| ***Objective:***<br>The objective of this optimised strategy is to maximise the volumes of ILW arisings, without incurring excess costs from not segregating ILW. Broadly this is achieved by treating wastes as ILW where possible, adopting wet decontaminating methods and concentrating activity (e.g. using ion exchange columns) and cementing most liquid wastes. |
| ***Impact on treatment of waste streams:***<br>Increased flow rates from active plant and building ventilation systems are used to maximise particulate collection and concentration to ILW levels (although ILW HEPAs are not the norm).<br>H-3 is treated by a dehumidifier [compared to catalysis and solid absorption in $ILW_{Max}$]. Kr-85 is directly discharged [compared to being treated by zeolite separation in $ILW_{Max}$].<br>Low-level liquid arisings are minimised using current practices, and all arisings are treated using ion exchange columns [compared to a central evaporator in $ILW_{Max}$]. All MALs, DFR and PFR raffinates, solvents and oils, and flocs and sludges are all cemented.<br>Solid legacy or decommissioning waste streams are segregated [compared to no segregation in $ILW_{Max}$]. Where possible, solid LLW volumes are decontaminated using wet techniques and the extracted activity is concentrated (e.g. on ion exchange resins) and treated as ILW. Decontaminated materials are grouted as LLW. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ activity capture techniques for some gaseous radionuclide (dehumidifier for H-3, activated carbon for iodines);<br>▪ ion exchange columns for low-level liquids;<br>▪ wet decontamination systems for solid LLW volumes;<br>▪ ion exchange plant to concentrate activity from decontamination liquids;<br>▪ cementation plant for all MALs, DFR and PFR raffinates, oils and solvents, and flocs and sludges; and<br>▪ equipment for grouting and packaging of segregated solid decommissioning and legacy wastes. |
| ***Key issues:***<br>Key technology dependencies include a cementation plant capable of handling a wide range of waste streams, wet decontamination systems for solid LLW and a ion exchange systems to concentrate activity.<br>Supporting R&D would be necessary to confirm the long term stability of some of these cemented waste streams, in particular the PFR raffinate and the solvents and oils, and to optimise the wet decontamination systems.<br>Large volumes of packaged solid ILW wastes will be generated.<br>Capital and running costs will be high for the cementation plant. |

| $LLW_{OptMin}$: Optimised Minimum LLW Volumes |
|---|
| ***Objective:*** <br> The objective of this strategy is to minimise as far as possible the solid LLW volumes arisings, without causing unacceptable doses to the public and workers, or excessive detrimental impacts to the environment and the local community. Broadly this is achieved by the direct discharge of low level liquid waste streams, and the direct treatment of solid ILW volumes without segregation or decontamination. |
| ***Impact on treatment of waste streams:*** <br> Airborne waste streams from active plant and building ventilation systems are minimised and discharged via HEPAs. All other gaseous waste streams are directly discharged. <br> All efforts are made to minimise low level liquid arisings, those that do result are directly discharged to sea. All MALs, DFR and PFR raffinates and most flocs and sludges are cemented, with the exception of LLLETP sludge which is directly discharged. Solvents and oils are incinerated. <br> All measures are taken to minimise arisings of solid LLW volumes. The Pits wastes are not retrieved and soils are left in situ. Cellulosic solid LLW is incinerated without abatement. Tritiated metals are smelted to release H-3. The remainder of the legacy and decommissioning solid LLW volumes are segregated and decontaminated to release materials for re-use, where possible. Solid residues are compacted and grouted. <br> All legacy and decommissioning solid ILW volumes are directly treated as ILW, without using any segregation or decontamination methods. |
| ***Technology requirements:*** <br> Key technology and plant requirements are: <br> ▪ cementation plant for MALs, DFR and PFR raffinates, ADU floc, and Shaft, silo and sludges; <br> ▪ incinerator for cellulosic LLW volumes; <br> ▪ smelter for tritiated metals; <br> ▪ liquid decontamination of decommissioning systems containing MALs [replacing robotic dismantling]; <br> ▪ equipment for segregating and decontaminating solid LLWs; and <br> ▪ equipment for grouting and packaging a wide range of solid decommissioning and legacy wastes. |
| ***Key issues:*** <br> Key technology dependencies include an incinerator for cellulosic material and a smelter for tritiated metals, as well as a cementation plant that is sufficiently flexible to handle a wide range of waste streams including the MALs, DFR and PFR raffinates, flocs and sludges etc. <br> Supporting R&D would be necessary to confirm the long term stability of some of these cemented waste streams, in particular the PFR raffinate. Wet decontamination techniques will require optimising for the solid LLWs. Other techniques are ‘low tech’ and routine, such as remote waste sorting and segregation, and grouting and packaging. <br> Capital and running costs will be low to moderate for the cementation plant, incinerator and smelter. |

| $LLW_{OptMax}$: Optimised Maximum LLW Volumes |
|---|
| ***Objective:***<br>The objective of this strategy is to maximise the solid LLW arisings, without causing unacceptable doses to the public and workers, or excessive detrimental impacts to the environment and the local community. Broadly this is achieved by decontaminating solid ILW to reclassify as LLW and not segregating solid LLW. |
| ***Impact on treatment of waste streams:***<br>Particulates from active plant and building ventilation systems are captured on HEPAs and these are cemented as LLW. A dehumidifier is used to treat H-3. Iodines are collected on activated carbon. Kr-85 is directly discharged.<br>Low-level liquid arisings are minimised using current practices, and all arisings are decontaminated using ion exchange columns, and the residue cemented. All MALs, DFR and PFR raffinates, solvents and oils, and flocs and sludges are cemented as ILW [compared to being diluted and cemented as LLW in $LLL_{Max}$].<br>All legacy and decommissioning solid LLW volumes are treated as LLW and are segregated and grouted.<br>The majority of the legacy and decommissioning solid ILW volumes are segregated and decontaminated to achieve LLW, and are grouted and packaged. Boron carbide is decontaminated by washing to remove H-3. Graphite is incinerated and the residues grouted. |
| ***Technology requirements:***<br>Key technology and plant requirements are:<br>▪ dehumidifier for H-3;<br>▪ activated carbon system for iodines;<br>▪ ion exchange system for low-level liquids [replacing central evaporator];<br>▪ wet decontamination systems for solid ILW volumes;<br>▪ cementation plant for all MALs, and diluted PFR and DFR raffinates, oils and solvents, and flocs and sludges;<br>▪ incinerator for graphite; and<br>▪ equipment for grouting and packaging of solid decommissioning and legacy wastes. |
| ***Key issues:***<br>Key technology dependencies include a cementation plant capable of handling a wide range of waste streams, including all MALs and diluted PFR and DFR raffinates, oils and solvents, and flocs and sludges.<br>Supporting R&D would be necessary to confirm the feasibility of cementing these waste streams, in particular the diluted PFR raffinate and the solvents and oils. Other techniques are 'low tech' and routine, such as remote waste sorting and segregation, and grouting and packaging.<br>This strategy generates large volumes of conditioned solid LLW.<br>Capital and running costs would be high for the cementation plant. |

***Step 2:*** This involved re-scoring of the optimised strategy options to determine how much improved the scores are with the alternative treatment methods replacing the original poorly performing representative treatment methods.

The re-scoring was performed against the same set of sub-attributes listed in Table 5.1, in exactly the same way as the first scoring exercise as described in Section 6. Re-scoring does not mean that every individual score will be changed, but only those scores relating to sub-attributes against which the performance of the strategy option is sensitive. In the case of some sub-attributes, scores can be lowered where the original treatment methods had 'very good' performance and the alternative treatment method has less good performance. For example, the 'very good' performance of $Liq_{Max}$ (Maximum Liquid Discharge) against sub-attribute 13.1: Undiscounted cost was achieved because the direct discharge of the PFR raffinate needs no major plant with high capital or running costs. Replacing 'direct discharge' with 'cementation' (from Table 7.1) makes the strategy option more expensive and, therefore, the score against this sub-attribute is lowered. The determination as to whether the original or optimised strategy options is the better, depends on the balance of how the overall scores for all sub-attributes change. In the case of undiscounted cost, the more sensitive scoring scheme in Appendix C4 was used.

Using this approach, the scores for the optimised strategy options are presented in Tables 7.3 to 7.6 in the A3 Tables which follow the Appendices. As before, to aid visual appreciation of the scores, all scores of 5 ('very good' performance) are coloured green. In addition, where a score has changed as a result of the optimisation, the previous score is indicated in parentheses.

To help understand these optimised scores, Table 7.7 below provides a summary of all of those scores where there is a difference in the scores awarded between each of the pairs that relate to liquid discharges, airborne discharges, solid ILW volumes and solid LLW volumes. This table shows that, overall, the differences between the scores for the optimised strategy options are small.

**Table 7.7:** Comparison of the optimised scores where they differ.

| Sub-attribute | MinOpt | MaxOpt |
|---|---|---|
| *Liquid discharges ($Liq_{MinOpt}$ and $Liq_{MaxOpt}$):* | | |
| 1.1 Routine doses (individuals in critical group) | 4 | 3 |
| 2.1 Routine radiation doses (societal) | 5 | 4 |
| 4.1 Air quality | 5 | 4 |
| 4.2 Water quality | 5 | 4 |
| 7.3 Accept other waste streams | 5 | 4 |
| 10.1 Waste minimisation | 2 | 3 |
| 10.3 Concentrate and contain | 5 | 4 |
| 11.1 Undiscounted cost | 2 | 5 |

| Sub-attribute | MinOpt | MaxOpt |
| --- | --- | --- |
| *Airborne discharges (*$Atm_{MinOpt}$ *and* $Atm_{MaxOpt}$*):* | | |
| 1.1 Routine radiation doses (individuals) | 5 | 4 |
| 1.3 Non radioactive hazards and risks (individuals) | 5 | 4 |
| 2.1 Routine radiation doses (societal) | 5 | 4 |
| 4.1 Air quality | 5 | 4 |
| 6.1 Maturity of technology | 5 | 4 |
| 7.1 Ability cope with various solid end-points | 4 | 3 |
| 10.2 Progressive discharge reductions | 5 | 3 |
| 10.3 Concentrate and contain | 5 | 4 |
| 10.4 Precautionary action | 4 | 3 |
| 10.5 Protection beyond national boundaries | 5 | 4 |
| 11.1 Undiscounted cost | 5 | 3 |
| *Solid ILW volumes (*$ILW_{MinOpt}$ *and* $ILW_{MaxOpt}$*):* | | |
| 1.1 Routine doses (individuals in critical group) | 3 | 5 |
| 1.3 Non radioactive hazards and risks (individuals) | 4 | 5 |
| 2.1 Routine radiation doses (societal) | 4 | 5 |
| 3.1 Routine radiation doses (workers) | 3 | 5 |
| 4.1 Air quality | 3 | 5 |
| 7.3 Accept other waste streams | 4 | 5 |
| 10.1 Waste minimisation | 4 | 3 |
| 10.3 Concentrate and contain | 4 | 5 |
| 10.5 Protection beyond national boundaries | 4 | 5 |
| *Solid LLW volumes (*$LLW_{MinOpt}$ *and* $LLW_{MaxOpt}$*):* | | |
| 1.1 Routine radiation doses (individuals) | 3 | 4 |
| 1.3 Non radioactive hazards and risks (individuals) | 4 | 5 |
| 3.1 Routine radiation doses (workers) | 4 | 3 |
| 4.1 Air quality | 3 | 5 |
| 4.4 Visual impact | 4 | 3 |
| 5.1 Preservation of habitat | 4 | 5 |
| 5.2 Conservation of species | 4 | 5 |
| 10.3 Concentrate and contain | 4 | 5 |
| 10.5 Protection beyond national boundaries | 4 | 5 |
| 11.1 Undiscounted cost | 5 | 2 |

# 8 Identifying the BPEO

The full details of the optimised strategy options scores are provided in Tables 7.3 to 7.6 (in the A3 Tables section which follows the Appendices), together with explanations of where and why particular scores have changed as a result of optimisation. These scores are summarised in Table 8.1.

**Table 8.1:** Summary of the scores for the optimised strategy options.

| | Liq Min Opt | Liq Max Opt | Air Min Opt | Air Max Opt | ILW Min Opt | ILW Max Opt | LLW Min Opt | LLW Max Opt |
|---|---|---|---|---|---|---|---|---|
| 1.1 Routine radiation doses | 4 | 3 | 5 | 4 | 3 | 5 | 3 | 4 |
| 1.2 Radiological accident risks | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 1.3 Non-rad. hazards and risks | 5 | 5 | 5 | 4 | 4 | 5 | 4 | 5 |
| 2.1 Routine radiation doses | 5 | 4 | 5 | 4 | 4 | 5 | 4 | 4 |
| 3.1 Routine radiation doses | 4 | 4 | 4 | 4 | 3 | 5 | 4 | 3 |
| 3.2 Radiological accident risks | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 3.3 Non-rad. hazards and risks | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 4.1 Air quality | 5 | 4 | 5 | 4 | 3 | 5 | 3 | 5 |
| 4.2 Water quality | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 |
| 4.3 Land | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 |
| 4.4 Visual impact | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 |
| 4.5 Nuisances (noise, traffic etc.) | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 4.6 Energy usage | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 |
| 5.1 Preservation of habitat | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 |
| 5.2 Conservation of species | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 |
| 6.1 Maturity of technology | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 |
| 7.1 Cope with different endpoints | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| 7.2 Cope with various timescales | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 7.3 Accept other waste streams | 5 | 4 | 4 | 4 | 4 | 5 | 4 | 4 |
| 8.1 Economic impacts | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 8.2 Culture and heritage | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 9.1 Economic impacts | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 9.2 Culture and heritage | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 10.1 Waste minimisation | 2 | 3 | 3 | 3 | 4 | 3 | 4 | 3 |
| 10.2 Discharge reduction | 5 | 5 | 5 | 3 | 5 | 5 | 5 | 5 |
| 10.3 Concentrate and contain | 5 | 4 | 5 | 4 | 4 | 5 | 4 | 5 |
| 10.4 Precautionary action | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| 10.5 Protection beyond borders | 5 | 5 | 5 | 4 | 4 | 5 | 4 | 5 |
| 11.1 Undiscounted cost | 2 | 5 | 5 | 3 | 3 | 3 | 5 | 2 |
| ***TOTALS*** | ***117*** | ***115*** | ***120*** | ***107*** | ***112*** | ***122*** | ***113*** | ***115*** |

Having scored the optimised strategy options against the various sub-attributes (Table 8.1), it is possible to assess and compare the relative performances of these strategy options in a general manner. As with the un-optimised strategy options, a number of basic observations were made:

1. None of the optimised strategy options score a 0 or a 1 and, therefore, overall the performance of these optimised strategies is better than the 'maximum/minimum' strategy options from which they were derived.
2. The lowest score awarded was 2 and this was to:
   - $Liq_{MinOpt}$ for attribute 10.1 (Waste minimisation) and 11.1 (Undiscounted cost), because this strategy option includes cementation of all liquid wastes, with the exception of the low level liquids, but does include direct cementation of large volumes of LLLETP sludge which in other optimised strategy options is discharged to sea or cemented following dewatering; and
   - $LLW_{MaxOpt}$ for attribute 11.1 (Undiscounted cost) because this strategy does not segregate general LLW metals and includes cementation of most liquid wastes, although LLLETP sludge is dewatering prior to cementation (hence the score 3 against 'Waste minimisation').
3. The number of scores of 5 ('very good' performance and coloured yellow in Table 8.1) has increased for all optimised strategy options. This is largely because optimisation to improve dose scores has reduced the number of liquid and gaseous waste streams that are directly discharged to the environment. As a direct consequence, other environmental impacts associated with these discharges have also been minimised, thus increasing their scores for some attributes – to 5 in many cases (e.g. attributes 4.2 'Water quality', 4.3 'Land quality' and 10.5 'Protection beyond national borders').
4. A small number of scores were lowered as a result of optimisation of the strategy options. In most cases this related to increasing waste volumes as a result of minimising discharges.

## 8.1 Aggregating Scores

There are various ways in which these scores can be analysed to determine which are the better performing optimised strategy options. Table 8.1 indicates the total scores for each of the optimised strategy options but these total scores can be misleading on their own because they can be biased in favour of options that score well for particular attribute groups due to differing number of sub-attributes in the groups.

An alternative way of presenting the scores is to calculate the average scores awarded for each attribute group (avoiding bias due to the number of sub-attributes), and these averaged scores are presented in Table 8.2. Yet another alternative presentation is to calculate the lowest score awarded in each attribute group because this avoids masking any poor scores by averaging, and these lowest scores are also presented in Table 8.2.

**Table 8.2:** Average and lowest scores for each optimised strategy option, plus their respective totals, awarded in each attribute group.

| | Liq Min Opt | Liq Max Opt | Atm Min Opt | Atm Max Opt | ILW Min Opt | ILW Max Opt | LLW Min Opt | LLW Max Opt |
|---|---|---|---|---|---|---|---|---|
| *Average scores:* | | | | | | | | |
| Group 1: Human health | 3.9 | 3.6 | 4.0 | 3.6 | 3.3 | 4.1 | 3.4 | 3.6 |
| Group 2: Environmental impact | 4.5 | 4.3 | 4.4 | 4.3 | 4.4 | 4.6 | 4.1 | 4.5 |
| Group 3: Technical issues | 4.8 | 4.5 | 4.5 | 4.0 | 4.5 | 4.8 | 4.5 | 4.5 |
| Group 4: Socio-economic issues | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Group 5: Environmental objectives | 4.2 | 4.2 | 4.4 | 3.4 | 4.2 | 4.4 | 4.2 | 4.4 |
| Group 6: Cost | 2.0 | 5.0 | 5.0 | 3.0 | 3.0 | 3.0 | 5.0 | 2.0 |
| ***Total*** | ***22.4*** | ***24.6*** | ***25.3*** | ***21.3*** | ***22.4*** | ***23.9*** | ***24.2*** | ***22.0*** |
| *Lowest scores:* | | | | | | | | |
| Group 1: Human health | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Group 2: Environmental impact | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 |
| Group 3: Technical issues | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| Group 4: Socio-economic issues | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Group 5: Environmental objectives | 2 | 3 | 3 | 3 | 4 | 3 | 4 | 3 |
| Group 6: Cost | 2 | 5 | 5 | 3 | 3 | 3 | 5 | 2 |
| ***Total*** | ***17*** | ***21*** | ***21*** | ***18*** | ***20*** | ***20*** | ***22*** | ***18*** |

It can be seen that the scores for all 8 optimised strategy options are broadly similar but there are some important differences.

From the point of view of determining which optimised strategy options perform best, it was considered that the lowest scores for the attribute groups (the lower half of the table above) is the most appropriate to use. This is because paying attention to the lowest scores is a conservative approach that avoids masking any particularly poor performance against specific sub-attributes, which would otherwise occur through averaging.

## 8.2 Comparing MinOpt and MaxOpt Strategies

The BPEO was not chosen simply on the basis of the highest scores for the optimised strategies. The scores were, instead, used to inform the decision making process by directing the evaluation to the comparative performance of all the optimised strategy options against the various attributes used. Thus, the four pairs of optimised strategies were compared and analysed to determine the optimised strategy options for liquid and airborne discharges, and the volumes of solid ILW and LLW waste that perform better.

In the case of $Liq_{MinOpt}$ and $Liq_{MaxOpt}$, which focus on liquid discharges, $Liq_{MinOpt}$ scores less well overall because, as shown in the table above, the direct cementing of waste streams with no dewatering, such as the MALs, and the lack of decontamination of ILW metals means that it only scores 2 against the 'Environmental objective' attribute group, which includes waste minimisation. The additional waste created also means that it scores less well on the 'Cost' attribute group. Thus, of these two, $Liq_{MaxOpt}$ is the preferred option. This preference is consistent with the average scores in Table 8.2.

In the case of $Atm_{MinOpt}$ and $Atm_{MaxOpt}$, which focus on atmospheric discharges, $Atm_{MaxOpt}$ scores less well against the attribute groups 'Technical issues' and 'Cost'. This is because this strategy includes the vitrification of the HALs and ADU floc which results in a lowest score of 3 against for the 'Technical issues' attribute group because vitrification is both less flexible and more expensive than cementation. If these waste streams were cemented instead of vitrified [thus generating a revised optimised strategy option, $Atm_{MaxOpt}$*] the score for the 'Maturity of technology' sub-attribute (6.1) would rise from 4 to 5, the score for the 'Ability to cope with different end-points' sub-attribute (7.1) would rise from 3 to 4 and the score for the 'Undiscounted cost' sub-attribute (11.1) would rise from 3 to 5. The impact on the average and lowest scores for the attribute groups, following these changes are given in Table 8.3.

With these modifications, the lowest scores still can not distinguish between the options of $Atm_{MinOpt}$ and $Atm_{MaxOpt}$*. Looking at the average scores, however, $Atm_{MinOpt}$ scores better because the scores reflect the reduced discharges associated with the abatement of tritium, C-14 and I-129. This is achieved, however, at a high cost relative for the small reduction in the individual or societal dose that are achieved and, thus, in the opinion of the Project Team, $Atm_{MaxOpt}$* is the preferred option. This conclusion is supported by the BPEO studies that have been carried out by BNFL for their gaseous discharges from Sellafield.

In the case of $ILW_{MinOpt}$ and $ILW_{MaxOpt}$, which focus on the volumes of solid ILW, $ILW_{MinOpt}$ scores the lower against 'Environmental impact' because it does not abate aerial discharges of tritium or I129; the higher against 'Environmental objectives' because it minimises the volume of solid ILW that is produced; and the lower against 'Cost' because it includes the higher cost of vitrifying the HALs, compared to the cementation options that is assumed in $ILW_{MaxOpt}$. If the vitrification of the HALs in $ILW_{MinOpt}$ is replaced by cementation [thus generating a revised optimised strategy option, $ILW_{MinOpt}$*], the score for the 'Undiscounted cost' sub-attribute (11.1) would rise from 3 to 5. The impact on the average and lowest scores for the attribute groups, following these changes are given in Table 8.3.

With these modifications and given the desirability of minimising solid waste arisings, with its associated cost savings, and the grossly disproportionate costs of abating aerial discharges of tritium or I-129, $ILW_{MinOpt}$* which includes cementation of the HALs is the preferred strategy option. This conclusion is consistent with the averaged scores above.

In the case of $LLW_{MinOpt}$ and $LLW_{MaxOpt}$, which focus on the volumes of solid LLW, $LLW_{MinOpt}$ scores the highest. The only difference in the attribute group scores are for 'Cost' in which $LLW_{MinOpt}$ scores higher because this option benefits from the anticipated cost savings associated with the free release of some contaminated metals, the reuse of some contaminated concrete and building materials, leaving the pit waste in situ and encapsulating contaminated soils in-situ. As there is no difference in the scores for the environmental attributes, $LLW_{MinOpt}$ is the preferred strategy option because it provides the same level of protection of the environment for no additional cost. This conclusion is supported by the averaged scores above.

**Table 8.3:** Average and lowest scores for each optimised strategy option (including revised options $Atm_{MaxOpt}$* and $ILW_{MinOpt}$* which include cementation rather than vitrification of the HALs), plus their respective totals, awarded in each attribute group.

| | **Liq Min Opt** | **Liq Max Opt** | **Atm Min Opt** | **Atm Max Opt*** | **ILW Min Opt*** | **ILW Max Opt** | **LLW Min Opt** | **LLW Max Opt** |
|---|---|---|---|---|---|---|---|---|
| *Average scores:* | | | | | | | | |
| Group 1: Human health | 3.9 | 3.6 | 4.0 | 3.6 | 3.3 | 4.0 | 3.4 | 3.6 |
| Group 2: Environmental impact | 4.5 | 4.3 | 4.4 | 4.3 | 4.4 | 4.6 | 4.1 | 4.5 |
| Group 3: Technical issues | 4.8 | 4.5 | 4.5 | 4.5 | 4.5 | 4.8 | 4.5 | 4.5 |
| Group 4: Socio-economic issues | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Group 5: Environmental objectives | 4.2 | 4.2 | 4.4 | 3.4 | 4.2 | 4.4 | 4.2 | 4.4 |
| Group 6: Cost | 2.0 | 5.0 | 5.0 | 5.0 | 5.0 | 3.0 | 5.0 | 2.0 |
| ***Total*** | ***22.4*** | ***24.6*** | ***25.3*** | ***23.8*** | ***24.4*** | ***23.8*** | ***24.2*** | ***22.0*** |
| *Lowest scores:* | | | | | | | | |
| Group 1: Human health | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Group 2: Environmental impact | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 |
| Group 3: Technical issues | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Group 4: Socio-economic issues | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Group 5: Environmental objectives | 2 | 3 | 3 | 3 | 4 | 3 | 4 | 3 |
| Group 6: Cost | 2 | 5 | 5 | 5 | 5 | 3 | 5 | 2 |
| ***Total*** | ***17*** | ***21*** | ***21*** | ***21*** | ***22*** | ***20*** | ***22*** | ***18*** |

On the basis of these considerations, it was concluded that the preferred optimised strategy options were:

- $Liq_{MaxOpt}$ for liquid discharges;
- $Atm_{MaxOpt}$*, which includes cementation of the HALs and the ADU floc, for airborne discharges;
- $ILW_{MinOpt}$*, which includes cementation of the HALs, for solid ILW volumes; and

- $LLW_{MinOpt}$ for solid LLW volumes.

These preferred optimised strategy options were then amalgamated to form a single coherent waste management strategy on the basis of their discharges and solid waste volumes that is considered to be the BPEO for the DSRP wastes. This was achieved by combining the representative treatment methods for liquid wastes from $Liq_{MaxOpt}$, with the representative treatment methods for airborne wastes from $Atm_{MaxOpt}$*, the representative treatment methods for solid ILW from $ILW_{MinOpt}$* and the representative treatment methods for solid LLW from $LLW_{MinOpt}$. This identified BPEO thus includes the key elements of the four preferred strategy options, so that it:

- does not require the abatement of liquid and airborne discharges using disproportionately expensive novel technologies to capture hard-to-scrub species such as H-3, Kr-85 and I-129;
- minimises the volumes of solid ILW and LLW, wherever practicable, by decontaminating, compacting, incinerating or segregating the majority of solid waste materials; and
- does not cause serious detriment to human health and the wider environment.

This representative treatment methods identified for each of the waste streams implied by this BPEO are defined in Table 8.4.

**Table 8.4:** The BPEO for management of the DSRP wastes, compiled from elements of the optimised strategy options $Liq_{MaxOpt}$, $Atm_{MaxOpt}$*, $ILW_{MinOpt}$* and $LLW_{MinOpt}$.

| Waste No. | Description | Representative treatment method |
|---|---|---|
| Airborne Wastes ($Atm_{MaxOpt}$*): | | |
| A1 | Particulates from active process and building ventilation | Current practice for the treatment of particulates from the ventilation of active processes and buildings, which is based on the use of HEPAs, where appropriate. |
| A2 | Particulates from treating contaminated ground | Where contaminated ground is remediated, allowing the direct release to the atmosphere of particulates from soils etc. This means no deliberate measures are taken to capture dust from treating contaminated ground, except for more active areas e.g. active drains. |
| A3 | H-3 | Allowing direct discharge of tritium. There are minimal health and safety implications, and environmental consequences from direct discharge and it would involve a grossly disproportionate cost to treat. This decision is supported by BNFL's gaseous waste stream BPEO studies. |

| Waste No. | Description | Representative treatment method |
|---|---|---|
| A4 | C-14 | Allowing direct discharge of C-14. There are minimal health and safety implications, and environmental consequences from direct discharge and it would involve a grossly disproportionate cost to treat. This decision is supported by BNFL's gaseous waste stream BPEO studies. |
| A5 | Kr-85 | Allowing direct discharge of Kr-85. There are minimal health and safety implications, and environmental consequences from direct discharge and it would involve a grossly disproportionate cost to treat. Future arisings are expected to be small because of the limited fuel material processing which is planned. This decision is supported by BNFL's gaseous waste stream BPEO studies. |
| A6 | Iodines | Allowing direct discharge of iodines. There are minimal health and safety implications, and environmental consequences from direct discharge and it would involve a grossly disproportionate cost to treat. This decision is supported by BNFL's gaseous waste stream BPEO studies. Future arisings are expected to be small because of the limited fuel material processing which is planned. This decision may need to be revised if there are future plans to vitrify the PFR raffinate because this would lead to enhanced iodine release. |
| Liquid Wastes ($Liq_{MaxOpt}$): | | |
| L1 | Low level liquid | Allowing direct discharge of low-level liquids. There are minimal health and safety implications, and environmental consequences from direct discharge via the LLLETP (which has the primary role of controlling the pH of the discharged liquids). In order to ensure that this would still be consistent with the environmental objective of progressively reducing discharges and achieving 'near to zero' by 2020 as required by the OSPAR Convention, BPM studies for individual waste streams will be performed. |
| L2 | MALs | |
| L2.1 | MALs from decommissioning | Cement decommissioning MALs. Their activity is too high for direct discharge and cementation was considered the most appropriate immobilisation method evaluated in this study. The MALs may require some appropriate treatment before cementation and this should be addressed in a BPM study. |
| L2.2 | Legacy MALs | Cement legacy MALs from the PFR and plant washing tank. Their activity is too high for direct discharge and cementation was considered the most appropriate immobilisation method evaluated in this study. The MALs may require some appropriate treatment before cementation and this should be addressed in a BPM study. |
| L3 | DFR raffinate | Cement DFR raffinate. Their activity is too high for direct discharge and cementation was considered the most appropriate immobilisation method evaluated in this study. The raffinate may require some appropriate treatment before cementation and this should be addressed in a BPM study. |

| Waste No. | Description | Representative treatment method |
|---|---|---|
| L4 | PFR raffinate | Cement PFR raffinate. Their activity is too high for direct discharge, and cementation was considered the most appropriate immobilisation method evaluated in this study, particularly in relation to the comparative cost of vitrification. It is recognised that there is an ongoing study to evaluate options for the management of PFR raffinate in greater detail. Note: this study has now confirmed the cementation option. |
| L5 | Solvents and oils | Either direct solidification of the solvents and oils, or incineration with cementation of any solid waste. In either case, the activity will be contained in a cement matrix. Their activity is too high for direct discharge and there would be significant non-radiological environmental consequences from their release to the marine environment. The incineration of washed solvent with scrubbing of the off-gas was the preferred option of the BPEO study for solvent disposal. |
| L6 | Flocs and sludges | |
| L6.1 | Ammonium diuranate | Cement the floc and direct discharge of the supernate. The activity of the floc is too high for direct discharge and cementation was considered the most appropriate immobilisation method evaluated in this study. There are minimal health and safety implications, and environmental consequences from the direct discharge of the supernate, which has an activity level equivalent to low level liquid. It is recognised that there is an ongoing study to evaluate options for the management of ADU floc in greater detail. |
| L6.2 | LLLETP sludge | Dissolve and direct discharge of the LLLETP sludge. This treatment was not optimised in this study because the likely health and safety, environmental and cost implications were below the threshold levels adopted in optimisation. It would, however, be common sense to minimise all arisings and treat in a similar manner to other sludges. This would be consistent with the environmental objective of progressively reducing discharges and achieving 'near to zero' by 2020 as required by the OSPAR Convention |
| L6.3 | Shaft and Silo sludge | Cement both Shaft and Silo sludges. Their activity is too high for direct discharge and their physical characteristics are inappropriate (e.g. contains insoluble solid components). Cementation was considered the most appropriate immobilisation method evaluated in this study. The sludges may require some appropriate treatment before cementation and this should be addressed in a BPM study. |
| L6.4 | Fuel storage pond sludges | Cement fuel storage pond sludges. Their activity is too high for direct discharge and their physical characteristics are inappropriate (e.g. contains insoluble solid components). Cementation was considered the most appropriate immobilisation method evaluated in this study. The sludges may require some appropriate treatment before cementation and this should be addressed in a BPM study. |
| Solid LLW Wastes ($LLW_{MinOpt}$): | | |
| S1 | LLW | |

| Waste No. | Description | Representative treatment method |
|---|---|---|
| S1.1 | General metals | Segregate and decontaminate LLW metals to achieve free release in so far as practicable. Otherwise grout and package. |
| S1.2 | Tritiated metals (note secondary circuit only) | Smelting tritiated metals to achieve free release creates lowest volume of LLW for storage or disposal from this waste stream. This treatment was not optimised in this study because the likely health and safety, environmental and cost implications were below the threshold levels adopted in optimisation. No consideration was made of the volume of metal which may require treatment. Smelting may not prove cost effective if only small volumes require treatment. A waste stream specific BPEO/BPM study is recommended to address this issue. |
| S1.3 | Concrete and building materials | Segregate and decontaminate LLW concrete and building materials to achieve free release in so far as practicable. Otherwise grout and package. |
| S1.4 | Cellulosic materials | Incineration of LLW cellulosic materials followed by cementation of the ash creates lowest volume of LLW for storage or disposal from this waste stream. This treatment was not optimised in this study because the likely health and safety, environmental and cost implications were below the threshold levels adopted in optimisation. Incineration may not prove cost effective if only small volumes require treatment. A waste stream specific BPEO/BPM study is recommended to address this issue. |
| S1.5 | Non-cellulosic compactables | Segregate and decontaminate non-cellulosic, compactable materials to achieve free release in so far as practicable. Otherwise grout and package. |
| S1.6 | Pits wastes | Not emptying the Pits to retrieve wastes creates lowest volume of LLW for storage or disposal from this waste stream. There are minimal health and safety implications, and environmental consequences from not retrieving, and it would involve a high cost to do so. This cost and the dose to the workers were identified as key issues in the BPEO for LLW at Dounreay, which was supported by assessments that indicate that even if coastal erosion breached the facility, there would be an insignificant radiological risk to the public at this time. However, the loss of control of the waste was seen as contrary to the environmental objective of contain and control. |
| S1.7 | Bulk non-compactables, non-combustible | Segregate and decontaminate bulk non-compactable, non-combustible materials to achieve free release in so far as practicable. Otherwise grout and package. |

| Waste No. | Description | Representative treatment method |
|---|---|---|
| S1.8 | Soils | Leave contaminated soils in-situ and do not treat, except for more active areas e.g. active drains. This creates lowest volume of LLW for storage or disposal from this waste stream. There are minimal health and safety implications, and environmental consequences from not treating soils. To be addressed further in site end-points study which is underway. |
| Solid ILW Wastes ($ILW_{MinOpt}$*): | | |
| S2 | CHILW, inc. PCM | Segregate and decontaminate CHILW materials to LLW classification in so far as practicable. Otherwise supercompact, grout and package. |
| S3 | Shaft and silo RHILW | Segregate and decontaminate Shaft and Silo RHILW materials to LLW classification in so far as practicable. Otherwise supercompact, grout and package. |
| S4 | RHILW in Stores | Segregate and decontaminate RHILW materials in stores to LLW classification in so far as practicable. Otherwise supercompact, grout and package. |
| S5 | Boron carbide | Release H-3 by washing or dissolving the boron carbide and direct discharge of the washing liquid. This creates lowest volume of ILW for storage or disposal from this waste stream. This treatment was not optimised in this study because the likely health and safety, environmental and cost implications were below the threshold levels adopted in optimisation. Alternatives are to treat as other ILW or decay store to achieve LLW classification. A waste stream specific BPEO/BPM study is recommended to address this issue. |
| S6 | Decommissioning ILW | |
| S6.1 | RHILW Metals (including those with surface contamination) | Segregate and decontaminate ILW metals materials to LLW classification in so far as practicable, which will not be possible for activated steels. Otherwise cut, package and grout. |
| S6.2 | Graphite | Incinerate graphite followed by cementation of the ash creates lowest volume of ILW for storage or disposal from this waste stream. This treatment was not optimised in this study because the likely health and safety, environmental and cost implications were below the threshold levels adopted in optimisation. Incineration may not prove cost effective if only small volumes require treatment. A waste stream specific BPEO/BPM study is recommended to address this issue. |
| S6.3 | Concrete and rock | Segregate and decontaminate concrete and rock to LLW classification in so far as practicable. Otherwise grout and package. |

The radioactive waste management strategy defined above is not intended to prescribe in detail how each waste stream should be treated on site at Dounreay. Rather it suggests ***representative*** approaches to treating individual waste streams that are consistent with an overall strategy to site waste management that balances gaseous and liquid discharges, with the generation of solid waste volumes. Therefore, when deciding how an individual waste stream is to be treated, a different treatment method may be chosen to the representative treatment identified but it should, ideally, have similar (or better) consequences for liquid and gaseous discharges, and solid waste volumes, to those of the representative treatment method.

## 8.3 Sensitivity Analysis

A simple sensitivity study was performed to examine the robustness of the above conclusion to the importance that is attached to each group of attributes. It is common in BPEO studies to 'weight' certain attribute groups in accordance with the significance the attribute groups are thought to have. The Project Team developed a simple weighting scheme that took account of the fact that the 'Environmental objectives' group was considered to have a relatively low significance because issues arising from the impacts of discharged are better measured in the 'Human health' and 'Environmental impact' groups. To put this another way, the Environmental objectives group of attributes relate to the intent to protect the environment through the minimisation of waste and reducing discharges etc. The Project Team believes these to be inherently important objectives but, in purely practical terms, the manner in which it can be ascertained whether or not these intentions have been met, is to measure quantitatively contamination in the environment and dose to humans (i.e. to measure the parameters which are addressed by attributes in the 'Human health' and 'Environmental impact' groups). Similarly, the 'Socio-economic issues' group is another measure of the impacts that may arise from processes undertaken at Dounreay and the resulting discharges. In broad terms, these can also be correlated to the parameters which are addressed by attributes in the 'Human health' and 'Environmental impact' groups.

With this in mind, a simple weighting scheme was developed for use in this study, and this is presented in Table 8.5.

**Table 8.5:** The weighting scheme used to test sensitivities in this study.

| Attribute group | | Weighting |
|---|---|---|
| Group 1 | Human health and safety | 5 |
| Group 2 | Environmental impact | 5 |
| Group 3 | Technical issues | 5 |
| Group 4 | Socio- economic | 3 |
| Group 5 | Environmental objectives | 1 |
| Group 6 | Financial cost | 5 |

These weightings were applied both to the average and lowest scores awarded to each attribute group (as defined in Table 8.3), and the results are presented in Table 8.6.

**Table 8.6:** Weighted average and lowest scores, plus their respective totals, awarded in each attribute group using the weighting scheme in Table 8.3.

| | Liq Min Opt | Liq Max Opt | Atm Min Opt | Atm Max Opt* | ILW Min Opt* | ILW Max Opt | LLW Min Opt | LLW Max Opt |
|---|---|---|---|---|---|---|---|---|
| *Average scores:* | | | | | | | | |
| Group 1: Human health | 19.5 | 18.0 | 20.0 | 18.0 | 16.5 | 20.0 | 17.0 | 18.0 |
| Group 2: Environmental impact | 22.5 | 21.5 | 22.0 | 21.5 | 22.0 | 23.0 | 20.5 | 22.5 |
| Group 3: Technical issues | 24.0 | 22.5 | 22.5 | 22.5 | 22.5 | 24.0 | 22.5 | 22.5 |
| Group 4: Socio-economic issues | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 |
| Group 5: Environmental objectives | 4.2 | 4.2 | 4.4 | 3.4 | 4.2 | 4.4 | 4.2 | 4.4 |
| Group 6: Cost | 10.0 | 25.0 | 25.0 | 25.0 | 25.0 | 15.0 | 25.0 | 10.0 |
| ***Total*** | ***89.2*** | ***100.2*** | ***102.9*** | ***99.4*** | ***99.2*** | ***95.4*** | ***98.2*** | ***86.4*** |
| *Lowest scores:* | | | | | | | | |
| Group 1: Human health | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Group 2: Environmental impact | 15 | 15 | 15 | 15 | 15 | 20 | 15 | 15 |
| Group 3: Technical issues | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Group 4: Socio-economic issues | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Group 5: Environmental objectives | 2 | 3 | 3 | 3 | 4 | 3 | 4 | 3 |
| Group 6: Cost | 10 | 25 | 25 | 25 | 25 | 15 | 25 | 10 |
| ***Total*** | ***71*** | ***87*** | ***87*** | ***87*** | ***88*** | ***82*** | ***88*** | ***72*** |

Comparison of the weighted scores in Table 8.6 with the unweighted scores in Table 8.3. shows no significant differences in the relative ordering of the strategy options. Thus, the application of this simple weighting scheme does not change the overall interpretation.

It is thus concluded that the BPEO described in the Table 8.4 is robust at a strategic level for the development of a coherent waste management strategy for the DSRP wastes. Nonetheless, it is recognised that a number of waste stream specific BPEO or BPM studies are required to address issues at a more detailed level than was possible in this assessment (as identified in Table 8.4).

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# Appendices

# Appendix A: Choosing the 'best' management option

The objective of the study described in this report is to review potential management options that could be applied to the DSRP wastes and to provide input for the determination of the overall 'best' strategy option.

When undertaking any research activity or industrial process, including those that may be used for the management of the DSRP wastes, it is inevitable that some environmental impact will result. It is desirable for this impact to be minimized but, pragmatically, the method used to reduce impacts needs to be balanced against other factors such as the availability of relevant technology, the extent of the impact and cost.

To help direct decisions for minimising environmental impacts, regulatory authorities in the UK have produced a series of guidelines over the last 100 years or so. The first set of guidelines was published in 1874 as part of the Alkali Act, which was brought in to reduce air pollution in urban areas. This Act set out the concept of 'Best Practicable Means' (BPM) which helped to identify appropriate pollution reduction technologies for industry by balancing costs against environmental benefits. The BPM concept has been the basis for environmental pollution control ever since, although it has been updated and extended in scope. The concept of the 'Best Practicable Environmental Option' (BPEO) can, itself, be considered to be an extension of the BPM approach.

The term 'BPEO' was originally introduced by the Royal Commission on Environmental Pollution (RCEP) in 1976, also in the context of the control of atmospheric pollution [RCEP, 1976]. Its basis is more explicitly to involve consideration of environmental aspects in the decision making process than might be done using the BPM approach alone. Since 1976, the BPEO approach has been applied more widely than to atmospheric pollution issues to cover many other potentially polluting practices, including the management of radioactive materials.

In 1986, a comprehensive review of systems of radioactive waste management was undertaken by the Department of the Environment using what was considered, at that time, to be a state-of-the-art approach to applying the principles of BPEO [DoE, 1986]. Subsequently, the RCEP expressed reservations, stating that they

*"..were not entirely happy with some aspects of the methodology and …would not wish the Report to be held out as a definitive model of how a BPEO study should be undertaken"* [RCEP, 1988].

The RCEP went on to develop their own definition of BPEO, as follows:

*"A BPEO is the outcome of a systematic consultative and decision-making procedure which emphasises the protection and conservation of the environment across land, air and water. The BPEO procedure establishes, for a given set of objectives, the option*

*that provides the most benefit or least damage to the environment as a whole, at acceptable cost, in the long term as well in the short term"* [RCEP, 1988].

The RCEP also provided a set of basic of principles for the application of the BPEO approach. These included, as the first three steps:

- **defining objectives** in terms that do not prejudge the means by which the objective is to be achieved;
- **generating options**, alternative options should be sought 'diligently and imaginatively'; and
- **evaluating the options** using a combination of quantitative methods and qualitative evaluation.

The approach has progressively evolved to become more sophisticated and has been extended for more general application. As a rule, wider ranges of options and attributes are now routinely considered; nevertheless, the level of detail to which options and attributes are addressed should reflect the overall context within which the appraisal is carried out. Under the 1990 Environmental Protection Act, a BPEO is simply defined as:

*"… the option which provides the most benefit or least damage to the environment as a whole, at acceptable cost, in the long term as well as the short term."*

Following the 1990 Environmental Protection Act, the BPEO approach was formally introduced into regulations controlling industrial processes as part of Integrated Pollution Control (IPC). This requires operators to demonstrate that the measures they take to reduce pollution represents the Best Available Techniques Not Entailing Excessive Cost (BATNEEC), having regard to the BPEO for those processes. In particular, by having regard to the BPEO, the identification of the 'best' technique was intended to account for the possibility of releases to a range of different media from a given source or process, as well as the possible existence of other sources of pollution in the vicinity.

Processes that may lead to releases of radioactivity are controlled under a different regulatory framework to IPC. The methodology developed for IPC BPEO studies can, nonetheless, be extended and adapted for use with environmental assessments involving radioactive discharges. This is supported by the Environment Agency of England and Wales which has recently issued a guidance document on the methodology which states that:

*"it can be applied flexibly and imaginatively as appropriate to particular circumstances"* [Environment Agency, 1997].

Although the RCEP has provided a set of basic principles for the application of the BPEO approach and the Environment Agency has produced its guidelines for IPC BPEO studies, there are, in fact, no prescribed 'rules' for designing and implementing a

BPEO study. There is, however, a growing body of precedent to demonstrate how the approach can be applied in different contexts. This illustrates that the concept itself is best treated as a framework, within which information on possible solutions to the problem (‘options’) and the measures on which they should be judged (‘attributes’) are brought together.

The primary concepts involved in a BPEO assessment can, essentially, be explained by considering the words of the acronym in reverse order.

| | |
|---|---|
| Option | Alternative ways of achieving the desired result have to be considered. |
| Environmental | Environmental (and safety) issues have to be considered at an early stage in the decision-making process. |
| Practicable | Options have to be in accordance with current technical knowledge and should not have disproportionately adverse financial or social implications. |
| Best | The final option after screening for environmental and practicable considerations. |

If rigorously and comprehensively applied, a BPEO study provides a framework for making environmentally responsible, efficient and cost-effective decisions in a transparent and auditable manner. It is important to recognize, however, that there are some limitations associated with the BPEO methodology and that these limitations can affect the chosen ‘best’ option.

The BPEO methodology has to rely, to some extent, on personal or expert judgment to compare and contrast issues such as practicability and potential environmental impacts. Different stakeholders may have a variety of perspectives on what is most important to them and could define different attributes or attribute different weightings to them. As such, the BPEO process should not, by itself, be used as *the* decision making process but rather as one contribution to decision making, thus recognising that the identified ‘best’ option may well change according to the values and perspectives of different stakeholders.

Furthermore, defining the practicability and potential environmental impacts for various options needs to be done with consideration of the available technologies and costs. Since technologies tend to improve with development, it is likely that the chosen ‘best’ option could change over time as a result. Sometimes it is not possible to identify a single ‘best’ option on the basis of the information available with which to compare the alternatives and that other considerations may be required to narrow the choice to a single preferred option.

The specific steps in applying the BPEO methodology to the DSRP wastes are outlined in Section 3.2.

# Appendix B: Attributes and Scoring Schemes

This Appendix describes in detail the different attributes and scoring schemes used in this study to evaluate the strategy options. The scoring of the different strategy options is discussed in Section 6.

For each sub-attribute, a calibrated scoring scheme is defined on a scale of 0 to 5, against which the performance of each strategy option is scored. A score of 0 is judged to be “intolerable” and a score of 5 is judged to be “very good” – intermediate scores are possible and would generally relate to a range of “acceptable” performance.

When referring to issues of radiological dose and risk, however, the term ‘intolerable’ means from a regulatory viewpoint, rather than from necessarily a human health impact viewpoint.

Some calibrated scoring schemes are defined quantitatively (e.g. for risks to human health) and others are defined qualitatively (e.g. air quality). Qualitative scoring schemes are adopted when no numerical data on performance are possible or available, for example when an evaluation is subjective.

## B1 Human Health and Safety

Attributes in this group reflect the confidence in the ability of a strategy option to protect human (public and worker) health from both radiological and non-radiological impacts. As such, three separate attributes were identified in this group: public health and safety (for individuals), public health and safety (societal) and worker health and safety (for individuals). These were each further divided into a number of sub-attributes.

It is standard practice to measure hazards to the health and safety of individual members of the public and workers in terms of the risk of death from the practice concerned. Where radiological hazards are considered, the risks to the next generation (in terms of the likelihood of severe hereditary effects) are also considered. The concept of risk is therefore a widely used measure that can be readily applied to the likely range of hazards that are considered to influence health and safety.

To provide ‘benchmark’ values as the basis for defining calibration schemes for the BPEO attributes, an indication of typical fatality risks associated with different situations is presented in Table B1. Other relevant benchmarks in any discussion of risk are the legally permitted upper limits and regulatory limits for risks from radiation exposure, since these represent an implicit understanding of what are considered to be ‘maximum tolerable’ and ‘broadly acceptable’ levels of risk.

**Table B1:** Illustration of level of risk from everyday activities.

| Risk of death (per year) | Activity/cause of death |
|---|---|
| 1 in 100 | Five hours solo rock climbing every week |
| 1 in 1,000 | Working in industry such as mining |
| 1 in 10,000 | Driving – road traffic accident |
| 1 in 100,000 | Working in a very safe industry |
| 1 in 1,000,000 | Death in house fire |
| 1 in 10,000,000 | Death by lightning strike |

***Attribute 1. Public Health and Safety (Individuals in critical group)***

This attribute relates to the health and safety of individuals in the critical group (i.e. those most affected).

Long-term radiation risks are considered likely to dominate public health and safety concerns associated with the long-term management of DSRP wastes. The Government has defined a risk target below which *"the requirement for optimisation is relaxed"* of $10^{-6}$ $y^{-1}$ for long-term risks from solid waste disposal. Similarly, a minimal radiological dose is typically assumed to be in the region of 10 μSv $y^{-1}$. On the basis that there is no clear benefit in being able to achieve better performance, it is therefore assumed that any waste management scheme which is easily capable of meeting these criteria should obtain the maximum score of 5.

Conversely, a level of involuntary risk higher than that associated with a risky but beneficial activity of the public (e.g. road transport) is judged to be unacceptable. Such a level of risk, about $10^{-4}$ $y^{-1}$, is also broadly consistent with the statutory dose limit for the public of 1 mSv $y^{-1}$. Any management option in which there would be difficulty showing that risks to the public were below this level is judged to be unacceptable, and would score 0.

The value of 1 mSv $y^{-1}$ is also the Basic Safety Limit (BSL) as defined by HSE in its Safety Assessment Principles for Nuclear Plants [HSE, 1992b]. The BSLs have been derived from the concept of a limit of tolerability that was developed in the Tolerability of Risk paper [HSE, 1992a]. A proposed plant must satisfy these limits in order to be considered for licencing. Having satisfied the BSLs, the ALARP principle comes into play to drive the risks from the plant even lower. Each BSL is complimented by a Basic Safety Objective (BSO). The BSO define the point beyond which the HSE assessors need not seek further safety improvements from the licensee in trying to achieve ALARP. The BSO for the dose received by any member of the public from all sources of radiation on a site is 0.02 mSv $y^{-1}$.

On the basis that the non-radiological risks associated with management of the DSRP wastes would be less than the radiological risks, it is assumed that the risks from both can be conservatively addressed on the same scale.

Based on these arguments, the requirements for a strategy option's performance to be judged intolerable (score 0) and very good (score 5) against the public health and safety (individuals in critical group) sub-attributes are summarised in Table B2, and the calibration scheme for these sub-attributes is provided in Table B3.

**Table B2:** Requirements for a strategy option to score 0 and 5 against the public health and safety (individuals in critical group) sub-attributes.

| Sub-Attribute | Intolerable performance (Score = 0) | Very good performance (Score = 5) |
|---|---|---|
| 1.1: Routine radiation dose | Difficult to demonstrate doses $< 1$ mSv $y^{-1}$ | Easy to demonstrate doses $< 10$ μSv $y^{-1}$ |
| 1.2: Radiological accident risks | Difficult to demonstrate risks $< 10^{-4}$ $y^{-1}$ | Easy to demonstrate risks $< 10^{-6}$ $y^{-1}$ |
| 1.3: Non-radiological hazards and risks | Difficult to demonstrate risks $< 10^{-4}$ $y^{-1}$ | Easy to demonstrate risks $< 10^{-6}$ $y^{-1}$ |

**Table B3:** Calibration schemes for the public health and safety (individuals in critical group) sub-attributes.

| Score | Calibration | Example |
|---|---|---|
| 0 | Difficult to demonstrate risk $< 10^{-4}$ $y^{-1}$ or dose $< 1$ mSv $y^{-1}$ | Double natural death rate at 20 y |
| 1 | Risk range of $10^{-4}$ to $3x10^{-5}$ $y^{-1}$ or dose range of 1 mSv to 300 μSv y-1 | |
| 2 | Risk range of $3x10^{-5}$ to $10^{-5}$ $y^{-1}$ or dose range of 300 μSv to 100 μSv $y^{-1}$ | Car accident risk for frequent traveller |
| 3 | Risk range of $10^{-5}$ to $3x10^{-6}$ $y^{-1}$ or dose range of 100 μSv to 30 μSv $y^{-1}$ | |
| 4 | Risk range of $3x10^{-6}$ to $10^{-6}$ $y^{-1}$ or dose range of 30 μSv to 10 μSv $y^{-1}$ | |
| 5 | Easy to demonstrate risk $< 10^{-6}$ $y^{-1}$ or dose < 10μSv $y^{-1}$ | Risk of fatal fire in typical home |

***Attribute 2. Public Health and Safety (Societal)***

In the case of societal public health and safety, a single sub-attribute of routine radiation dose is adopted. The calibrated scoring system is required to reflect the understanding that this sub-attribute measures the collective dose to the public from any incident. In the case of the management of the DSRP wastes, it is assumed that C-14 and I-129 will be the primary contributors and that the collective dose will be assessed by integrating over a 500 year period. The calibration scheme for this sub-attribute is shown in Table B4.

**Table B4:** Calibration scheme for the public health and safety (societal) sub-attribute.

| Score | Routine Dose |
|---|---|
| 0 | Difficult to demonstrate doses < 100 person Sv |
| 1 | 100 to 75 person Sv |
| 2 | 75 to 50 person Sv |
| 3 | 50 to 25 person Sv |
| 4 | 25 to 1 person Sv |
| 5 | Easy to demonstrate doses < 1 person Sv |

***Attribute 3. Worker Health and Safety***

In the case of worker health and safety (individuals), a scoring system is required to reflect the understanding that the risks to individual workers are associated with practices that bring direct benefits through employment. In this regard, the HSE has considered in some detail what constitutes a limit to the tolerable risk imposed in the workplace. The largest risks are often tolerated where the activity itself (e.g. mining or fishing) is an important component in sustaining a community. In such circumstances, individual risk levels as high as $10^{-3}$ $y^{-1}$ may be tolerated.

With this in mind, when considering the risks to workers from management of the DSRP wastes, it is assumed that the risks from both radiological hazards and non-radiological hazards can be conservatively addressed on the same scale.

Any operations for which it would be difficult to show that such risks were at least consistent with the maximum tolerable risk of $10^{-3}$ $y^{-1}$ are, therefore, considered to score zero, since it is most unlikely that they would be permitted under Health and Safety Legislation. The corresponding limit on occupational dose (if this were a discriminating factor between options) is 20 mSv $y^{-1}$ which is the BSL and equivalent to a radiological risk of around 1 in 1000.

A maximum score for worker health and safety is achieved when the risk can readily be shown to be at least as good as that in very safe industries, since no better performance should reasonably be expected: this is in the region of $10^{-5}$ $y^{-1}$. In terms of radiological exposure, a worker need not be classified as a radiation worker if it is unlikely that the public dose limit of 1 mSv $y^{-1}$ will be exceeded, and the BSO is defined as 2 mSv $y^{-1}$.

Based on these arguments, the requirements for a strategy option's performance to be judged intolerable (score 0) and very good (score 5) against the worker health and safety (individuals) sub-attributes are summarised in Table B5, and the calibration scheme for these sub-attributes is provided in Table B6.

**Table B5:** Requirements for a strategy option to score 0 and 5 against the worker health and safety (individuals) sub-attributes.

| Sub-Attribute | Intolerable performance (Score = 0) | Very good performance (Score = 5) |
|---|---|---|
| 3.1: Routine radiation doses | Difficult to demonstrate doses < 20 mSv $y^{-1}$ | Easy to demonstrate doses < 2 mSv $y^{-1}$ |
| 3.2: Radiological accident risks | Difficult to demonstrate risks < $10^{-3}$ $y^{-1}$ | Easy to demonstrate risks < $10^{-4}$ $y^{-1}$ |
| 3.3: Non-radiological hazards and risks | Difficult to demonstrate risks < $10^{-3}$ $y^{-1}$ | Easy to demonstrate risks < $10^{-4}$ $y^{-1}$ |

**Table B6:** Calibration scheme for worker health and safety (individuals) sub-attributes.

| Score | Calibration | Example |
|---|---|---|
| 0 | Difficult to demonstrate risks < $10^{-3}$ $y^{-1}$ or doses of < 20 mSv $y^{-1}$. | Very hazardous construction operation. $10^{-3}$ is the maximum tolerable risk to workers in any industry from Figure 6 of HSE (1992a). |
| 1 | Risk range of $10^{-3}$ to $8x10^{-4}$ $y^{-1}$ or dose range of 20 to 16 mSv $y^{-1}$ | |
| 2 | Risk range of $7.5x10^{-4}$ to $5.5x10^{-4}$ $y^{-1}$ or dose range of 15 to 11mSv $y^{-1}$ | Hazardous component to work, such as high winds |
| 3 | Risk range of $5x10^{-4}$ to $3x10^{-4}$ $y^{-1}$ or dose range of 10 to 6 mSv $y^{-1}$ | |
| 4 | Risk range of $2.5x10^{-4}$ to $10^{-4}$ $y^{-1}$ or dose range of 5 to 2 mSv $y^{-1}$ | |
| 5 | Easy to demonstrate risks < $10^{-4}$ $y^{-1}$ or doses of < 2 mSv $y^{-1}$ | Well established operation with clear procedures, and average level for a classified radiation worker |

## B2 Environmental Impact

Two attributes are recognised in this group: physical environment, and flora and fauna to reflect the fact that there is a clear distinction in UK environmental and planning laws between the consequences of industrial and construction activities on these two elements. The physical environment attribute is further subdivided into air quality, water quality, land, visual impact, nuisances (e.g. noise and traffic) and energy usage. The flora and fauna attribute is further subdivided into preservation of habitat and preservation of species.

It is not easy to derive direct quantitative scoring schemes for environmental attributes. This is partly because quantitative information is generally unavailable but also because the significance of certain impacts is subjective. It is, however, possible to consider qualitative examples that provide a baseline against which the degree of acceptability of different waste management schemes may be calibrated. This is the approach taken in this study.

In this study, environmental impact includes the consequences of radioactivity in any discharges. So, for example, restrictions on use of the foreshore due to radiological contamination would be accounted for in the 'Land Quality' sub-attribute. Note, however, that the impacts from releases of activity on human health and safety, and on flora and fauna, are addressed in separate attributes.

Calibration schemes for environment attributes are intended to provide a measure of the acceptability of the change, associated with any scheme, which occurs relative to the pre-existing environment. Thus, a strategy option that causes no discernible, detrimental change to the environment would score 5. By contrast, a strategy option that causes detrimental impacts to the environment that were intolerable would score 0.

***Attribute 4. Physical Environment***

This attribute consists of several sub-attributes. Any waste management option for which there would be no discernible, detrimental change in any of these sub-attributes would merit a score of 5. In this context 'no discernible, detrimental change' is defined as when any effects of a development:

- are all within statutory limits or guidelines;
- have no cumulative detriment; and
- are not observable against the background environment.

By contrast, any scheme that would be unacceptable in respect of a single sub-attribute is assumed to score zero overall.

Based on these arguments, the requirements for a strategy option's performance to be judged intolerable (score 0) and very good (score 5) against the physical environment sub-attributes are summarised in Table B7, and the calibration scheme for these sub-attributes is provided in Table B8. Note the attribute 4.6: Energy usage is discussed separately later on.

**Table B7:** Requirements for a strategy option to score 0 and 5 against the physical environment sub-attributes. See later text for 4.6: Energy usage.

| Sub Attribute | Intolerable performance (score = 0) | Very good performance (score = 5) |
|---|---|---|
| 4.1: Air quality | Persistent objectionable substances in air in buildings off the site | No discernible reduction in air quality |
| 4.2: Water quality | Sterilisation of water resource | No discernible reduction in water quality |
| 4.3: Land quality | Sterilisation of substantial area of land | No discernible reduction in land quality |
| 4.4: Visual amenity | Construction completely out of keeping with existing landscape | No discernible visual impact |

| Sub Attribute | Intolerable performance (score = 0) | Very good performance (score = 5) |
|---|---|---|
| 4.5: Nuisance | Long-term disturbance/ disruption of local life | No outward signs of the waste management scheme |

**Table B8:** Calibration scheme for physical environment sub-attributes. See later text for 4.6: Energy usage.

| Score | Calibration | Example |
|---|---|---|
| 0 | Gross, objectionable disruption to the physical environment | Long-term restrictions on the use of and access to substantial areas of the local environment |
| 1 | Substantial changes to the physical environment, discernable widely in the area surrounding the site | Permanent gaseous discharges that can be smelt away from the site or liquid discharges that discolour the water away from the site |
| 2 | Obvious changes to the physical environment, discernable widely in the area surrounding the site | Intermittent gaseous discharges that can be smelt away from the site or liquid discharges that discolour the water away from the site |
| 3 | Obvious changes to the physical environment, discernable in the immediate area adjacent to the site | Intermittent gaseous discharges that can be smelt close to the site or liquid discharges that discolour the water close to the site |
| 4 | Marginal change to the physical environment, discernable in the area adjacent to the site | Large development on Dounreay site in keeping with existing structures, resulting in measurable impacts to the local environment but low consequences |
| 5 | No discernible reduction in quality of the physical environment | Small development on the existing Dounreay site with no affect on the wider environment |

For the sub-attribute 4.6 (Energy Usage), a quantitative calibration scheme is used, that compares the estimated energy usage of the different strategy options to the current site usage. In this case, ‘Energy usage’ is defined as electricity usage, since this is the most dominant source of energy required to power all of the strategy options, although it should be noted that a number of strategy options will require small additional sources of energy – most notably gas to fire the incinerators that are a component technology of some strategy options.

For this sub-attribute, a 0 score is not defined because the calibration scheme is comparative rather than definitive. For reference, the current (2001) Dounreay site energy usage is 4.47 MW $yr^{-1}$. The calibration scheme for this energy usage sub-attribute is shown in Table B9.

**Table B9:** Calibration scheme for the energy usage sub-attribute.

| Score | Calibration |
|---|---|
| 0 | - |
| 1 | > 75 % of the current total site power usage |
| 2 | 50 to 75% of the current total site power usage |
| 3 | 25 to 50% of the current total site power usage |
| 4 | 1 to 25% of the current total site power usage |
| 5 | < 1% of the current total site power usage |

***Attribute 5. Flora and Fauna***

This attribute consists of two sub-attributes: preservation of habitat and conservation of species. Any waste management option for which there would be no discernible, detrimental change to habitat or any indigenous species would merit a score of 5. In this context 'no discernible, detrimental change' is defined as when any effects of a development:

- have no cumulative detriment to habitat or species; and
- are not observable against the background natural environment.

A development or process is considered intolerable if it is capable of causing complete loss of a natural ecosystem (e.g. loss of rare species or sensitive habitats from the region). This may be a result of direct impact on the flora and fauna or by changes to the environment that affect crucial elements of their habitat (e.g. the draining of a marsh supporting rare species). Based on these arguments, the calibration scheme for these flora and fauna sub-attributes is provided in Table B10.

**Table B10:** Calibration scheme for the flora and fauna sub-attributes.

| Score | Calibration | Example |
|---|---|---|
| 0 | Complete loss of natural ecosystem | Total loss of rare species or sensitive habitat from the region |
| 1 | Substantial and widespread changes to the natural ecosystem | Total of rare or sensitive species from the area around the site but other similar ecosystems in region are unaffected |
| 2 | Significant and widespread changes to the natural ecosystem | Reduction in population of rare species or reduction in area of sensitive habitat across the region |
| 3 | Significant but localised changes to the natural ecosystem | Reduction in population of common species or reduction in area of habitat around the site but ecosystems in wider region are unaffected |
| 4 | Marginal and localised change to the natural ecosystem | Development and its impacts restricted to land with no recognised sensitive or rare species |
| 5 | No discernible reduction in quality of the natural ecosystem | Development takes place on existing made ground or agricultural land |

## B3 Technical

Attributes in this group address the ability of a strategy option to perform its planned waste management function correctly and safely. Two separate attributes were identified in this group, namely viability and flexibility.

Viability is the ease with which it can be demonstrated that a waste strategy option is technically feasible within constraints imposed by the DSRP, considering the existing maturity of technology and the necessary R&D requirement to implement a strategy option on site. Flexibility is the scope for the strategy option to be varied, if required to meet requirements for different end-points for the solid wastes (e.g. different physical or chemical characteristics of the wasteform), possible different timescales of waste arisings or the ability to accept different waste streams if they arise.

The strategy options are varied and have been defined on the basis of the required technologies only at a general level. It is necessary, therefore, to consider qualitative measures of acceptability for each attribute to define the corresponding calibration scheme. Although such measures are not numerical, it is possible to be sufficiently specific to allow for a measure of quantitative analysis and comparison of the technical performance of alternative schemes. The basis for defining calibration schemes for each attribute is presented below.

***Attribute 6. Viability***

Viability is addressed by a single sub-attribute: maturity of technology. This measures the 'track record' of a given process or technology, and includes the R&D requirement concerned with the degree to which the solution can be taken off-the-shelf and applied to management of the DSRP wastes.

A strategy option that employs processes or technologies that are well established, have been applied to similar waste streams under similar circumstances, and are easy to implement would score 5. Conversely, a strategy option that employs processes or technologies that are entirely unproven and hypothetical, even if they are theoretically within the bounds of current technology, would score 0.

Based on these arguments, the calibration scheme for the maturity of technology sub-attribute is provided in Table B11.

**Table B11:** Calibration scheme for the maturity of technology sub-attribute.

| Score | Calibration | Example |
|---|---|---|
| 0 | Unproven and not achievable with existing technology in the timescale of the DSRP. | Transmutation |
| 1 | Untested approach, complex process and never applied under circumstances relevant to DSRP waste management. | |
| 2 | Novel technology, shown to be workable in trials, but never applied on 'industrial' scale relevant to DSRP waste management. | Cryogenic distillation of Kr-85. |

| Score | Calibration | Example |
|---|---|---|
| 3 | "Outdated" technology known to be workable under circumstances relevant to DSRP waste management or novel technology requiring significant further development. | Chemical separation of high active liquors |
| 4 | Established approach, with track record but used under different circumstances to those of DSRP waste management needing additional development. | Vitrification of raffinates. |
| 5 | Established approach, with good track record and applied to similar waste streams under similar circumstances to those of DSRP waste management. | Cementation of low level liquids. |

***Attribute 7 Flexibility***

Flexibility is addressed by three sub-attributes: the ability to cope with various end-points for solid wastes, various timescales and different waste streams.

A strategy option that employs processes or technologies that are known to be flexible, such that they could cope, over a variety of timescales, with a range of DSRP waste streams and others that may not yet have been identified, would score 5. Conversely, a strategy option that employs processes or technologies that have no flexibility and allow for no contingency planning in terms of future modification to the DSRP (e.g. in terms of waste arisings, timescales and objectives), would score 0.

Based on these arguments, the requirements for a strategy option's performance to be judged intolerable (score 0) and very good (score 5) against the flexibility sub-attributes are summarised in Table B12, and the calibration scheme for these sub-attributes is provided in Table B13.

**Table B12:** Requirements for a strategy option to score 0 and 5 against the flexibility sub-attributes.

| Sub-Attribute | Intolerable performance (Score = 0) | Very good performance (Score = 5) |
|---|---|---|
| 7.1: Accept other solid waste endpoints | Entirely dependent on solid waste endpoint being pre-defined in the DSRP | Easily adaptable to cope with redefinition of solid waste endpoint during the course of the DSRP |
| 7.2: Accept other timescales | Entirely dependent on timescales being pre-defined in the DSRP | Fully flexible to cope with waste treatment and waste arisings on other timescales during the course of the DSRP |
| 7.3: Accept other waste streams | Entirely dependent on waste streams being pre-defined in the DSRP | Fully flexible to cope with new or additional waste streams identified during the course of the DSRP |

**Table B13:** Calibration scheme for the flexibility sub-attributes.

| Score | Calibration | Example |
|---|---|---|
| 0 | Entirely dependent on decisions regarding waste streams, time scales and solid waste endpoints being pre-defined in the DSRP | Strategy option based on a single technology with no inherent flexibility |
| 1 | Allows flexibility to cope with a single small change in terms of either revised waste streams, time scales or solid waste endpoints during the course of the DSRP | Strategy option based on a few processes and technologies, one of which offers a small degree of flexibility |
| 2 | Allows flexibility to cope with a couple of small changes in terms of either revised waste streams, time scales or solid waste endpoints during the course of the DSRP | Strategy option based on a few processes and technologies, two of which offer small degrees of flexibility |
| 3 | Allows flexibility to cope with numerous changes in terms of revised waste streams, time scales and solid waste endpoints during the course of the DSRP | Strategy option based on a several processes and technologies, a few of which offer a small degree of flexibility |
| 4 | Allows for substantial flexibility to cope with revised waste streams, time scales and solid waste endpoints during the course of the DSRP | Strategy option based on a large number of processes and technologies, several of which are independently flexible |
| 5 | Allows full flexibility to cope with revised waste streams, time scales and solid waste endpoints during the course of the DSRP | Strategy option based on a large number of processes and technologies, all of which are independently flexible |

## B4 Social, Political and Economic

Attributes in this group are concerned with possible impacts to the local community and communities elsewhere, in terms of economy, and culture and heritage. ‘Local’ is defined as the northernmost part of Caithness within a few tens of kilometres of the site, including Reay, Thurso and Wick, where the local residents may perceive themselves to be directly affected by options to manage the DSRP wastes.

***Attributes 8 and 9 : Local and elsewhere***

In the absence of detailed socio-economic analyses, it is inappropriate to define a quantitative calibration scheme. A semi-quantitative scheme can, however, be devised that represents the potential change in economic and cultural values of the affected community or groups within it. The influence of a particular strategy option on these communities may also be manifest in a number of ways but can be broadly represented via the project impact on its size and stability. For example, it would be unacceptable if a scheme was directly responsible for significant depopulation of a region.

The potential economic and cultural effects of the strategy options at both the ‘local’ and ‘elsewhere’ scales may be both positive and negative (e.g. increased employment as opposed to planning blight). As a consequence, a calibration scheme is used in which 3 represents no tangible change to the communities, 4 and 5 are different levels of net benefit, and 2, 1 and 0 are different levels of net detriment, with 0 being reserved for severe damage to the local economy leading to long term depopulation or severe damage to the community socio-economic systems.

Based on these arguments, the requirements for a strategy option's performance to be judged intolerable (score 0) and very good (score 5) against the local and elsewhere sub-attributes are summarised in Table B15, and the calibration scheme for these sub-attributes is provided in Table B16.

**Table B15:** Requirements for a strategy option to score 0 and 5 against the local and elsewhere sub-attributes.

| Sub-Attribute | Intolerable performance (Score = 0) | Very good performance (Score = 5) |
|---|---|---|
| 8.1: Economic impact - local | Severe damage to local economy or community | Major enhancement to the local economy |
| 8.2: Cultural and heritage impact - local | Severe damage to local community through depopulation | Major enhancement of local community through increased population |
| 9.1: Economic impact - elsewhere | Severe damage to economy remote from the site | Major enhancement to economy remote from the site |
| 9.2: Cultural and heritage impact - elsewhere | Severe damage to community through depopulation remote from the site | Major enhancement of community through increased population remote from the site |

**Table B16:** Calibration scheme for the local and elsewhere sub-attributes.

| Score | Calibration | Example |
|---|---|---|
| 0 | Severe damage to local economy or community | Development causes cessation to inward investment and people move away from the area |
| 1 | Significant and long term detriment to economy or community | Fall in house prices and reduction in employment |
| 2 | Marginal and short term detriment to economy or community | Intrusion to community without economic benefit |
| 3 | No tangible effects on the economy or community | No change in life style or quality of life |
| 4 | Marginal and short term benefit to economy or community | Moderate increased employment and cultural diversity |
| 5 | Major enhancement of economy or community | Development increases inward investment and people move into the area. |

## B5 Environmental Objectives

There is only a single attribute in this group which is further divided into a number of sub-attributes that measure each strategy option's consistency with the strategic environmental objectives set out in a number of guidelines and regulations, including the minimisation of solid waste volumes, progressive reductions in future discharges, an ability to concentrate and contain contaminants, implementation of precautionary action (which includes protection of future generations) and protection beyond national borders.

***Attribute 10. Environmental Objectives***

This attribute addresses compatibility of the strategies with defined national and international environmental policy objectives. These include the minimisation of solid waste volumes, progressive liquid discharge reductions in accordance with OSPAR, a 'concentrate and contain' strategy for liquid and gaseous waste, precautionary action in terms of progressive hazard reduction (including protection of future generations) and protection beyond national borders.

With regard to solid waste minimisation, a strategy option may perform better or worse than is assumed for the reference waste management strategy detailed in the DSRP. As a consequence, a calibration scheme is used which compares a strategy option's performance against the DSRP. In this scheme, 3 represents no change in the generation of solid waste volumes, whilst 4 and 5 relate to reduced solid waste volumes, and 2, 1 and 0 relate to increased solid waste volumes.

With regard to progressive discharge reductions, a strategy option may similarly perform better or worse than is assumed for the reference waste management strategy detailed in the DSRP. As a consequence, a calibration scheme is used which compares a strategy option's performance against the DSRP for meeting the OSPAR target of 'near zero' liquid discharges by 2020. In this scheme, 3 represents no change in the rate of discharge reductions, whilst 4 and 5 relate to an increased rate of discharge reductions, and 2 and 1 relate to a decreased rate of discharge reductions. A score of 0 score relates to there being no overall reduction in discharges at the end of the DSRP period compared to the present day.

With regard to concentrate and contain, a calibration scheme is used which assesses the proportion of the current radionuclide inventory which becomes contained in a passively safe solid form as a consequence of management of the DSRP wastes. Strategy options that concentrate and contain in excess of 90 % of the current inventory will score 5. Conversely, strategy options that discharge in excess of 90 % of the current inventory will score 0.

With regard to precautionary action, scoring is based on a quantitative assessment of the rate of site hazard reduction. A strategy option may similarly perform better or worse with regards to precautionary action than is assumed for the reference waste management strategy detailed in the DSRP. As a consequence, a calibration scheme is used which compares a strategy option's performance against the DSRP. In this scheme, 3 represents no change in the rate at which hazards are reduced, whilst 4 and 5 relate to an increased rate of hazard reduction, and 2 and 1 relate to a decreased rate of hazard reductions. A score of 0 score relates to there being no overall reduction in hazard at the end of the DSRP period compared to the present day. In this way, a high score reflects adherence to the principle of sustainable development where this current generation pursues an option that leaves little responsibility for future action by following generations.

With regard to protection beyond national borders, a calibration scheme is used which assesses the likely degree of 'concern' invoked in Governments and other stakeholder groups in neighbouring countries as a consequence of the different strategy options. Strategy options that are likely to be of no concern, or welcomed in neighbouring states, will score 5. Conversely, strategy options that are likely to invoke legal challenges from abroad, will score 0.

Based on these arguments, the requirements for a strategy option's performance to be judged intolerable (score 0) and very good (score 5) against the environmental objectives sub-attributes are summarised in Table B17, and the calibration scheme for these sub-attributes is provided in Tables B18a and b.

**Table B17:** Requirements for a strategy option to score 0 and 5 against the environmental objectives sub-attributes.

| Sub-Attribute | Intolerable performance (Score = 0) | Very good performance (Score = 5) |
|---|---|---|
| 10.1: Waste minimisation | Volume of solid waste generated is > 10 x DSRP | Volume of solid waste generated is 0.01 x DSRP |
| 10.2: Progressive discharge reductions | No overall reduction in discharges by the end of the DSRP | Rate of discharge reduction is greater than or equal to 3 x DSRP |
| 10.3: Concentrate and contain | > 90 % of current radionuclide inventory is discharged | > 90 % of current radionuclide inventory is immobilised in passively safe solid form |
| 10.4: Precautionary action | Rate of hazard reduction by immobilisation or discharge is 0.1 x DSRP | Rate of hazard reduction by immobilisation or discharge is 10 x DSRP |
| 10.5: Protection beyond national borders | Legal challenge from abroad | No implications or positive international response |

**Table B18a:** Calibration scheme for some environmental objectives sub-attributes.

| Score | 10.1: Waste minimisation | 10.2: Progressive discharge reduction | 10.3: Concentrate and contain |
|---|---|---|---|
| 0 | Volume of solid waste generated is > 10 x DSRP | No overall reduction in discharges by the end of the DSRP | > 90 % of current radionuclide inventory is discharged |

| Score | 10.1: Waste minimisation | 10.2: Progressive discharge reduction | 10.3: Concentrate and contain |
|---|---|---|---|
| 1 | Volume of solid waste generated is 10 to 6 x DSRP | Rate of discharge reduction is 0.1 x DSRP | 70 to 89 % of current radionuclide inventory is discharged |
| 2 | Volume of solid waste generated is 2 to 5 x DSRP | Rate of discharge reduction is 0.9 to 0.2 x DSRP | 50 to 69 % of current radionuclide inventory is discharged |
| 3 | Volume of solid waste generated is equal to DSRP | Rate of discharge reduction is equal to DSRP | 30 to 49 % of current radionuclide inventory is discharged |
| 4 | Volume of solid waste generated is 0.1 to 1 x DSRP | Rate of discharge reduction is 1 to 2 x DSRP | 10 to 29 % of current radionuclide inventory is discharged |
| 5 | Volume of solid waste generated is < 0.1 x DSRP | Rate of discharge reduction is greater to or equal to 3 x DSRP | < 10 % of current radionuclide inventory is discharged |

**Table B18b:** Calibration scheme for some environmental objectives sub-attributes.

| Score | 10.4: Precautionary action | 10.5: Protection beyond national borders |
|---|---|---|
| 0 | Rate of hazard reduction by immobilisation or discharge is > 10 x slower than DSRP | Legal challenge from abroad |
| 1 | Rate of hazard reduction by immobilisation or discharge is 10 x slower than DSRP | Formal complaint lodged by foreign Government or supra-national body through diplomatic channels |
| 2 | Rate of hazard reduction by immobilisation or discharge is 2 to 9 x slower than DSRP | Questions raised in foreign Parliamentary debates or in international conferences |
| 3 | Rate of hazard reduction is equal to DSRP | Major story reported in overseas media |
| 4 | Rate of hazard reduction by immobilisation or discharge is 2 to 9 x faster than DSRP | Minor story reported in overseas media |
| 5 | Rate of hazard reduction by immobilisation or discharge is greater or equal to 10 x faster than DSRP | No implications or positive international response |

## B6 Financial Cost

There is only a single attribute and one sub-attribute in this group which measures the undiscounted cost of implementing each strategy option, as measured throughout the lifetime of the DSRP but within the constraints and scope of this BPEO study. This includes the capital costs of new plant, plus operational and decommissioning costs, as well as the cost of storage on site of the volumes of solid wastes generated. Costs of final disposal are not included because the final management route after storage is beyond the scope of this BPEO study.

It should be noted that all cost data is based on the best estimates currently available to the Project Team.

***Attribute 11. Cost***

With regard to undiscounted cost, a strategy option may be cheaper or more expensive than is assumed for the reference waste management strategy detailed in the DSRP. As a consequence, a calibration scheme is used which compares a strategy option's cost against the DSRP. In this scheme, 3 represents a cost equal to the DSRP, whilst 4 and 5 relate to a lower cost, and 2 and 1 relate to a higher cost. For reference, the anticipated cost of the entire DSRP is £3,875 M.

Based on these arguments, the calibration scheme for the undiscounted cost sub-attribute is provided in Table B19.

**Table B19:** Calibration scheme for the undiscounted cost sub-attribute.

| Score | Calibration |
|---|---|
| 0 | Cost relative to the DSRP > £10,000M |
| 1 | Cost relative to the DSRP > £10,000M – > £600M |
| 2 | Cost relative to the DSRP > £599M – > £200M |
| 3 | Cost relative to the DSRP > £199M – < £200M |
| 4 | Cost relative to the DSRP < £201M – < £600M |
| 5 | Cost relative to the DSRP < £601M |

# Appendix C: Supporting Information for Scoring

In this Appendix, supporting information used to determine scores for the strategy options against the sub-attributes is presented. Most of the information relates to the determination of scores for sub-attributes with a qualitative calibration scheme, as described in Appendix B.

## C1 Radiological Dose

### C1.1 Attribute 1.1. Routine radiation dose to public (individuals in critical group)

The determination of the total radiological dose to members of the public (individuals in critical group) arising from the treatment of each of the waste streams in any given strategy option is difficult to determine because little quantitative information exists on some of the representative treatment methods considered. As a consequence, the following approach was used in the determination of doses:

- identify whether each representative treatment method has a liquid discharge and, if so, make an estimate of the potential dose on a scale from low to high, then for methods rated medium or higher make an quantitative estimate of potential dose to the critical group; and
- identify whether each representative treatment method has an aerial discharge and, if so, make an estimate of the potential dose on a scale from low to high, then for methods rated medium or higher make an quantitative estimate of potential dose to the critical group.

The quantitative estimates of potential dose required a number of assumptions to be made:

***Liquid Discharges***

The most significant assumptions for liquid discharges are:

- the maximum dose from liquid LLW discharges under the DSRP is 5.9 μSv $yr^{-1}$;
- dose to the critical group (taken to be winkle pickers on the shore) from liquid discharges is calculated using the formula:

  $$\text{Dose [Sv]} = (\text{Total } \alpha \times 4.17 \times 10^{-17}) \text{ [Bq]} \times (\text{Total } \beta \times 1.42 \times 10^{-19}) \text{ [Bq]}$$

- wet scrubbing of aerial discharges diverts all radionuclides to the liquid LLW waste stream;
- direct discharge of liquids and sludges is assumed to take place at a constant rate over 60 years (the timescale for the DSRP);
- treatment of raffinates leads to an annual dose of 0.1% of that which would occur if the raffinates were directly discharged;

- dose rate from vitrification is based on the DVP concept design discharges;
- dose rate from de-watering sludge is calculated from 50 % of the sludge inventory;
- direct discharge of the sludge in the Shaft and Silo does not include direct discharge of the wastes stored within.

For each strategy option, sufficient data were available on liquid discharges to identify the significant inputs contributing to dose. Nevertheless, there is considerable uncertainty associated with these inputs.

Table C1.1 gives the maximum dose arising from liquid discharges during the DSRP for each strategy option, and a series of alternatives considered during the optimisation stage (identified as –i, -ii, -iii etc.), on the basis of the assumptions listed above.

**Table C1.1:** Calculated maximum doses to the public (individuals in critical group) arising from liquid discharges from the strategy options and a series of alternatives considered during the optimisation stage.

| **Strategy Option** | | **Comment** | **Maximum Dose ($\mu Sv\ yr^{-1}$)** |
|---|---|---|---|
| $Liq_{Min}$ | Minimise liquid discharges | Presence of central evaporator virtually eliminates dose from liquid discharges. | < 0.1 |
| $Liq_{MinOpt}$ | First optimised liquid discharges | Ion exchange replaces central evaporator (no impact on dose). ADU floc still cemented but supernate discharged. | < 0.1 |
| $Liq_{Max}$ | Maximise liquid discharges | Direct discharge of all liquids, especially raffinates, leads to high dose rates. | 5914 |
| $Liq_{MaxOpt}$-i | PFR & DFR raffinates and solvents & oils cemented | | 1328 |
| $Liq_{MaxOpt}$-ii | PFR & DFR raffinates, solvents & oils, all MALS and sludges cemented | | 1188 |
| $Liq_{MaxOpt}$ | Second optimised liquid discharges | PFR & DFR raffinates, solvents & oils, all MALS and sludges, and ADU floc cemented but supernate discharged. | 52 |
| $Liq_{Inter}$ | Intermediate liquid discharges | The waste stream that affects this option most is derived from the liquid decontamination of RHILW. | 12 |
| $Atm_{Min}$ | Minimise aerial discharges | The choice of cementation to minimise discharges to air has the combined effect of reducing discharges to water. | < 0.1 |
| $Atm_{MinOpt}$ | First optimised airborne discharges | ADU floc still cemented but supernate discharged. | < 0.1 |
| $Atm_{Max}$ | Maximise aerial discharges | The maximisation of discharges to air, in particular the inclusion of an evaporator, virtually eliminates dose from liquid discharges. | < 0.1 |
| $Atm_{MaxOpt}$ | Second | Addition of abatement to vitrification and | < 0.1 |

| Strategy Option | | Comment | Maximum Dose (μSv yr$^{-1}$) |
|---|---|---|---|
| | optimised airborne discharges | incineration plants does not affect liquid discharges as wet scrubber liquors would be cemented. | |
| $Atm_{Inter}$ | Intermediate aerial discharges | The most significant waste stream is liquid LLW, although dose is relatively evenly distributed between the techniques. | 22 |
| $ILW_{Min}$ | Minimise ILW solid volumes | Direct discharge of all liquids, especially raffinates, leads to high dose rates. | 5914 |
| $ILW_{MinOpt}$-i | PFR & DFR raffinates and solvents & oils cemented | | 1328 |
| $ILW_{MinOpt}$-ii | PFR & DFR raffinates, solvents & oils, all MALS and sludges cemented | | 1188 |
| $ILW_{MinOpt}$ | First optimised ILW volumes | PFR & DFR raffinates, solvents & oils, all MALS and sludges, and ADU floc cemented but supernate discharged. | 52 |
| $ILW_{Max}$ | Maximise ILW solid volumes | The presence of a central evaporator virtually eliminates dose from liquid discharges. | < 0.1 |
| $ILW_{MaxOpt}$ | Second optimised ILW volumes | Optimisation does not affect liquid discharges | < 0.1 |
| $ILW_{Inter}$ | Intermediate ILW solid volumes | Cementing liquid LLW virtually eliminates dose from liquid discharges. | < 0.1 |
| $LLW_{Min}$ | Minimise LLW solid volumes | Direct discharge of all liquids, especially raffinates, leads to high dose rates. | 5914 |
| $LLW_{MinOpt}$ | First optimised ILW volumes | PFR & DFR raffinates, solvents & oils, all MALS and sludges, and ADU floc cemented but supernate discharged. LLLETP sludge still discharged. | 52 |
| $LLW_{Max}$ | Maximise LLW solid volumes | The presence of a central evaporator virtually eliminates dose from liquid discharges. | < 0.1 |
| $LLW_{MaxOpt}$ | Second optimised ILW volumes | Optimisation does not affect liquid discharges | < 0.1 |
| $LLW_{Inter}$ | Intermediate LLW solid volumes | The presence of a central evaporator virtually eliminates dose from liquid discharges. | < 0.1 |

***Aerial Discharges***

The key waste streams considered to contribute to the aerial doses to members of the public (individuals in critical group) on the basis of different possible treatment options are summarised in Table C1.2.

**Table C1.2:** Key contributors to aerial doses to public (individuals in critical group) and main assumptions.

| Waste stream | | Treatment method | Assumptions |
|---|---|---|---|
| A1 | Particulate from Building | No HEPAs | Current site annual discharges multiplied by 1000 |
| A3 | Gaseous Tritium | Direct Discharge | No significant source excluding tritiated metals and Boron Carbide |
| A4 | Gaseous Carbon-14 | Direct Discharge | No significant source excluding Incineration of Graphite |
| A5 | Gaseous Krypton-85 | Direct Discharge | Inventory of 3 TBq released from fuels |
| A6 | Gaseous Iodine-129 | Direct Discharge | Inventory of 12.4 GBq released from PFR Raffinate |
| L1 | Low Level Liquid | Evaporate with Abatement | Assumes 0.0001% of Site Proposed Liquid Discharge RSA Authorisation Variation released |
| | | Evaporate without Abatement | Assumes 1% of Site Proposed Liquid Discharge RSA Authorisation Variation released |
| L2.1 | MAL Decomm | Evaporate with Abatement | Assumes D1204 Decom MAL - released at 0.0001% of Current D1204 Gaseous DDLs. Inventory unknown. |
| | | Evaporate without Abatement | Assumes D1204 Decom MAL - released at 1% of Current D1204 Gaseous DDLs |
| L4 | PFR Raffinate | Vitrify with Abatement | PFR Raffinate Vit Concept Design Process Flowsheet -Gas - Assumes abatement of scrubber, condenser, acid wash, Particulate Filter, Caustic wash, HEPAs - DF of 1E+6 |
| | | Vitrify without Abatement | PFR Raffinate Vit Concept Design Process Flowsheet -Flue Gas |
| L5 | Solvents (Washed) and Oils | Incinerate with Dry Abatement | BPEO Incinerator Dry Abatement Option 5 Process Flowsheet - Gaseous Discharges - Assumes abatement of Bag Filter, Double HEPAs - DF of 1E+7 |
| | | Incinerate without Abatement | All aerial inventory released - BPEO Option 5 Flowsheet |
| S1.2 | Tritiated Metals (H3) | Smelt | All Inventory of 1.8E+12 Bq - All released |
| S1.4 | Cellulosic Materials | Incinerate with Abatement | Assumes an Operating campaign of 13 years to treat Legacy and Decomm Wastes - based on average activity of LLW Solid Waste of all Pits and facilities (approx - Alpha 2E+7Bq/m3, Beta 2E+8 Bq/m3). |
| | | Incinerate without Abatement | Assumes Abatement of Double HEPAs - DF 1E+4. |
| S5 | Boron Carbide (H-3) | Release by Wash/Dissolve | Assumes that 50% released to Air - no abatement and 50% to liquid no abatement |

| Waste stream | | Treatment method | Assumptions |
|---|---|---|---|
| S6.2 | Graphite (C-14) | Incinerate with Abate | Assumes 90% abated |
| | | Incinerate without Abate | Assumes all released to Air (1E+13 Bq) |

To evaluate doses from aerial discharges, the following dose conversion factors were adopted.

**Table C1.2:** Dose conversion factors for aerial discharges to doses to members of the public (individuals in critical group) .

| Species | Factor (Sv/Bq) |
|---|---|
| Alpha | 9.65E-15 |
| Beta | 3.25E-16 |
| Tritium | 4.71E-21 |
| Carbon-14 | 7.33E-18 |
| Krypton-85 | 5.92E-21 |
| Iodine-129 | 1.14E-15 |

On the basis of the waste streams and assumptions listed in Table C1.2, and the dose conversion factors above, the maximum public doses due to aerial discharges for the different strategy options and optimised strategy options were calculated, and these doses are listed in Table C1.4. This table also summarised the maximum doses due to liquid discharges for the strategy options, the resulting total doses and scores.

**Table C1.4:** Calculated maximum doses to members of the public (individual in critical group) arising from aerial discharges from the strategy options and optimised strategies, plus the maximum doses due to liquid discharges for the strategy options, the resulting total doses and scores

| Strategy Option | Liquid discharge dose ($\mu Sv\ yr^{-1}$) | Aerial discharge dose ($\mu Sv\ yr^{-1}$) | Total Dose ($\mu Sv\ yr^{-1}$) | Score |
|---|---|---|---|---|
| $Liq_{Min}$ | < 0.1 | 14 | 14 | 4 |
| $Liq_{MinOpt}$ | < 0.1 | 14 | 14 | 4 |
| $Liq_{Max}$ | 5914 | 7 | 5921 | 0 |
| $Liq_{MaxOpt}$ | 52 | 8 | 60 | 3 |
| $Liq_{Inter}$ | 12 | 7 | 19 | 4 |
| $Atm_{Min}$ | < 0.1 | 0 | < 0.1 | 5 |
| $Atm_{MinOpt}$ | < 0.1 | 0 | < 0.1 | 5 |
| $Atm_{Max}$ | < 0.1 | $9.6x10^6$ | $9.6x10^6$ | 0 |
| $Atm_{MaxOpt}$ | < 0.1 | 30 | 30 | 4 |

| Strategy Option | Liquid discharge dose ($\mu Sv\ yr^{-1}$) | Aerial discharge dose ($\mu Sv\ yr^{-1}$) | Total Dose ($\mu Sv\ yr^{-1}$) | Score |
|---|---|---|---|---|
| $Atm_{Inter}$ | 22 | 0 | 22 | 4 |
| $ILW_{Min}$ | 5914 | 192 | 6106 | 0 |
| $ILW_{MinOpt}$ | 52 | 30 | 82 | 3 |
| $ILW_{Max}$ | < 0.1 | 34 | 34 | 3 |
| $ILW_{MaxOpt}$ | < 0.1 | 0 | < 0.1 | 5 |
| $ILW_{Inter}$ | < 0.1 | 42 | 42 | 3 |
| $LLW_{Min}$ | 5914 | 222 | 6136 | 0 |
| $LLW_{MinOpt}$ | 52 | 14 | 66 | 3 |
| $LLW_{Max}$ | < 0.1 | 15 | 15 | 4 |
| $LLW_{MaxOpt}$ | < 0.1 | 15 | 15 | 4 |
| $LLW_{Inter}$ | < 0.1 | 0 | < 0.1 | 5 |

### C1.1 Attribute 2.1. Routine radiation dose to public (societal)

The approach to the determination of dose to public (societal) was essentially the same as that adopted for doses to public (individuals in critical group), as described above.

The key waste streams considered to contribute to dose to members of the public (societal) on the basis of different possible treatment options were summarised in Table C1.2. To evaluate societal doses, the following dose conversion factors were adopted.

**Table C1.5:** Dose conversion factors for aerial discharges to doses to public (societal) .

| Species | Factor Per so Sv/Bq |
|---|---|
| Alpha | 1.10E-10 |
| Beta | 3.00E-12 |
| Tritium | 1.20E-15 |
| Carbon-14 | 1.80E-12 |
| Krypton-85 | 2.40E-17 |
| Iodine-129 | 3.60E-11 |

On the basis of the waste streams and assumptions listed in Table C1.2, and the dose conversion factors above, the dose to public (societal) for the different strategy options and optimised strategy options were calculated, and these doses are listed in Table C1.6, for both the contribution from liquid and aerial discharges, plus the resulting scores.

**Table C1.6:** Calculated maximum doses to public (societal) arising from aerial discharges from the strategy options and optimised strategies, plus the maximum doses due to liquid discharges for the strategy options, the resulting total doses and scores

| Strategy Option | Liquid discharge dose (person Sv) | Aerial discharge dose (person Sv) | Total Dose (person Sv) | Score |
|---|---|---|---|---|
| $Liq_{Min}$ | < 1 | < 1 | < 1 | 5 |
| $Liq_{MinOpt}$ | < 1 | < 1 | < 1 | 5 |
| $Liq_{Max}$ | 213 | 2 | 215 | 0 |
| $Liq_{MaxOpt}$ | 1 | 2 | 3 | 4 |
| $Liq_{Inter}$ | 1 | 2 | 3 | 4 |
| $Atm_{Min}$ | < 1 | < 1 | < 1 | 5 |
| $Atm_{MinOpt}$ | < 1 | < 1 | < 1 | 5 |
| $Atm_{Max}$ | < 1 | 8800 | 8800 | 0 |
| $Atm_{MaxOpt}$ | < 1 | 4 | 4 | 4 |
| $Atm_{Inter}$ | 1 | 0 | 1 | 4 |
| $ILW_{Min}$ | 213 | 26 | 239 | 0 |
| $ILW_{MinOpt}$ | 1 | 4 | 5 | 4 |
| $ILW_{Max}$ | < 1 | < 1 | < 1 | 5 |
| $ILW_{MaxOpt}$ | < 1 | < 1 | < 1 | 5 |
| $ILW_{Inter}$ | < 1 | 2 | 2 | 4 |
| $LLW_{Min}$ | 210 | 6 | 216 | 0 |
| $LLW_{MinOpt}$ | 2 | < 1 | 2 | 4 |
| $LLW_{Max}$ | < 1 | 22 | 22 | 4 |
| $LLW_{MaxOpt}$ | < 1 | 3 | 3 | 4 |
| $LLW_{Inter}$ | < 1 | < 1 | < 1 | 5 |

## C2 Radiological and Non-Radiological Risk

### C2.1 Attribute 1.2 (Radiological Accident Risks)

In general, the scoring of the risk attributes will not provide significant differences between the options since, albeit at different scales of cost, the risks associated with any of the options can be engineered such that the risk to both members of the public and the workers are below the Basic Safety Objectives that are specified in the NII's Safety Assessment Principles which, in turn, are based on the levels of risk that are considered to be acceptable in “The Tolerability of Risk” [HSE, 1992a] namely a risk of death of < $10^{-6}$/year for members of the public and $10^{-5}$/year for workers. The exceptions, where the scope for engineering is limited, are the options where the waste is left in-situ, such as some of the options for the LLW in the pits and for contaminated land.

Intuitively, however, some options will have a greater potential for risk than others. For example, the strategy of minimising liquid discharges will maximise the quantity of radioactivity that will be placed in interim storage on-site and thus maximise the source term that is available to be released as a result of an event such as a fire. The intermediate strategy treats the liquid arisings and discharges some of the treated liquid. Thus, for this option, the complexity of the plant is, in general, greater than for the alternative strategies, which, in principle, could lead to a higher level of risk.

To evaluate the extent to which these differences are significant, a two-stage approach was adopted. In the first, the three strategies for each waste stream were assessed in terms of whether the risk is high, medium or low. Once completed, the major sources of risk were identified as shown in Table C2.1.

The second stage addressed the quantitative value for the risk associated with each strategy. In many cases, the operations that would be undertaken are similar to those that are carried out at the existing facilities and these risks have already been assessed in the relevant safety cases. In these cases, the appropriate risks could be taken directly from the safety case or could be derived in cases where the safety case addressed a relevant process but considered a waste stream with a different activity content.

The following safety cases were utilised:

***Building D2700***

This building contains the DCP, which was designed to immobilise MTR raffinates in 500 litre drums and store them in the Interim Drum Store or the Store Extension. The safety case therefore considers all the hazards associated with the cementation process and the storage of the waste drums.

Values could be obtained directly for the risk associated with the legacy MALs and MTR raffinates. In order to determine the risk for the PFR and DFR raffinates, it was necessary to scale the values obtained for MTR raffinates. Since there are 8 tanks of MTR raffinates, and only 4 each for the DFR and PFR raffinates, the event frequencies for the PFR and DFR raffinates are halved compared to the MTR raffinates.

The assessment of the risk due to fires shows that the effect is limited in extent and thus is not sensitive to the total inventory of the waste that is stored.

***Building D1208***

The plant in this building was originally built to receive, treat and store radioactive liquid waste arisings from the MTR and DFR fuel reprocessing programmes. They have subsequently been extended and modified to receive, process and store liquid waste arisings from PFR fuel reprocessing as well.

The safety case for this building addresses the risks associated with the process of chemical separation (floc).

***Building D9867***

This is the high alpha – low beta-gamma ILW store.

The safety case for this building addresses the risks associated with managing both short and long-lived CHILW. For the options where the waste is segregated, the risks were increased to take into account the additional time that would be spent with this waste in the glovebox.

***Facility D1212***

This facility comprises the low active waste pits. The safety case was used to assess the risks associated with handling LLW.

The risks that were derived from these safety cases are shown in Table C2.1 (in A3 Tables following Appendices). In addition, there are other potentially significant risks including:

- aircraft crash followed by a fire involving aircraft fuel,
- evaporation, including evaporator implosion,
- vitrification,
- condenser faults which could release tritium, and
- fires involving air filters.

The risk due to aircraft crash is, however, considered to be greatest in the current period before the most active liquors are conditioned and, for any of the options, there is the option of storing the waste packages underground. Thus, there is no discernible distinction in the risk associated with the different strategies.

The hazards due to evaporation and vitrification have been considered in the safety cases for the HAL and vitrification facilities at Sellafield and have been shown to be acceptably low.

The risk due to fires in air filters is not considered to be significant based on assessments that have been carried out for other buildings.

The scoring of the risks for each strategy is limited by the fact that many of the safety cases only demonstrate that the risk for the building is less than $10^{-6}$/y and the total risk for each option considers several such cases. However, on the basis of the analysis that has been carried out, it is judged that a total risk for all of the options except two of less than $10^{-5}$ is conservative and that there is no significant difference in risk between the other options. On this basis, all the options bar two would score 3 as shown in the table below. The exceptions are $Atm_{Max}$ and $LLW_{Min,}$ for which there is no abatement of discharges to the atmosphere. In these case, there is the potential for larger discharges to the atmosphere following an accident and, at the plants handling the most active waste streams, there is the potential for the risk to the most exposed individual to be greater than $10^{-4}$ $y^{-1.}$ Thus, a score of 0 was allocated to these strategies.

| Description | Minimum | Maximum | Intermediate |
|---|---|---|---|
| Liquid Discharge Levels | 3 | 3 | 3 |
| Airborne Discharge Levels | 3 | 0 | 3 |
| More Active Solid Wastes | 3 | 3 | 3 |
| Less Active Solid Wastes | 0 | 3 | 3 |

### C2.2 Attribute 1.3 (Non-radiological Accident Risks)

No significant non-radiological risks have been identified with any of the strategies considered for managing liquid wastes and therefore all three strategies were allocated a score of 5.

The same score was given to the strategy of minimising airborne discharges and the intermediate strategy. However, the strategy that leads to the maximum gaseous discharges includes the vitrification of the DFR and PFR raffinates without any abatement of the potential release of hazardous matter such as NOx and SOx that may be released as a result of the accident. No assessment has been made of the associated risk but, since there is clearly an increased risk, the score for this strategy is reduced to 4.

Similarly, for the strategies that address the management of ILW and LLW, $ILW_{Max,}$ $ILW_{Inter,}$ $LLW_{Max}$ and $ILW_{Inter}$ are given a score of 5. However, $ILW_{Min}$ also has no abatement of gaseous discharges and, in addition, the solvents and oils are discharged directly to sea. In $LLW_{Min\_}$ the solvents and oils are also discharged directly to sea. As before, no estimate has been made of the associated non-radiological risk, but the score has been reduced to 4.

### C2.3 Attribute 3.1 (Routine Worker Radiation Doses)

The approach to scoring the strategies in the context of routine doses to the workers was the same as for scoring the risk to members of the public, which involved reviewing the safety cases for the existing plant. For each process, the maximum individual dose to a worker was assessed to be less than the BSO of 2 mSv/y.

However, in the case of managing discharges of liquid waste, the three strategies involve significantly different processes, which may result in significantly different doses.

The strategy that maximises the discharge involves very little operator action and was given a score of 5. The strategy that minimises the discharge of liquid waste largely involves concreting the arisings with no other treatment. Since this would involve monitoring the process and some maintenance of the plant, this strategy may result in an operator being involved in several operations and receiving a dose above 2 mSv $y^{-1}$. It was therefore given a score of 4 although an assessment was not carried out. The most complex strategy, from the point of view of operator action, is the intermediate one, which has the greater potential for an operator to receive more than 5 mSv $y^{-1}$. However, the plant would be designed and managed so that no operator would receive more than the UKAEA design target of 10 mSv $y^{-1}$ and, thus, this strategy was given a score of 3.

The same scores of 4 and 3 were given to the minimum and intermediate strategies for managing the discharge of gaseous wastes. However, the non-abatement of gaseous discharges from the treatment of the raffinates was judged to have the potential of subjecting some workers to unabated discharges from the vitrification plant. An assessment of the resulting dose has not been made but, on the basis that the dose may exceed the BSL of 20 mSv/y, this strategy was given a score of zero.

In the case of the management of ILW, $ILW_{Min}$ involves segregating and decontaminating solid wastes to minimise the volume of solid waste and it was considered to be the option that had the greatest potential for operators to receive doses greater than 5 mSv $y^{-1}$. It was therefore given a score of 3. $ILW_{Max}$ involves similar processes to $Liq_{Min,}$ particularly in terms of concreting the liquid waste streams, and was given a score of 4, while $ILW_{Inter}$ is similar to $Liq_{Inter}$ and was given a score of 3.

Similar arguments were used to score the LLW strategies i.e. $LLW_{Min}$ directly discharges the liquid waste streams as in $Liq_{Max,}$ $LLW_{Max}$ involves to maximum practicable decontamination of ILW in order to reduce it to LLW and was therefore given a score of 3, while $LLW_{Inter}$ is similar to $Liq_{Min}$ This resulted in the scores that are summarised below.

| Description | Minimum | Maximum | Intermediate |
|---|---|---|---|
| Liquid Discharge Levels | 4 | 5 | 3 |
| Airborne Discharge Levels | 4 | 0 | 3 |
| Volume of Solid ILW | 3 | 4 | 3 |
| Volume of Solid LLW | 5 | 3 | 4 |

In the case of the optimised strategies, the worker dose for $Liq_{MinOpt}$ and $Liq_{MaxOpt}$ will be similar as they involve a similar level of activity associated with the cementation of liquid wastes. In $Atm_{MaxOpt}$, the score of 0 is increased to 4 because the evaporation of the decommissioning and legacy MALs, the vitrification of the PFR and DFR raffinate and ADU floc and the incineration of solvents and oils is now carried out with filtration systems on the gaseous discharge paths and the worker doses will again be similar to $Liq_{Min}$. The doses for $ILW_{MinOpt}$ and $ILW_{MaxOpt}$ remain the same as for $ILW_{Min}$ and $ILW_{Max}$ and those for $LLW_{MaxOpt}$ will be very similar to $LLW_{Max}$, but the treatment and cementation of liquid wastes decreases the score for $LLW_{MinOpt}$ relative to $LLW_{Min}$ so that it becomes the same as for $Liq_{Min}$.

Thus, the scores for the optimised strategies are as shown in the table below.

| Description | Minimum | Maximum |
|---|---|---|
| Liquid Discharge Levels | 4 | 4 |
| Airborne Discharge Levels | 4 | 4 |
| Volume of solid ILW | 3 | 4 |
| Volume of solid LLW | 4 | 3 |

### C2.4 Attribute 3.2 (Radiological Accident Risks)

The assessment of the scores relating to the radiological risks to the workforce was carried out in exactly the same way as the assessment of the risks to members of the public. In the safety cases that were reviewed, the maximum risk was found to be $3x10^{-5}$/y due to the potential handling of CHILW waste drums that were off specification or a breach of the glovebox containment in D9867. No significant differences between the strategies for managing both liquid and gaseous discharges were identified and the risk associated with each was assessed at less than $10^{-5}$/y, which corresponds to a score of 3.

### C2.5 Attribute 3.3 (Non-radiological Accident Risks)

In the case of the strategies for managing liquid discharges, all of the existing safety cases identify the radiological risk as being greater than that due to non-radiological hazards. It is considered that, even when other processes are taken into account such as evaporation and vitrification, the non-radiological risk will not exceed the radiological one and both were given the same score.

In the case of the strategies for managing gaseous wastes, the strategy of maximising gaseous discharges includes the unabated release of hazardous gasses that would be released form the vitrification of the PFR and DFR raffinates and incinerating solvents and oils without any abatement of the gaseous emissions, with the resulting discharge of NOx and SOx. No assessment has been made of the resulting risk to workers on the site but, to reflect the significantly enhanced risk, this strategy was given a score of 2.

## C3 Energy Usage

The significance of the energy usage associated with each strategy option was judged in relation to the current energy usage of the site. Over the last five years, the average has been 4.15 MW or 36,300 kWh/year [Miller, 2001].

The main users of energy associated with the processes that are related to the management of radioactive waste are as follows.

***Ventilation and Filter Systems***

The energy consumed by the current Heating and Ventilation Systems (HVACs), per year, is as follows:

| | |
|---|---|
| D1204 | 55 kW |
| D1213 Fuel Criticality Area (FCA) | 415 kW |
| D1200 | 50 kW |
| Other buildings | 60 kW |
| Total building ventilation | 580 kW |

To this will be added the new stack filters on D1213 for which the energy consumption will be 800 kW. Thus for options that include the ventilation of all buildings within a radiologically controlled area and the stack filters on D1213, the energy consumption for ventilation and filtration is taken to be 1.38MW.

***Evaporators***

The energy consumption for a central evaporator that evaporates all the low level liquid on the plant was based on a throughput of 150 $m^3$/day and operating 24 hours/ day. It was assumed to operate 350 days/year with an efficiency of 95 % and an ambient temperature of the feedstock of 150ºC. The calculated energy consumption for an electrical evaporator was 6.7 MW and for a steam heated evaporator was 9.5 MW.

The annual costs and CO2 emissions would be as follows:

| **Fuel** | **Annual Consumption (kWh)** | **Assumed Cost (p/kWh)** | **Annual Cost (£)** | **Annual CO2 Emissions (tonnes)** | **Annual Carbon Emissions (tonnes)** |
|---|---|---|---|---|---|
| Electricity | 40,100,000 | 4.25 | 1,704,000 | 20,900 | 5,690 |
| Steam (from oil fired boiler plant) | 57,300,000 | 1.5 | 859,500 | 16,600 | 4,530 |

For the present study, it was assumed that an electrical evaporator would be used.

For the options where evaporation would be confined to plant where local evaporation would be required, it was assumed that the total throughput would be reduced by at least an order of magnitude and that the energy consumption would be 0.7 MW.

***Vitrification***

Vitrification is an option for the solidification of the DFR and PFR raffinates. It is assumed that their concentration is such that no further evaporation is required and that any further evaporation would be carried out in heated tanks, for which the energy consumption would be relatively small. The vitrification process itself was based on an energy consumption of 0.8 kWh/kg of waste. Based on a throughput of 1,000 Te from each waste stream, the energy consumption is taken to be 0.06 MW.

***Incineration***

The energy consumption of a typical small incinerator is 0.02 MW.

***Cementation***

Based on the available records for the energy consumption of the existing cementation plant when it operated, the energy consumption would be relatively low compared to the total consumption for the building and is taken to be 0.01 MW.

***Smelting Tritiated Metals***

In options $Liq_{Max}$, $Liq_{Inter}$, $Atm_{Max}$ and $LLW_{Min}$, tritium is removed form contaminated metals by heating. The tritium would be removed if the steel were heated to between 800 and 1,000 ºC. Based on a specific heat for steel of 450 J/kg ºC, the required energy to raise the 500Te of contaminated steel to 1,000 ºC would be 62 MW hrs or 0.0 2% of the current energy consumption for the site.

If the steel were melted, using an energy requirement of 12MJ/kg (3.3kW hrs.), the energy requirement for 500Te would be 1,650MW hrs. or 4.5% of the current energy consumption for the site. The smelting could be carried out in a few months but, for the purpose of scoring, the energy consumption has been averaged over 10 years and a value of 0.02MW was used.

***Freezing***

Option $Atm_{Min}$ includes freezing the contents of the sludge and silo and removing them as solids before the sludge is cemented. The scheme has not been engineered and the energy required to freeze the sludges has not been calculated. A project for which freezing is planned is the freezing of the coolant in the primary circuit of DFR during the period when the pipework is cut into sections and removed. The required energy for this process is calculated to be 2MW. In the case of the pond and silo, the period for which freezing would be required would be only a few months and, for the purpose of scoring, a value of 0.2 MW was taken.

***Summary***

The main potential users of energy for the options considered in this report are the ventilation plant and evaporation. Currently, the major single user of energy is maintaining the sodium in PFR in a molten state, which consumes 1.6MW.

On the basis of the above energy consumption rates, apart from the management of NaK and Na, which is outside the scope of the present report, the scores for the 12 options are as follows:

| Description | Minimum | Maximum | Intermediate |
|---|---|---|---|
| Liquid Discharge Levels | 1 | 3 | 3 |
| Airborne Discharge Levels | 3 | 1 | 3 |
| ILW Waste Volumes | 4 | 1 | 2 |
| LLW Waste Volumes | 4 | 1 | 2 |

In the case of the optimised strategies that are discussed in Section 7, the replacement of the central evaporator by local ion exchange plant in the case of $Liq_{MinOpt}$ and $Atm_{MaxOpt,}$ increases the score to 3 and, in the case of $ILW_{MaxOpt}$ and $LLW_{MaxOpt,}$ increases the score to 4. Thus the scores for the optimised strategies are as shown below.

| Description | MinOpt | MaxOpt |
|---|---|---|
| Liquid Discharge Levels | 3 | 3 |
| Airborne Discharge Levels | 3 | 3 |
| Volume of ILW Waste | 4 | 4 |
| Volume of LLW Waste | 4 | 4 |

# C4 Costs

### C4.1 The original options

For each of the original strategic options in Table 4.2, the cost of managing each waste stream was estimated in terms of the extent to which the management increased or decreased the cost with respect to the cost of implementing the DSRP. In some cases, cost estimates have already been produced for the options that were considered and these were used in the present study. In others, no estimates exist and approximate costs were identified based on the judgement and experience of the Project Team.

In some cases, the options assumed additional waste management plant to that which is included in the DSRP. In these cases, it was assumed that the decommissioning costs associated with the additional plant would be half the capital cost.

Some options would result in an increased volume of waste to be managed. The cost of managing this waste was evaluated on the same basis as the DSRP costs were derived. The most relevant of these are summarised in the table below. However, it is recognised that many of the underlying assumptions about how and where the waste will be treated and stored are no longer valid and thus these values, together with the indicative capital and decommissioning costs, have been used merely to indicate any options which would have major cost implications.

**Table C4.1:** Unit costs of managing certain wastes streams. Note: * excludes final disposal component.

| Waste Type | Strategy Outline | Unit Cost (£k/m$^3$) |
|---|---|---|
| Dounreay<br>MTR Raffinate | D1208 store<br>DCP process to 2011<br>DCP Store to 2042<br>Dispose to Nirex (2040-42) | 144 |
| Dounreay<br>PFR raffinate | D1208 store<br>Transfer to vitrification plant<br>Vitrify (2010 to 2012)<br>Transfer to BNFL<br>Store at BNFL to 2085<br>Disposal to HLW repository | 365<br>Unevaporated |
| Dounreay<br>NCS ILW (D9875) | D9875 store<br>Repack (2015 to 2029)<br>Grout<br>Dispose to Nirex (2015 to 2029) | 195* |
| Dounreay<br>NCS ILW (DCP store) | DCP store<br>Repack (2015 to 2029) | 154* |

| Waste Type | Strategy Outline | Unit Cost (£k/$m^3$) |
|---|---|---|
| | Grout<br>Dispose to Nirex (2015 to 2029) | |
| Dounreay<br>CS ILW | D9867 store<br>Transfer to Sellafield (from 2007)<br>Process in BNFL's WTC<br>Store at Sellafield<br>Dispose to Nirex (2015-29) | 31* |
| Dounreay<br>Solvent (5B20) | Incinerate (1997-2006) | 29 |
| Dounreay<br>ADU Floc | D1208 Store<br>Convert to Oxide (2010)<br>Encapsulate in DCP (2010-24)<br>DCP Store<br>Dispose to Nirex (2015-24) | 134* |
| Dounreay<br>Solid LLW | WRACS<br>Storage (Whatlings or D3110)<br>Disposal at Dounreay | 2.1 |

The derivation of the costs associated with each of the options is shown in Table C4.1 and the major costs are summarised for each strategy option below. The key cost component for most strategies is the solid waste costs, therefore the key factor is the waste volume produced and waste loading for the different processes.

***Strategy Option $Liq_{Min}$: Minimise Liquid Waste Discharges***

The main cost implications of this strategy are summarised in the table below and discussed in the following text.

| Process | Cost (£M) |
|---|---|
| Central evaporator to treat all low level liquid arisings | 100 |
| Increased quantities of waste resulting from the absence of liquid decontamination and the increased use of robotic equipment to handle the contaminated waste. | 220 |
| The direct cementation of MALs, solvents, oils floc and sludges with no de-watering | 93 |
| ***Total*** | ***£413*** |

*The Central Evaporator*

The main cost associated with the central evaporator is cost of electricity. If the evaporator is assumed to operate for 50 years and treat 150 $m^3$ of water per day, the estimated electricity cost is £85M. The remainder is the installation, licencing and decommissioning costs.

*Additional Waste*

The cost implication of not decontaminating depends on the effectiveness of the method and the quantity of waste that can be treated. In this estimate, it is assumed that the volume of legacy CHILW and RHILW is increased by 20% and that the volume of ILW metals is increased by 30%. An allowance of £50M has been made for the provision of additional robotic equipment.

*Direct Cementation*

Typically, sludges contain 75% by volume of water which, in the DSRP, would be removed and treated prior to discharge so that only the sludge would be encapsulated as waste. Thus encapsulating the sludges directly increases the amount of waste from this source by a factor of four.

***Strategy Option $Liq_{Max}$: Maximum Liquid Waste Discharges***

In this case, the main cost implications are as follows.

| Process | Cost (£M) |
|---|---|
| The direct discharge of the raffinates, the MALs, floc, sludges, solvents, oils and boron carbide to sea | -562 |
| Use wet scrubbers to abate aerial discharges rather than HEPA filters | 28 |
| Catalytic oxidation to abate aerial discharges of tritium – aerial to liquid route. | 20 |
| Caustic scrubbers to abate the aerial discharge of C-14 and I-129 | 15 |
| Liquid absorption of Kr-85 | 45 |
| Smelt tritiated metals to remove the tritium | 1 |
| Leave the Pit wastes in-situ | -70 |
| Wash contaminated soils to allow free release | -18 |
| Incineration of graphite | -6 |
| ***Total*** | ***-£587*** |

*Discharge of Liquid Wastes*

Over 90% of the saving is the cost associated with the construction of a vitrification plant for the PFR raffinates, a cementation plant for the DFR raffinates and the treating, storing and disposing of these wastes. The difference is due to the costs of treating, storing and disposing of the other wastes and the incinerator for oils and combustible solvents.

*Wet Scrubbers*

The cost is based on the assumption that the scrubbers would be installed on 10 buildings, the installation costs would be twice that for installing in an inactive building and the operational costs would be similar to the installation costs.

*Catalytic Oxidation for Aerial Tritium Abatement*

This option has been studied by BNFL to evaluate the BPEO for Sellafield and they have estimated that the cost is in the order of £150M to £200M [BNFL, 2001a]. On the basis that the inventory of tritium at Dounreay is much lower, this cost has been reduced by an order of magnitude.

*Caustic Scrubbers for Aerial C-14 Abatement*

The cost is based on that of up to £3M for a new packed bed scrubber in Thorp with an allowance for installation in an active plant, and operational and decommissioning costs.

*Liquid Absorption of Aerial Kr-85*

A study carried out for Dounreay estimated that the cost of liquid absorption of Kr-85 from FCA reprocessing operations would be £45M [Hunsley et al, 1997].

*Furnace for Tritiated Metals*

The cost is based on commercial plant with the same allowances for licencing active plant, operation and decommissioning as for other plant above. An estimate for smelting 500Te of metal at Dounreay is £520k.

*Leaving the Pit Wastes In-situ*

The cost of capping the waste has been estimated to be equal to the cost of retrieving it [Maul et al., 2002]. Thus the saving associated with leaving the waste in-situ is the costs associated with treating, storing and disposing of them if they are removed.

*Washing Contaminated Soil*

This cost assumes that soil washing is successful enough for all 50,000 m3 of the potentially contaminated soil to be released compared to the cost of segregation and the disposal of 80% of the soil as LLW.

*Incineration of Graphite*

The cost saving is the difference between grouting the graphite as ILW and its subsequent storage and disposal and the cost of an active incinerator. The cost does not include the abatement of C-14 from the aerial discharge.

***Strategy Option $Liq_{Inter}$: Intermediate Liquid Waste Discharges***

In this case, the main cost implications are as follows.

| **Process** | **Cost (£M)** | **Comment** |
|---|---|---|
| Encapsulating the PFR raffinate in cement instead of vitrifying it proceeded by chemical separation. | -315 | |
| Dehumidifier to abate aerial discharges of tritium – aerial to liquid route. | 25 | |
| Caustic scrubbers to abate the aerial discharge of C-14. | 15 | As $Liq_{Max}$ |
| Smelt tritiated metals to remove the tritium | 1 | As $Liq_{Max}$ |
| Leave the Pit wastes in-situ | -70 | As $Liq_{Max}$ |
| Incineration of graphite | -6 | As $Liq_{Max}$ |
| ***Total*** | ***-£350*** | |

*Cementation of PFR Raffinate*

In the current DSRP strategy, the DFR raffinate would be cemented in a new cementation plant and the PFR raffinate would be vitrified. If both were cemented in the same plant, the costs of the costs of the vitrification plant, its decommissioning and the increased costs associated with vitrifying the PFR raffinates, which is estimated to be £340M, would be saved. Relative this cost saving for cementing the PFR raffinate, an allowance of £25M has been made in this option for the installation, operation and decommissioning of a chemical separation plant, but no credit has been taken for any reduction in the associated costs of waste disposal.

*Dehumidifiers for Aerial Tritium Abatement*

This is a nominal cost based on experience at Sellafield.

***Strategy Option $Atm_{Min}$: Minimum Airborne Discharges***

In this case, the main cost implications are as follows.

| **Process** | **Cost (£M)** | **Comment** |
|---|---|---|
| Use wet scrubbers to abate aerial discharges rather than HEPA filters | 28 | As $Liq_{Max}$ |
| Dehumidifier to abate aerial discharges of tritium – aerial to liquid route. | 25 | As $Liq_{Inter}$ |
| Caustic scrubbers to abate the aerial discharges of C-14 and I-129. | 15 | As $Liq_{Max}$ |
| Cryogenic Distillation of Kr-85 | 53 | |
| No flushing of contaminated circuits or decontamination of concrete during decommissioning and the cost of robotic equipment to handle the contaminated waste. | 140 | |
| Cementation of the PFR raffinate instead of vitrification. | -340 | |

| Process | Cost (£M) | Comment |
|---|---|---|
| The direct cementation of MALs, solvents, oils floc and sludges with no de-watering. | 93 | As $Liq_{Min}$ |
| The storage of tritiated metals to allow decay in an unventilated store | -5 | |
| Leave the Pit wastes in-situ | -70 | As $Liq_{Max}$ |
| Encapsulate contaminated soils in-situ | -20 | |
| ***Total*** | ***-£81*** | |

*Cryogenic Distillation of Aerial Kr-85*

The cost of cryogenic distillation for the installation of a plant at THORP was estimated to be £300M to £400M by BNFL in 1999 [BNFL, 2001b]. However, Dounreay will discharge a much lower inventory and a study carried out by Dounreay estimated that the cost of abating Kr-85 emissions from FCA reprocessing operations would be £53M [Hunsley et al., 1997] and this value is used above.

*No decontamination of Contaminated Circuits or Concrete*

The estimate assumes that not decontaminating would increase the amount of metal and concrete ILW that would be produced by decommissioning by 30% and incur £50M of robotic costs as in $Liq_{Min}$.

*Cementation of PFR Raffinate.*

The cost saving of cementing the PPFR raffinate instead of vitrifying it is taken to be £340M as in $Liq_{Min}$. In this case, no allowance has been made for a chemical separation plant.

*Decay Storage of Tritiated Metals*

This option saves the costs of volume reduction, packing, and ventilation during storage and disposal on the assumption that after storage the metal can be released. In the above cost saving, credit is only taken for the waste management costs.

***Strategy Option $Atm_{Max}$: Maximum Airborne Discharges***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| Central evaporator to treat all low level liquid arisings | 100 | As $Liq_{Min}$ |
| Evaporation of legacy MALs and decontamination liquors during decommissioning using local evaporators. | 20 | |
| Vitrification of the DFR raffinate and ADU floc instead of cementation. | 200 | |
| Vitrification of the sludges from the shaft, silo, ponds and the LLLETP | 90 | |

| Process | Cost (£M) | Comment |
|---|---|---|
| Smelt tritiated metals to remove the tritium | 1 | As $Liq_{Max}$ |
| Supercompaction of CHILW | -6 | |
| Incineration of graphite | -6 | As $Liq_{Max}$ |
| ***Total*** | ***£399*** | |

*Evaporation of MALs*

The cost is based on the assumption that two local evaporators would be required each of which would consume a tenth of the electricity that would be consumed by the postulated central evaporator in $Liq_{Min}$.

*Vitrification of DFR raffinate and ADU Floc*

The cost estimate assumes that both can be vitrified in the same plant that would be used for the PFR raffinate at the same cost per unit volume. It represents the difference in the operational costs of vitrification compared to cementation and makes allowance for the fact that the amount of ADU floc per unit volume of glass will be restricted by the uranium content of the floc and its restriction on the liquor loading on the glass. This results in the concentration of ADU floc in the glass being four times less than for PFR raffinate.

*Vitrification of Sludges*

The cost estimate assumes that the sludges could be vitrified in the plant that would be used to vitrify the PFR and DFR raffinate at the same cost per unit volume. An additional cost of £10M has been included for batch tanks and other ancillary plant.

*Supercompaction of CHILW*

The estimate assumes that supercompaction would reduce the volume of CHILW by 20%

***Strategy Option $Atm_{Inter}$: Intermediate Airborne Discharges***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| Dehumidifier to abate aerial discharges of tritium – aerial to liquid route. | 25 | As $Liq_{Inter}$ |
| Molecular sieve absorption to abate the aerial discharges of C-14. | 25 | |
| Liquid absorption of Kr-85 | 45 | As $Liq_{Max}$ |
| Absorption on silver to abate the aerial discharges of I-129 | 25 | |
| Vitrification of the DFR raffinate and ADU floc instead of cementation. | 200 | As $Atm_{Max}$ |

| Process | Cost (£M) | Comment |
|---|---|---|
| No treatment of contaminated soils. | -25 | |
| Supercompaction of CHILW | -6 | As $Atm_{Max}$ |
| No decontamination of concrete from decommissioning | 18 | |
| ***Total*** | ***£307*** | |

*Molecular Sieve Absorption to Abate the Aerial Discharges of C-14*

In the absence of available costs, a nominal value is used.

*No Treatment of Contaminated Soils*

This option saves the complete costs in the DSRP associated with segregation, packaging, storage and disposal of the soil.

*No Decontamination of Concrete from Decommissioning.*

The cost assumes that the effect of not decontaminating the concrete from decommissioning will increase the volume by 30% as in $Atm_{Min}$.

***Strategy Option $ILW_{Min}$: Minimum ILW Volume***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| The direct discharge of the raffinates, the MALs, floc, sludges, solvents, oils and boron carbide to sea | -562 | As $Liq_{Max}$ |
| Supercompaction of CHILW | -6 | As $Atm_{Max}$ |
| Incineration of graphite. | -6 | As $Liq_{Max}$ |
| ***Total*** | ***-£574*** | |

*Supercompaction of CHILW*

The estimate assumes that supercompaction would reduce the volume of CHILW by 20%

***Strategy Option $ILW_{Max}$: Maximum ILW Volumes***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| No decontamination of CHILW, RHILW, ILW metals or concrete and the associated use of robotic dismantling. | 199 | |
| Catalytic oxidation to abate aerial discharges of tritium – aerial to solid route. | 20 | As $Liq_{Max}$ |
| Zeolite separation to abate the discharges of Kr-85. | 40 | |
| Absorption of airborne I-129 on activated carbon. | 8 | |

| Process | Cost (£M) | Comment |
|---|---|---|
| Central evaporator to treat all low level liquid arisings | 100 | As $Liq_{Min}$ |
| The direct cementation of MALs, solvents, oils floc and sludges with no de-watering. | 93 | As $Liq_{Min}$ |
| Encapsulating the PFR raffinate in cement instead of vitrifying it. | -340 | As $Atm_{Min}$ |
| No segregation of LLW general metals, decontamination and treatment with ion exchange. | 27 | |
| ***Total*** | ***£147*** | |

*No decontamination of ILW*

The estimate is based on increasing the amounts of CHILW and RHILW by 20%, ILW metals by 50% and ILW concrete by 30% and a cost of £50M for robotic dismantling.

*Zeolite Separation to Abate Kr-85*

BNFL have considered this option for reducing the Kr-85 discharges from Sellafield. In the BPEO, the cost was estimated to be 1.6 times the cost of cryogenic distillation [BNFL, 2001c], which is included in $Atm_{Min}$. However, Dounreay will discharge a much lower inventory and a study for Dounreay on the solid absorption of Kr-85 from FCA reprocessing estimated that the cost would be £40M.

*Absorption of airborne I-129 on activated carbon*

BNFL have estimated the cost of installing an 8m long by 2m square column in an inactive plant to be £414k [BNFL, 2001a]. With the same allowances as above for installation on an active plant, operation and decommissioning and it is assumed that beds are installed on both the buildings that handle PFR raffinate and graphite, the cost increases to £4M. Waste treatment costs account for a further £4M.

*No segregation of LLW general metals*

The estimate assumes that the lack of segregation doubled the volume of general LLW metals and no credit has been taken for the benefits of decontamination.

***Strategy Option $ILW_{Inter}$: Intermediate ILW Volumes***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| Catalytic oxidation to abate aerial discharges of tritium – aerial to solid route. | 20 | As $Liq_{Max}$ |
| Cryogenic distillation to abate the discharges of Kr-85. | 53 | As $Atm_{Min}$ |
| Absorption of airborne I-129 on silver. | 25 | As $Atm_{Inter}$ |
| Local evaporators to treat all level liquid arisings | 10 | |

| Process | Cost (£M) | Comment |
|---|---|---|
| Supercompaction of CHILW | -6 | As $Atm_{Max}$ |
| Dissolve and discharge boron carbide. | -10 | As $Liq_{Max}$ |
| ***Total*** | ***£92*** | |

*Local Evaporation of Low Level Liquids*

The estimate is based on the assumption that if local evaporation is only carried out on liquids whose activity is above a predetermined threshold, the operational costs will be a tenth of those of evaporating all low level liquid at a central evaporator.

***Strategy Option $LLW_{Min}$: Minimum LLW Volumes***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| Free release of all contaminated general metals | -17 | |
| Reuse of all contaminated concrete and building materials. | -316 | |
| Heat tritiated metals to remove the tritium | 1 | As $Liq_{Max}$ |
| Incineration of cellulosic materials | 4 | |
| Leave Pit wastes in-situ | -70 | As $Liq_{Max}$ |
| No treatment of contaminated soils. Leave them in-situ | -25 | As $Atm_{Inter}$ |
| No flushing of contaminated circuits or decontamination of concrete during decommissioning and the cost of robotic equipment to handle the contaminated waste. | 140 | As $Atm_{Min}$ |
| The direct discharge of the raffinates, the MALs, floc, sludges, solvents, oils and boron carbide to sea | -562 | As $Liq_{Max}$ |
| ***Total*** | ***-£845*** | |

*Reuse of all Contaminated General Metals.*

The total saving due to storage and disposal costs if all the general metals were released would be £27M. The above assumes that this could be achieved for £10M.

*Free Release of all Contaminated Concrete and Building Materials.*

The total saving due to storage and disposal costs if all the contaminated concrete and building materials were reused would be £336M. The above assumes that this could be achieved for £10M.

*Incineration of Cellulosic Materials*

The estimate is based on saving the cost of managing the materials and assuming that the cost of the incinerator is the same as that for incinerating solvents and oils.

***Strategy Option $LLW_{Max}$: Maximum LLW Volumes***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| No segregation of general LLW metals and concrete. | 363 | |
| No segregation and compaction of cellulosic materials | 3 | |
| No segregation of bulk non-compactable and non-combustible waste | 3 | |
| No segregation of contaminated soil | 5 | |
| Encapsulate the CHILW, RHILW, boron carbide, ILW metals and ILW concrete as LLW | 29,120 | |
| Incinerate graphite | -6 | As $Liq_{Max}$ |
| Catalytic oxidation to abate aerial discharges of tritium – aerial to liquid route. | 20 | As $Liq_{Max}$ |
| Zeolite separation to abate the discharges of Kr-85. | 40 | As $ILW_{Max}$ |
| Absorption of airborne I-129 on activated carbon. | 8 | As $ILW_{Max}$ |
| Central evaporator to treat all low level liquid arisings. | 100 | As $Liq_{Min}$ |
| Cementation of MALs, raffinates, oils, solvents, ADU floc and sludges as LLW | 9,724 | |
| ***Total*** | ***£39,382*** | |

*No segregation of general LLW metals and concrete*

It is assumed that not segregating LLW material would double the amount of LLW metal and concrete to be managed.

*No segregation and compaction of cellulosic materials*

It is assumed that this would increase the amount of cellulosic materials to be managed by a factor of 4.75.

*No segregation of bulk non-compactable and non-combustible waste*

It is assumed that this would increase the volume of this waste stream by 30%

*No segregation of contaminated soil*

It is assumed that this would increase the amount of soil to be managed as LLW by 25%.

*Diluting ILW in Grout so that it is LLW*

The dilution has been based on the reduction of the inventory per unit volume that would be required for each of the waste streams to produce LLW.

*Diluting Liquors to Produce LLW*

Again the dilution is based on the reduction of the inventory per unit volume that would be required for each of the waste streams to produce LLW.

***Strategy Option $LLW_{Inter}$: Intermediate LLW Volumes***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| No decontamination of general LLW metals and concrete | 107 | As $LLW_{Max}$ |
| Decontamination of pit wastes after retrieval | -11 | |
| Catalytic oxidation to abate aerial discharges of tritium – aerial to liquid route. | 20 | As $Liq_{Max}$ |
| Cryogenic distillation to abate the discharges of Kr-85. | 53 | As $Atm_{Min}$ |
| Absorption of airborne I-129 on silver. | 25 | As $ILW_{Inter}$ |
| Local evaporators to treat all level liquid arisings | 10 | As $ILW_{Inter}$ |
| Encapsulating the PFR raffinate in cement instead of vitrifying it. | -340 | As $Atm_{Min}$ |
| ***Total*** | ***-£243*** | |

*Decontamination of pit wastes after retrieval*

The cost saving is based on reducing the volume of the pit wastes by 30% and a nominal cost for the decontamination of £10M

**Scoring**

In order to cover the range of the estimated costs above, the following scoring scheme has been chosen.

| Cost Relative to DSRP (£M) | Score |
|---|---|
| >+10,000 | 0 |
| +10,000 to +600 | 1 |
| +599 to +200 | 2 |
| + 199 to -200 | 3 |
| -201 to -600 | 4 |
| -601 to -1,000 | 5 |

Using this scheme, the scores for the original strategic options are as follows:

| Description | Minimum | Maximum | Intermediate |
|---|---|---|---|
| Liquid Discharge Levels | 2 | 4 | 4 |
| Airborne Discharge Levels | 3 | 2 | 2 |
| ILW | 5 | 3 | 3 |
| LLW | 5 | 0 | 4 |

### C4.2 The optimised options

***Optimised Option $Liq_{MinOpt}$***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| The direct cementation of MALs, solvents, oils floc and sludges with no de-watering. | 93 | As $Liq_{Min}$ |
| No decontamination of CHILW or RHILW | 98 | |
| ***Total*** | ***£191*** | |

*No decontamination of RHILW or ILW metals.*

Relative to $Liq_{Min,}$ liquid decontamination of systems containing residual MALs removes the costs associated with robotic equipment for handling them but the costs associated with not decontaminating CHILW and RHILW are retained (from additional solid ILW waste).

***Optimised Option $Liq_{MaxOpt}$***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| The direct discharge of the LLETP sludge, ADU floc supernate and boron carbide to sea | -15 | |
| Encapsulating the PFR raffinate in cement instead of vitrifying it proceeded by chemical separation. | -315 | As $Liq_{Inter}$ |
| Catalytic oxidation or dehumidifier to abate aerial discharges of tritium – aerial to liquid route. | 25 | As $Liq_{Inter}$ |
| Caustic scrubbers to abate the aerial discharge of C-14 and I-129. | 15 | As $Liq_{Max}$ |
| Heat tritiated metals to remove the tritium | 1 | As $Liq_{Max}$ |
| Leave the Pit wastes in-situ | -70 | As $Liq_{Max}$ |
| Wash contaminated soils to allow free release | -18 | As $Liq_{Max}$ |
| Incineration of graphite | -6 | As $Liq_{Max}$ |
| ***Total*** | ***-£383*** | |

*The direct discharge of the LLETP sludge, ADU floc supernate and boron carbide*

The cost saving is the same as in $Liq_{Max}$ for these waste streams but the raffinates and MALs are now encapsulated.

***Optimised Option $Atm_{MinOpt}$***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| Dehumidifier to abate aerial discharges of tritium – aerial to liquid route. | 25 | As $Liq_{Inter}$ |
| Caustic scrubbers to abate the aerial discharges of C-14 and I-129. | 15 | As $Liq_{Max}$ |
| Cementation of the PFR raffinate instead of vitrification. | -340 | As $Atm_{Min}$ |
| The direct cementation of MALs, solvents, oils floc and sludges with no de-watering. | 93 | As $Liq_{Min}$ |
| The storage of tritiated metals to allow decay in an unventilated store | -5 | As $Atm_{Min}$ |
| Leave the Pit wastes in-situ | -70 | As $Liq_{Max}$ |
| Encapsulate contaminated soils in-situ | -20 | As $Atm_{Min}$ |
| ***Total*** | ***-£302*** | |

***Optimised Option $Atm_{MaxOpt}$***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| Local evaporators to treat all level liquid arisings | 10 | As $ILW_{Inter}$ |
| Evaporation of legacy MALs and decontamination liquors during decommissioning using local evaporators. | 20 | As $Atm_{Max}$ |
| Smelt tritiated metals to remove the tritium | 1 | As $Liq_{Max}$ |
| Supercompaction of CHILW | -6 | As $Atm_{Max}$ |
| Incineration of graphite | -6 | As $Liq_{Max}$ |
| ***Total*** | ***£19*** | |

***Optimised Option $ILW_{MinOpt}$***

In this case, the main cost implications are as follows.

| Process | Cost (£M) | Comment |
|---|---|---|
| Direct discharge of ADU floc and boron carbide | -14 | As $Liq_{Max}$-Opt |
| Supercompaction of CHILW | -6 | |
| Incineration of graphite. | -6 | As $Liq_{Max}$ |
| ***Total*** | ***-£26*** | |

***Optimised Option ILW$_{MaxOpt}$***

In this case, the main cost implications are as follows.

| **Process** | **Cost (£M)** | **Comment** |
|---|---|---|
| No decontamination of CHILW, RHILW, ILW metals or concrete | 149 | As ILW$_{Max}$ |
| Dehumidifier to abate aerial discharges of tritium – aerial to liquid route. | 25 | As Liq$_{Inter}$ |
| Absorption of airborne I-129 on activated carbon. | 8 | As ILW$_{Max}$ |
| The direct cementation of MALs, solvents and oils, flocs and sludges with no de-watering. | 93 | As ILW$_{Max}$ |
| Encapsulating the PFR raffinate in cement instead of vitrifying it. | -340 | As Atm$_{Min}$ |
| ***Total*** | ***-£65*** | |

***Optimised Option LLW$_{MinOpt}$***

In this case, the main cost implications are as follows.

| **Process** | **Cost(£M)** | **Comment** |
|---|---|---|
| Free release of all contaminated general metals | -17 | As LLW$_{Min}$ |
| Reuse of all contaminated concrete and building materials. | -316 | As LLW$_{Min}$ |
| Heat tritiated metals to remove the tritium | 1 | As Liq$_{Max}$ |
| Incineration of cellulosic materials | 4 | |
| Leave Pit wastes in-situ | -70 | As Liq$_{Max}$ |
| No treatment of contaminated soils. Leave them in-situ | -25 | As Atm$_{Inter}$ |
| Direct discharge of LLETP sludge, ADU floc and boron carbide. | -15 | As Liq$_{Max}$-Opt |
| ***Total*** | ***-£438*** | |

***Optimised Option LLW$_{MaxOpt}$***

In this case, the main cost implications are as follows.

| **Process** | **Cost (£M)** | **Comment** |
|---|---|---|
| No segregation of general LLW metals. | 27 | |
| No segregation and compaction of cellulosic materials | 3 | As LLW$_{Max}$ |
| No segregation of bulk non-compactable and non-combustible waste | 3 | As LLW$_{Max}$ |
| No segregation of contaminated soil | 5 | As LLW$_{Max}$ |
| Incinerate graphite | -6 | As Liq$_{Max}$ |
| Dehumidifier to abate aerial discharges of tritium – aerial to liquid route. | 25 | As Liq$_{Inter}$ |
| Absorption of airborne I-129 on activated carbon. | 8 | As ILW$_{Max}$ |

| Process | Cost (£M) | Comment |
|---|---|---|
| The direct cementation of MALs, solvents, oils floc and sludges with no de-watering. | 93 | As $Liq_{Min}$ |
| ***Total*** | ***£158*** | |

*No segregation of general LLW metals*

Because the volume of concrete is 160,000 $m^3$, this option now includes the segregation of concrete, but no segregation of LLW metals is retained.

**Scoring**

Based on the scoring scheme used in Section C4.1, the scores for the optimised options are as follows:

| Description | Minimum | Maximum |
|---|---|---|
| Liquid Discharge Levels | 3 | 4 |
| Airborne Discharge Levels | 4 | 3 |
| ILW | 3 | 3 |
| LLW | 4 | 2 |

However, now that the more extreme costs have been removed, a more sensitive scoring scheme would be:

| Cost Relative to DSRP (£M) | Score |
|---|---|
| +500 to +300 | 1 |
| +299 to +100 | 2 |
| + 99 to -100 | 3 |
| -101 to -300 | 4 |
| -301 to -500 | 5 |

On this basis, the scores for the optimised options would be:

| Description | Minimum | Maximum |
|---|---|---|
| Liquid Discharge Levels | 2 | 5 |
| Airborne Discharge Levels | 5 | 3 |
| ILW | 3 | 3 |
| LLW | 5 | 2 |