

# **Nuclear Decommissioning Authority**

## **The Radiological Hazard Potential: A Progress Measure for Nuclear Cleanup**

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## 1. INTRODUCTION

In its current decommissioning strategy for nuclear plant and the management of radioactive waste, the White Paper Cmnd 2919 ('Review of Radioactive Waste Management Policy - Final Conclusions') places a requirement to demonstrate that "the hazards presented by the plant ... are reduced in a systematic and progressive way". This requirement has been repeated in the consultation paper on nuclear decommissioning .

The setting of a goal of progressive hazard reduction presumes an ability to assess whether such reductions are in fact taking place.

One difficulty is that currently there is a wide range of definitions of the terms "hazard" and "risk" and it is very common for these terms to be used interchangeably. To technical audiences, their meaning is quite different. The Health and Safety Executive (HSE) has defined "hazard" and "risk" and these definitions are used in this paper, together with "hazard potential" as defined below.

- Hazard is the potential for harm arising from an intrinsic property or disposition of something to cause detriment
- Risk is the chance that someone or something that is valued will be adversely affected in a stipulated way by the hazard
- Hazard Potential is a measure of the harm that could be caused by the material in the form it is in.

Using this definition, the 'hazard' presented by a radioactive material will be from the 'intrinsic property' - its radioactivity. This will only diminish by radioactive decay, and it is hazard potential, rather than hazard, which will be reduced by the retrieval and treatment of stored materials.

The NII position was summed up in their 2001 "Guidance for Inspectors on the Management of Radioactive Materials and Radioactive Waste on Nuclear Licensed Sites", which contains a highly relevant checklist of the attributes of a system of passively safe storage including multiple barriers, a stable wastefrom, durable containers, fit-for-purpose storage buildings, minimum dependence on active safety systems, retrievability, and the absence of foreclosing future options. It is evident that this guidance provides 'best practice' guidance for the reduction of hazard potential. It does not, however, provide a method of assessing progress in hazard reduction in any but the most general terms.

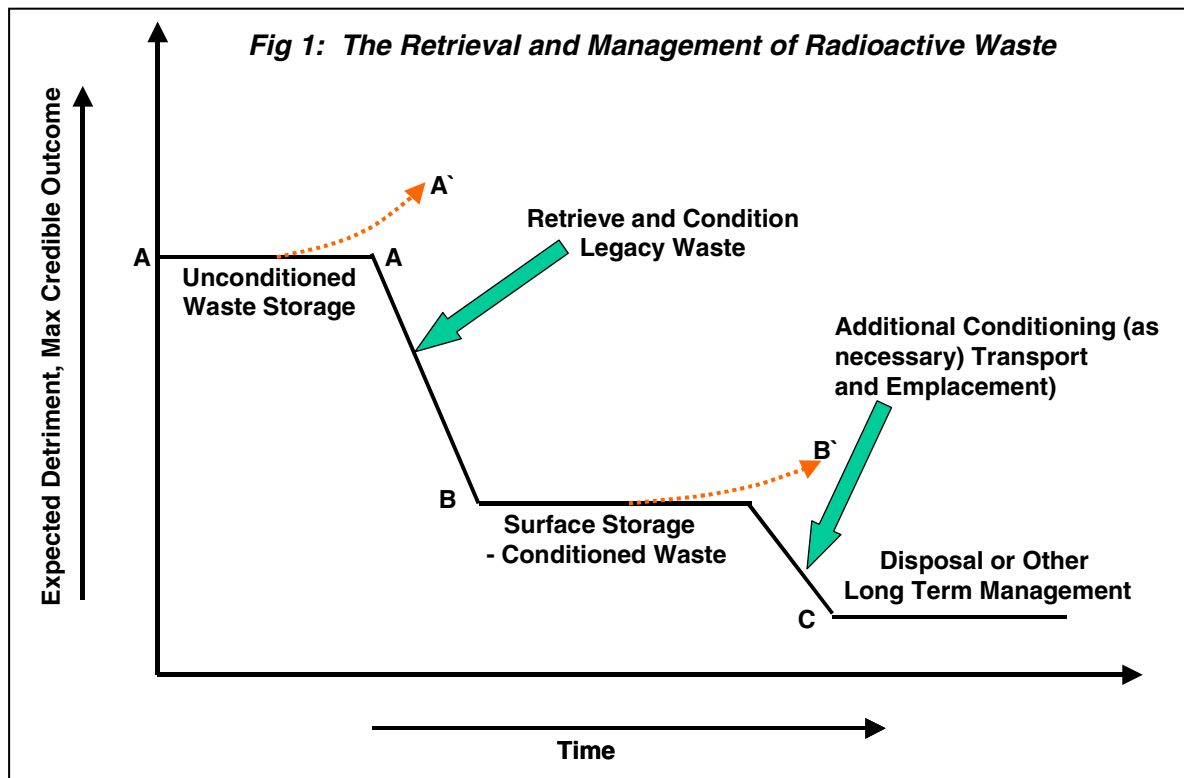
A method of measuring hazard potential has been developed. The present paper deals with the hazard posed by radiological materials. An analagous measure, the "Chemical Hazard Potential" has also been developed to consider the hazard potential of non-radioactive materials. The present paper is largely based on an earlier paper, but has been updated to reflect the name change to Radiological Hazard Potential, to include more recent development work and to remove historical background in order to simplify the paper.

This paper provides

- A clear articulation of the purpose of the Radiological Hazard Potential (RHP),
- An explanation of the various factors used to calculate the RHP and
- A justification and explanation of the values attributed to these factors

**2. CONCEPT AND CURRENT UK CONTEXT**

The process of managing radioactive materials from the ‘raw untreated’ state to a form for long term management can be visualised by means of the diagram below. Here the potential for the material to cause harm is highest when stored in its raw state (A - A), with the potential for the situation to worsen with time (A – A’). The potential to cause harm is reduced by retrieving and conditioning the material into a more passive form suitable for long term storage (A – B). The material is then stored awaiting the long term management option decided upon. Again, the situation could worsen with time (B-B’).

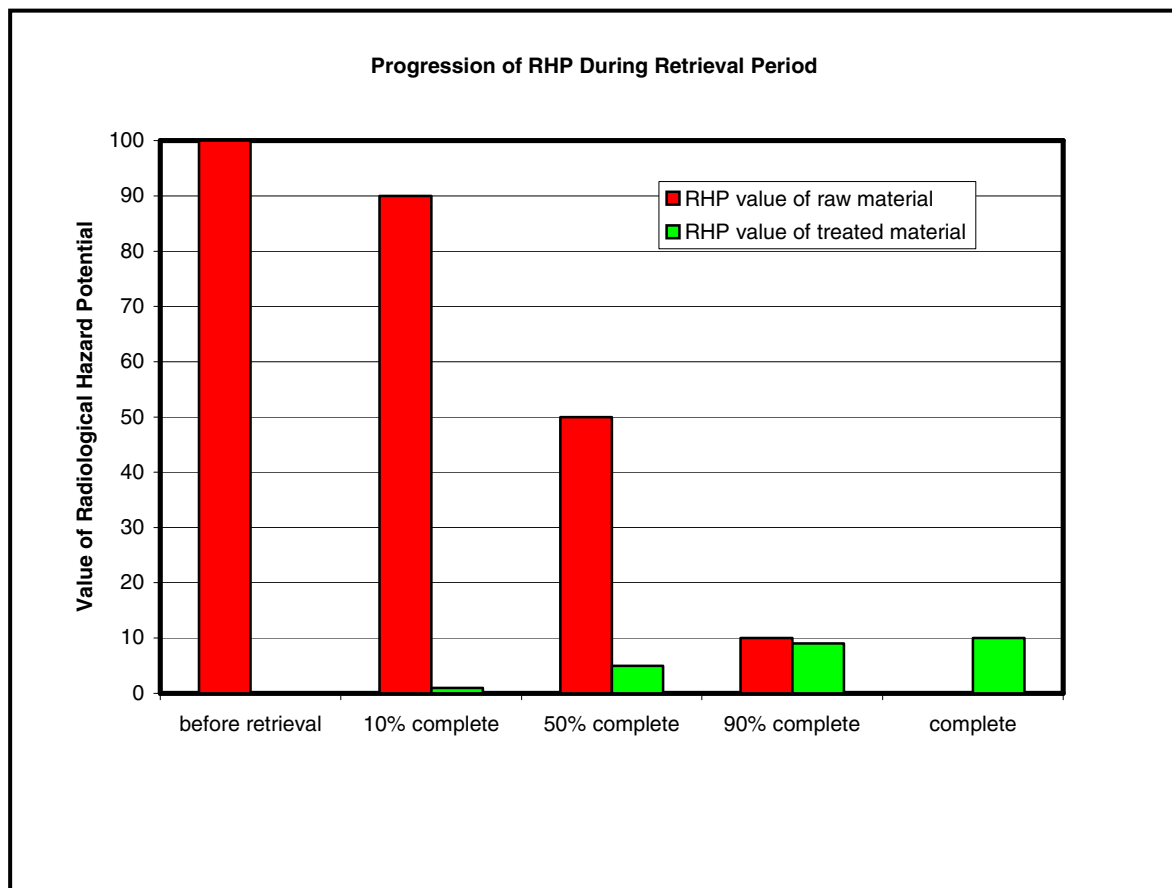


The emphasis of the RHP development has been to develop a measure that will reflect the amounts of nuclear materials in storage and the impact of decommissioning/cleanup activities in the short to medium term (say over the next 10 to 30 years) during which time wastes will be converted into forms suitable (at least) for interim storage. The Indicator does not attempt to try to reflect long-term processes associated with disposal or the evolution of wastefoms on geological timescales, nor very short-term effects (i.e. less than a few months) during extended retrieval/remediation activities where the hazard potential might temporarily increase. In terms of the diagram below, the Indicator concentrates on the path from ‘A’ to ‘B’ and, is designed to be applicable to all stored radioactive materials.

In this context, RHP is aimed at tracking progress from one storage state to another, here ‘A’ to ‘B’. Calculations would be made for the initial and final states, but no attempt would normally be made to carry out detailed RHP calculations for the transient stages of the retrieval and conditioning process unless these have an impact on the ongoing storage arrangements for the material. The modelling of any short-term increases in hazard potential arising from remediation or store management operations lies beyond the scope of the RHP,

which is intended to be a measure of progress towards passively safe storage rather than a continuous “hazard monitor”.

All risks and hazards arising from remediation activities will be controlled, monitored and regulated through the usual extensive safety assurance regime. As such, values of the RHP between ‘A’ and ‘B’ will normally simply reflect the proportion of the material retrieved and conditioned, as shown below:



Thus it is not expected that the RHP will be calculated on a day-to-day basis; rather, calculation of annual or project end snapshots is more in keeping with the intended use. Where a relatively constant buffer stock of material is maintained then the RHP is calculated for the stock using average inventories over the period in question, if the stock is replenished less frequently than annually. Faster replenishment indicates a transient stock that should be assessed as either feed or product forms.

The proposed uses of the RHP are:

1. To track the progress of hazard potential reduction within individual storage facilities, sites and across the UK.
2. To allow scenarios to be compared on the basis of their effectiveness in reducing hazard potential, as one criterion in the wider planning process.

### 3. TECHNICAL DETAILS

The proposed Radiological Hazard Potential starts from a term which represents the maximum hazard potential of the material concerned, and then modifies this with factors to account for its physical and chemical form/properties as indicated by its ease or difficulty of storage using a specified storage mode. The RHP is designed to be a relative, rather than an absolute, measure, allowing comparison between different radioactive materials and between materials stored in different forms at different locations.

The inherent potential to cause harm is influenced by:

- The radiological inventory
- The physical state or form of the material – gas, liquid, solid etc.
- The ease or difficulty of storage using a specified storage mode taking into account the chemical, physical and radiological properties of the material

The RHP attempts to address these by the use of the following factors:

#### 3.1 Inventory

A number of potential candidates to represent the waste inventory can be envisaged. One possibility is the activity of the material (i.e. the total number of Becquerels), and another is the physical amount of the material (i.e. the volume). However, neither of these are appropriate measures of 'potential to cause harm', since different radionuclides present widely differing hazards, and physical measures such as volume or activity do not take this into account. Consequently, the inventory term chosen is the Ingestion Toxic Potential (ITP) of the material. This takes into account the specific nature of individual radionuclides in terms of their half life, persistence in the body etc and calculates a theoretical dose, which is therefore a better measure of the potential harm to man. The dose/risk relationships used have been derived by the International Committee on Radiological Protection (ICRP) and are subject to regular review. An assessment<sup>1</sup> has been performed that shows that the ITP also provides a good measure of potential harm to marine biota; the ITP can therefore be considered to be a measure of potential harm to man and the environment.

The ITP is a quantity derived from Annual Limits on Intake, an internationally accepted concept that has been acknowledged by the Government's Radioactive Waste Management Committee (RWMAC) as a valid method of establishing equivalent hazards of different waste types<sup>2</sup>. The ITP is the volume of water required to dilute a material to a concentration that would be safe to drink if a population were to use the mixture as its sole source of water. A fuller explanation of ITP and its calculation is given in Appendix 1. Examination of the Form Factor (see Section 3.2) reveals that in a relatively few instances, the appropriate ITP is one which takes into account an inhalation, rather than an ingestion, route for the hazard. This modification and its justification are also described in Appendix 1.

In defining the Inventory term in this manner, it is recognised that other means by which the hazard from radioactive materials might manifest itself are not being directly taken into account within the RHP methodology. The principal example is the potential for harm to

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<sup>1</sup> "Radiological Hazard Potential as Measure Of Potential Detriment To The Environment", EGR10, July 2006.

<sup>2</sup> Radioactive Waste Advisory Committee, Response to the Government's Consultation Document: "Managing radioactive Waste Safely", June 2002

operators of nuclear plant. It is considered that the existing safety regimes in place will adequately protect workers – it is not the role of the RHP to quantify risks of this sort.

### 3.2 Form Factor

The Form Factor of the RHP represents the physical state of the material e.g. whether it is a gas, liquid, or solid. This will affect the mobility of the material and hence its potential for dispersion in the environment and its subsequent ability to cause harm. The Form Factor answers the question ‘what proportion of the material would be released (taken to mean moved away from the main body of the radioactive material) if containment was lost completely for a short period (e.g. 1 day)’. In this situation, a gas or liquid might be expected to disperse quickly, but a solid block of glass would remain immobile. The factor does not consider the likelihood of any such loss of containment (management arrangements will be in place to prevent such occurrences), but is intended to reflect the consequences in the event that such a situation occurs. This is in keeping with the objective of the RHP to assess the potential of a material to do harm, rather than the likelihood of such harm occurring.

At one end of the range of values used to represent the Form Factor, liquids and gases, which are assumed to be completely released, are given a factor of 1. At the other end of the scale, a monolithic solid (for example a container of vitrified HLW or a clean, activated component weighing several tonnes) would in practice release virtually no material and has been conservatively assigned a value of  $10^{-6}$ , a one part per million release.

Between these two extremes:

- Sludges and flocs may not disperse as completely as liquids and are in fact a mixture of particulates and water. Hence if data is available for the separate solid and liquid components, it is recommended to use the Form Factors for a powder and liquid separately. Otherwise, if inventory data is only available for the mixture, a Form Factor of 1 is considered to be appropriate for watery sludges and 0.1 for those containing a substantial solids burden.
- Powders present a greater challenge when assigning Form Factors. However there are very few radioactive materials that are stored in powder form. Assignment of values has therefore been dominated by consideration of Pu and U oxide powders. These are fairly dense materials and while fine particles (perhaps less than 10 microns or so) might be expected to be dispersed following a release, larger particles would be relatively immobile. Experimental data<sup>3</sup> used in safety cases to model airborne releases from powder spillages indicate a 10% release is a reasonable upper limit, i.e. a 0.1 factor is assigned to powders.
- Loose contamination on the surface of solid objects should be treated as a powder. As the Form Factor for powders is much higher than that of the solid it is associated with, the results will be sensitive to assumptions made here. It will therefore be important to make explicit and defensible assumptions in respect of the inventory of the loose contamination.
- Discrete solid items (e.g. pellets, miscellaneous solid items) are assigned a value of  $10^{-5}$  (a factor of 10 greater than for monolithic solids) to differentiate their behaviour from more massive solid objects.

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<sup>3</sup> For example “Resuspension of Particulate Material from Grass. Experimental Programme 1979-1980”, J A Garland, Feb. 1982, AERE-R-10106

In deriving these Form Factors, the aim has been to be conservative: i.e. to assume more material would be dispersed than would probably be the case. This concept also extends to consideration of materials that could change spontaneously and quickly to a more mobile state if control were lost (e.g. uranium hexafluoride, sodium metal, uranium hydride). In these cases the more mobile state should be assumed when assigning the Form Factor.

Form Factors should be quoted to only one significant figure to avoid conveying spurious precision. In summary, the factors proposed are:

| Form                                     | Value of factor        |
|------------------------------------------|------------------------|
| Gases, liquids, watery sludges and flocs | 1                      |
| Other sludges                            | 0.1                    |
| Powders and loose contamination          | 1/10 = 0.1             |
| Discrete solids                          | 1/100,000 = 0.00001    |
| Monolithic solids                        | 1/1,000,000 = 0.000001 |

It is important to record the assumptions behind the Form Factor assigned. For example, what size solids were assumed and what assumptions were made for surface contamination.

### 3.3 Control Factor

The physical, chemical and radiological properties of radioactive materials vary widely and a factor is needed to reflect these attributes. To address this, the concept of 'how difficult is it to store any given material' has been developed as a surrogate for these properties. Characteristics such as heat generation, corrosiveness, combustibility, chemical stability (especially with respect to exposure to air and water), Wigner energy, criticality, and the potential for reactivity excursions will all affect the level of difficulty associated with the storage mode for any given material.

A reasonable yardstick by which to assess 'difficulty of storage' is the length of time that the radioactive material could be left with no monitoring or other intervention, whilst retaining confidence that containment would be maintained and the material under scrutiny would remain 'under control'. A long time here will indicate an easily stored material, while a short time will indicate one that is more difficult to store. The time period selected will depend not only on the properties of the material, but also on the mode of storage considered for it. The examples below demonstrate the range of differing time intervals that the Control Factor needs to cater for, and indicate how these might change if the storage regime were to change.

- The radioactive decay of highly active liquid wastes generates a substantial amount of heat. The tanks containing these liquids are continuously cooled by systems containing multiple levels of redundancy. Loss of these cooling systems would eventually result in the liquids boiling and control being lost. A high degree of control is therefore required.
- Other wastes generate hydrogen and loss of the ventilation system could result in an explosive atmosphere developing. Control systems are therefore needed to ensure that hydrogen concentrations are maintained at safe levels.
- Uranium Hexafluoride ('hex') is highly unstable when exposed to air or water, but is passivating to the steel containers used to store it. Paradoxically, then, the presence of hex in a container ensures that the only concern is corrosion of the container from the outside, and assured storage times for hex cylinders in covered stores are

relatively long. However, if the containers were stored in the open air, a shorter control period might be appropriate.

- Solid materials that have been activated, but contain no surface contamination merely require physical isolation to provide shielding. Very long control periods could therefore be justified here.

Derivation of the Control Factor relies upon divorcing the concept of the idealised 'radioactive material storage mode' from the actual condition of the current storage facilities. Knowledge of the current facility conditions is essential when determining the risk of a significant loss of containment, but should not be taken into account when evaluating the RHP, since this aims to assess the intrinsic hazard potential of the material (c.f. the definition of hazard and hazard potential set out in Section 1). The identification and control of risk will nevertheless be key when assigning priorities during nuclear site cleanup, but will be addressed through other means. Given this limitation, the RHP cannot, and should not, be used as the sole means for determining priorities.

It is also important to note that the Control Factor concept being presented here relies upon discriminating between monitoring and intervention in the sense used above, and the monitoring and intervention likely to be considered necessary to satisfy the requirements of a nuclear safety case. Nuclear safety cases require that the highest reasonably practicable levels of monitoring and intervention be applied so that risks are reduced to a minimum. If these levels were to be used for the Control Factor here, it would not be possible to discriminate between many of the diverse range of stored materials for which the RHP is likely to be applied.

The Control Factor therefore attempts to take account of the differing intrinsic properties of radioactive materials by posing the question below:

“For the current/proposed storage mode, what monitoring period would a competent and experienced design engineer be likely to propose at the design stage as being necessary to ensure containment, based on the intrinsic hazard of the material, the mode of storage, and how these might evolve?”

To address this question, a four stage process has been developed as described below. Further background to the process is provided in Appendix 2, supplemented by the frequently asked questions detailed in Appendix 3. Worked examples for hypothetical facilities are given in Appendix 4.

Step 1. The storage mode of the materials for which the Control Factor is required must be nominated. For existing situations, this will usually be the current method of storage, while for future situations a mode of storage will need to be postulated. In either case, the Control Factor is assigned as if the facility was at the design stage, with the mode of storage having no design flaws and starting in pristine condition. This applies even where the actual storage arrangements for the material have known shortcomings and a limited remaining life. Example storage modes are open ponds, open silos/tanks, closed tanks, storage building, boxes, drums etc. Further examples are given in Appendix 4.

Step 2. The inherent physical and chemical properties of the stored material which could threaten the storage mode must now be considered. The following eight characteristics have been identified as having potential relevance here:

1. Heat – is the material heat generating to an extent leading to reaction, change of state etc.?
2. Corrosive – is the material corrosive with respect to its containment or packaging?
3. Combustible – will the material burn in air?
4. Corroding – will the material change state if exposed to air or water? This will have high significance if (a) corrosion affects a significant part of the activity inventory, or (b) the corrosion would aid dispersion of the inventory.
5. Secondary – does the material produce secondary hazards (e.g. hydrogen) in normal storage, requiring secondary systems e.g. agitation? Is the material liable to dry out and disperse as a powder?
6. Water – does the material react exothermically with water?
7. Gas – does the material react exothermically with air?
8. Other factors – for example, are Wigner energy or criticality relevant? Is there the potential for reactivity excursions? In practice it is unlikely that either criticality or Wigner energy will affect the Control Factor, since the RHP relates to ‘steady state’ storage rather than to operations, but the category has nevertheless been included to guide practitioners to take account of these or any other relevant property when assigning the Control Factor.

Step 3. With the materials taken to be in the storage modes nominated at the first stage, each material can then be reviewed by reference to the eight characteristics identified at the second stage. The Control Factor for each material can then be assigned using engineering judgement based on its properties and the requirements these place on the storage mode.

It is important here to emphasise that it is the material being stored and its mode of storage, and not the state of the particular plant or facility, which is considered when assigning the Control Factor. Thus additional containment of the same type will not change the Control Factor, whereas a move into a different containment mode could have an effect.

When assigning Control Factors, the practitioners will need to recall that the RHP is intended to be a relative measure; the purpose of the Control Factor is to distinguish between those materials that are more difficult to store and those that are relatively easy, in order to measure progress. The process should therefore identify those characteristics of the storage mode – ‘storage features’ – which need to remain effective in order that the material remains sufficiently under control so that a bulk release cannot take place. This will involve keeping storage conditions within identified parameters that the prudent design engineer might propose as necessary to ensure containment.

The Control Factor will be the time that would be required without corrective action for conditions to evolve to the point where they are no longer within these parameters. On this basis, catastrophic failures other than those that might arise directly from the properties of the materials (e.g. seismic events, aircraft crashes, major failure of vessels, and so forth) should not be considered, as we are here concerned with ‘failures of neglect’ – those failures which might arise if the material was left unattended and that would likely go unnoticed by anyone not specifically tasked with monitoring the facility. Furthermore, specific plant faults should not be considered in this process unless they are directly associated with the identified storage features and could be argued to be aspects of the design proposed by the competent and experienced design engineer.

For example, a covered pond used as the mode of storage for corrodible spent fuel might, in view of the eight intrinsic property characteristics listed above, have ‘storage features’

including water temperature, pH, and the presence of a covering layer of water. A failure of any of these storage features would prejudice the ongoing containment of the stored material and consequently, the hypothetical competent and experienced design engineer would propose monitoring to ensure these remained effective. The rate of heating from the fuel would determine the potential rise in temperature to cause rapid corrosion. A change of pH could similarly affect the rate of corrosion and hence the release of activity. The presence of water would be assured unless it was removed by evaporation. If, for example, the temperature would take days to breach desired conditions, the pH weeks and the water loss by evaporation months, then the Control Factor would be 'days'. Other possible means of loss of control, e.g. those associated with the age or specific features of the actual facility used to store the fuel, or with aspects of the idealised mode of storage that cannot be classed as storage features as defined above should not be considered here.

Step 4. Based on the limiting time without corrective action for conditions to evolve to the point where they could prejudice the ongoing containment of the stored material, the appropriate Control Factor should be assigned using the table below. It is important that the assumptions made in each of the steps are recorded so that an auditable trail is available for the derivation of the Control Factor. When assigning Control Factors, the practitioners need to recall that the RHP is intended to be a relative measure; the purpose of the Control Factor is to distinguish between those materials that are more difficult to store and those that are relatively easy, in order to measure progress.

Exact factors based on time have been avoided because of the spurious precision inferred, and rounded decades of time in hours have been used as shown in the table below.

| Control Time<br>(Engineering Judgement) | Typical Factor | Rounded decade<br>Control Factor |
|-----------------------------------------|----------------|----------------------------------|
| hours                                   | 1              | 1                                |
| days                                    | 24             | 10                               |
| weeks                                   | 168            | 100                              |
| months                                  | 730            | 1,000                            |
| years                                   | 8,760          | 10,000                           |
| decades                                 | 87,600         | 100,000                          |

Note that the worked examples in Appendix 4 cover the whole range of Control Factors, and some materials will move across the whole range from hours to decades during conditioning.

#### **4. RADIOLOGICAL HAZARD POTENTIAL**

The Radiological Hazard Potential (RHP) takes the three factors described above and combines them to arrive at a calculated value as follows:

$$\text{Radiological Hazard Potential} = \frac{\text{Inventory} \times \text{Form Factor}}{\text{Control Factor}}$$

For example, a material with a large inventory, in liquid form (high Form Factor) and with other inherent properties that make it relatively difficult to store (low Control Factor), will have a high RHP value. However, a conditioning programme that turned this material into a

monolithic solid (low Form Factor), and reduced the difficulty of storage (high Control Factor), would produce a much lower RHP.

The two modifying factors (Form Factor and Control Factor) can, in the extreme, reduce the value of the RHP for a given Inventory by a factor of  $10^6 / 10^{-5} = 10^{11}$ . In contrast, the Inventory can only reduce through radioactive decay.

The Form Factor ranges from 1 to  $10^{-6}$ , and the Control Factor ranges from hours to decades ( $10^5$  hours). Testing has shown that the Inventories range up to  $10^{15}$ , hence the RHP has an extremely large range.

Worked examples are given in Appendix 3.

## APPENDIX 1. INGESTION TOXIC POTENTIAL

### A1.1. Calculation of Ingestion Toxic Potential

This appendix sets out a simple step-by-step process for calculating the Ingestion Toxic Potential of a stored radioactive material containing, or contaminated with, a number of isotopes:

#### For Each Isotope

- 1 Look up the adult ingestion committed effective dose coefficient  $e(50)$  for the isotope, as published by the International Commission on Radiological Protection<sup>4</sup> to give a Sv/Bq conversion factor for uptake over a 50 year period.
- 2 Convert the  $e(50)$  to an Annual Limit of Intake. This is the quantity (Bq / year) of activity which would give rise to a 1mSv (0.001Sv) dose per year. =  $0.001/e(50)$  Bq (assuming the Dose Limit (DL) for an adult member of the public).
- 3 Calculate the Specific Ingestion Toxic Potential (SITP). This is the concentration that 1TBq of activity would have to be diluted to, so that an adult using the water as their sole source of drinking water throughout the year would not exceed their annual dose limit (taken to be 1mSv). The volume of water drunk per year by a "standard man" ( $Q$   $m^3$  / year) is published by NRPB<sup>5</sup>. Therefore:  
$$SITP = Q / (0.001/e(50)) m^3/TBq.$$
- 4 Calculate the Ingestion Toxic Potential (ITP) for the total quantity ( $X$  TBq) of the isotope present in the material,  $ITP = X \times SITP m^3$  of water.

#### For the Stored Material

- 5 The ITP for the stored material is the sum of the ITPs for each component isotope.

### A1.2. Methodology for the Incorporation of the Inhalation Pathway Into the RHP

A potential difficulty with using ITP as the inventory term in the RHP arises since certain radionuclides present a greater hazard to humans (per Bq) if they were to be inhaled than would be the case if they were ingested (i.e.  $e(50)_{inhalation} > e(50)_{ingestion}$ ). Consequently it is considered prudent to modify the inventory term, on a conservative basis, to allow for this possibility. The modification is carried out in two steps.

The first step is to consider the form and short-term stability of the material. Materials stored as gases or as fine particulate (e.g. with diameters smaller than typically  $10\mu m$ ) may, if control were lost, escape in a form where inhalation is a distinct possibility. Similarly, certain unstable materials (e.g. contaminated sodium) could, if control were lost, change spontaneously and quickly into one of these forms. However, for stable materials in other forms (e.g. liquids, sludges, larger particulates, monolithic solids, encapsulated wastes etc.) it is considered unlikely that much, if any, of the material could be inhaled following a release. For these materials, ingestion is considered to be the likely dominant pathway in the event of a release, and the ITP therefore provides a realistic assessment of the maximum intrinsic

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<sup>4</sup> "Age dependent doses to members of the public from intake of radionuclides: part 5 compilation of ingestion and inhalation dose coefficients", ICRP72, 1996.

<sup>5</sup> Robinson, CA, 'Generalised Habit Data for Radiological Assessments', Chilton, NRPB-N636 (1996)

harm potential. In consequence, the modification to the inventory term is limited to the following material types:

- Gases;
- Fine particulates with diameters small enough to be easily entrained in air;
- Materials which, if control was lost, could change spontaneously and quickly (i.e. within 24 hours as used to assess the Form Factor) into a gas or fine particulate dust. The requirement for the change to be spontaneous is intended to exclude materials that are merely combustible, but not self-combustible, from this category.
- Any other material where inhalation is identified to be a potential significant release pathway following a loss of control (none have been identified at present).

The second step is to consider, for the cases identified in the previous paragraph, whether any of the constituent components of the material are more harmful if ingested, rather than inhaled. If this is the case (i.e.  $e(50)_{\text{ingestion}} > e(50)_{\text{inhalation}}$ ), the original ITP calculation for this constituent will be retained (a conservative assumption). Conversely, if inhalation does have the potential to be a more harmful pathway,  $e(50)_{\text{inhalation}}$  should be used in place of  $e(50)_{\text{ingestion}}$  in the ITP calculation for that constituent. This is justified as follows:

The maximum harm arising from a release of radioactive material via a particular exposure pathway is more properly expressed in Sv and may be calculated by multiplying the quantity (in Bq) of each radionuclide to which the individual is exposed by the appropriate dose coefficient for the pathway (Sv/Bq), and then summing over all the constituent radionuclides to give  $\text{Harm}_{\text{pathway}}$  (say). However, if the individual were exposed to more than one pathway, then a bounding approach would evaluate the harm in terms of the most damaging pathway for each radionuclide (i.e. use the highest  $e(50)$  value for each component), and then sum to calculate  $\text{Harm}_{\text{bounding}}$ . This is a very similar calculation to that outlined above for ITP; re-writing the formula for ITP in terms of "Harm" we find that  $\text{ITP} = \text{Harm}_{\text{ingestion}} \times Q / \text{DL}$  (where the definitions of Q and DL are given in A1.1 above). Hence the natural way to extend the formula for ITP, to allow for the possibility that pathways other than ingestion might be the most damaging, is to substitute the multi-pathway calculation of harm ( $\text{Harm}_{\text{bounding}}$ ) for the ingestion-only version of the calculation  $\text{Harm}_{\text{ingestion}}$ . The difference between the two calculations is simply the use of the bounding dose coefficient value for all the pathways under consideration. In the present context this amounts to using the maximum of  $e(50)_{\text{ingestion}}$  and  $e(50)_{\text{inhalation}}$ .

It should be noted that in the above description,  $e(50)$  coefficients have been referred to as if they were unique quantities. However, referring to ICRP source documentation, it is clear that in a number of cases, several  $e(50)$  values are quoted, depending upon the solubility class of the radionuclide (which relates to the typical speed at which the material metabolises within the body). In keeping with the overall conservative philosophy adopted for the RHP, the bounding  $e(50)$  (i.e. the highest coefficient given for any solubility class) should be used in such cases.

The modification to cater for the possibility of inhalation is unlikely to apply particularly often in practice, since very few radioactive materials are stored as dusts, or are unstable in the sense defined above. Consequently the majority of RHP calculations will be based upon the harm potential arising from possible ingestion and will thus utilise a standard ITP calculation. In the few cases where it is necessary to modify the ITP calculation to allow for the possibility of inhalation, the approach outlined above is considered to be highly bounding since the

methodology takes no credit for the fact that exposure times in radioactive plumes are likely to be far shorter than the time a population might be exposed if drinking water supplies were to become contaminated.

A useful way of thinking about the inhalation modification is to consider its similarities with the concept of wind chill factors used to convey weather forecast information. Wind chill factors attempt to quantify the consequences of a relevant effect (cold temperatures seem worse on a windy day), by making a correction to the quantity normally used to convey such information (the ambient air temperature). This is achieved in practice by first expressing the two effects in terms of a common currency (in this case, heat flux) and then calculating an equivalent correction to the fundamental quantity. In the context of the RHP correction, the relevant effect is the potential for inhalation doses, the fundamental quantity is the ITP and the common currency is harm.

### A1.3. Summary of Modification to the Standard ITP Methodology

To summarise, the inventory term in RHP calculations will utilise the ITP of the radioactive material, except in cases where it could be argued that, following a loss of control, inhalation could provide a significant exposure pathway. In such instances, if constituent components are more harmful if inhaled rather than ingested (i.e.  $e(50)_{\text{inhalation}} > e(50)_{\text{ingestion}}$ ) then the calculation should use  $e(50)_{\text{inhalation}}$  in place of  $e(50)_{\text{ingestion}}$  for these component radionuclides.

In other words, for gases, fine particulate dusts, certain unstable materials or any other material where inhalation is identified to have the potential to be a significant release pathway in the event of control being lost, the ITP calculation should use the maximum of  $e(50)_{\text{inhalation}}$  and  $e(50)_{\text{ingestion}}$  for each constituent component. For other materials, the standard method for calculating the ITP should be retained. This modification to the methodology is unlikely to apply very often in practice since relatively few radioactive materials are stored as fine powders, or are unstable in the sense defined above.

The proposed inventory term for the RHP is therefore the volume of water needed to dilute the material so that it could be used safely as a population's sole source of drinking water, modified in a pessimistic but consistent manner to allow for the possibility that some materials are more harmful if inhaled rather than ingested.

**APPENDIX 2. FURTHER GUIDANCE FOR EVALUATION OF CONTROL FACTORS.**

1. The Control Factor is primarily concerned with the intrinsic properties of the stored material and secondarily with the extent to which these properties place requirements on the assumed mode of storage; not the other way around.
2. The 'designer' considers only the mode of storage of the material (open ponds, open silos/tanks, closed tanks, storage building, boxes, drums etc.) that is either in use, or is proposed for the future.
3. The 'designer' then considers this mode of storage as a concept without reference to the detailed design or condition of any existing facilities.
4. The 'designer' identifies the 'storage features' needed to keep the material under sufficient control to ensure containment and specifies the operational regime which needs to be maintained to ensure the long term effectiveness of these storage features. Other aspects of the design likely to be needed for the operational management of the facility should not be considered in this process.
5. The limiting storage feature, i.e. the feature that requires monitoring most frequently to determine that it is still operating within the defined regime, determines the Control Factor. If no limiting feature can be identified, then the Control Factor should be set to 'decades'.
6. Since changing the mode of storage of a material can affect the Control Factor assigned to it, the mode considered needs to be explicitly defined and recorded for each material.
7. Although the activity inventory of the material may affect the mode of storage selected, it should not otherwise affect the Control Factor.
8. The RHP is intended to measure progress towards reducing the hazard potential of stored radioactive materials. Any short-term changes in hazard potential arising from remediation or facility management operations should not be included in the Control Factor unless these change the assumed mode of storage.
9. Small releases that would be covered by safety cases (e.g. diffusion of tritium during storage) are not considered to be grounds for additional monitoring when determining the Control Factor. The Control Factor question is intended to relate to issues that could affect the release of a significant proportion of the material.
10. In the case where various materials are co-located, it is quite feasible that consideration of the 'Control Factor question' could give different results for different materials. In real situations, such co-location would involve monitoring at the frequency required by the most 'difficult' radioactive material. However, if any of these co-located materials would remain unaffected if control of the others were to be lost, then individual Control Factors should be used.
11. The Control Factor question is not intended to consider any monitoring necessary to cater for potential catastrophic failures other than those resulting from the properties of the materials (e.g. seismic events, aircraft crashes, major failure of vessels, and so forth should not be considered). This is for four reasons:
  - a. The Control Factor question is intended to provide a quantifiable and auditable measure for how difficult the material is to control based on its intrinsic physical, chemical and radiological properties. The issue of catastrophic failure pertains more to the storage facility than the properties of the material.
  - b. It is assumed that the generic containment has a current safety case justifying why catastrophic failure will not occur.
  - c. The consequences of a catastrophic failure are accounted for in the Form Factor; inclusion here would lead to double counting.
  - d. External events leading to a catastrophic failure are common to all stored radioactive materials and this is therefore not a discriminator.

12. Security considerations, which might involve catastrophic failure, are not reflected in the Control Factor or elsewhere in the RHP.
13. It is not possible to improve a Control Factor by adding redundancy in safety mechanisms or fallback safety systems.

### APPENDIX 3. FREQUENTLY ASKED QUESTIONS.

This section records the answers to questions raised by practitioners attempting to apply the RHP. The questions raised to date have been predominantly due to the difficulty of applying the idealised 'storage mode' concept against a background of years of practitioner experience with the actual state of particular, real storage arrangements. It is important to go back to the mechanisms which could lead to the storage features being compromised, rather than thinking in terms of the safety case for a particular plant.

**Q1. The Control Factor is intended to relate to only those Storage Features which protect against significant failure of a containment barrier and the potential for the subsequent release of bulk material (noting that other storage Features/containment barriers may prevent or mitigate the actual release of bulk material). Small releases are not to be accounted for. How much material has to be released before a failure is considered significant?**

A: Because of the applicability of the RHP to a wide number of wastes, it is not considered desirable to derive an activity level or percentage figure for what constitutes a bulk release. Some judgement must be applied and in making such judgement it is better to consider:

- the nature of the containment barrier(s)
- what aspects of the barrier are most important in maintaining containment
- what storage features relate to these key aspects of the containment
- the monitoring period required to ensure these key aspects are maintained

For example, for the case of self heating highly active liquor (example 1, Appendix 4), it is judged there are 3 key Storage Features:

1. HAL vessel
2. Cell structure
3. HAL cooling

Other storage features such as the off-gas system (for the containment of small routine arisings) and the cooling coil gamma monitoring system (to detect activity breakthrough into the cooling water) were not judged to be significant in comparison.

**Q2. Why does the Control Factor not consider Catastrophic Events?**

A: Only catastrophic failures resulting from the material properties need to be considered (e.g. a hydrogen explosion evolving from corroding fuel). Other catastrophic failures such as major vessel failures, external events (e.g. seismic events, aircraft crashes) should not be considered. This is for four reasons:

- The Control Factor question is intended to provide a quantifiable and auditable measure for how difficult the material is to control, based on its intrinsic physical, chemical and radiological properties. The issue of catastrophic failure pertains more to the storage facility than the properties of the material.
- It is assumed that the generic containment has a current safety case justifying why catastrophic failure will not occur.

- The consequences of a catastrophic failure are accounted for in the Form Factor; inclusion here would lead to double counting.
- External events leading to a catastrophic failure are common to all stored radioactive materials and this is therefore not a discriminator.

**Q3. How do I select a Control Factor for mixed wastes?**

A: In the case where various materials are co-located if the materials are mixed together (i.e. cannot be retrieved separately) then a single Control Factor should be used, based on the worst case.

Where the materials are separated then the impact of loss of control of one material on another material needs to be considered. If it is the case that:

1. loss of control of one material (material A) can result in bulk releases from other material types (material B) and
2. the monitoring period for Material A (e.g. weekly) is shorter or equal to the monitoring period for Material B (e.g. years)

Then a single Control Factor (Material A's) can be used (i.e. weekly). Otherwise use separate Control Factors.

**Q4. Is corrosion of vessels taken into account in the assessment of the Control Factor?**

A: Yes. Both internal corrosion of the vessel caused by the stored material and external corrosion caused by the storage environment are considered in the assessment of the Control Factor.

**Q5. Is vessel failure taken into account in the assessment of the Control Factor?**

A: Vessel failures that may be reasonably anticipated by a competent design engineer are included in the assessment of the Control Factor. Catastrophic vessel failure, as a result of errors in construction or external events (e.g. aircraft crash), are not included in the assessment of the Control Factor, for the reasons given in Section 3.3 of this report. Notice that this does not rule out all catastrophic failures - for example if a material slowly evolves hydrogen which may result in a fire which damages the containment, then this failure is relevant to the Control Factor.

**Q6. Is the presence of a pond purge relevant to the assignment of the Control Factor?**

A: Pond purge provides certain storage features (cooling, pH control) that are relevant to the Control Factor. However, catastrophic events introduced by the presence of the purge (for example, fracture of a pond purge line) are not considered; these are the subject of more detailed safety assessments.

**Q7. Is the possibility of a leak to/from a vessel considered as part of the Control Factor?**

A: If a leak of material into/out of a vessel affect the control of the material then they must be considered. However, see the notes about catastrophic vessel failure above.

**Q8. Can the Control Factor change with time?**

A: No. The Control Factor is assigned once and should be assumed to apply for the entire time of storage under the specified storage mode. In practice, more frequent inspections may allow extension of the design life of a particular building, but this is a safety argument which is outside the scope of the Control Factor. Materials stored in facilities which are outside their design lives retain the Control Factor which would be appropriate to the designated storage mode at the design stage.

## APPENDIX 4. CONTROL FACTOR ASSIGNMENTS

This appendix contains a range of examples illustrating the process of assigning the Control Factor as described in the paper.

|           | Storage mode                                                                         | Material Properties |                                                                              | Storage Features     |                                                                                                                                                                                                           | Control Factor                                                                                                                                                                      |
|-----------|--------------------------------------------------------------------------------------|---------------------|------------------------------------------------------------------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1         | Highly active liquor stored in stainless steel tanks provided with cooling coils     | Heat                | The liquor is strongly self-heating                                          | Cooling              | Provided to prevent boiling of the liquor. In the absence of cooling, the liquor will boil in a number of hours.                                                                                          | Limiting storage feature is the requirement for cooling. Loss of cooling could result in a bulk loss of material by boiling within a number of hours.<br><br>Control Factor = hours |
|           |                                                                                      | Corrosive           | Aqueous nitric acid solution corrodes stainless steel vessel slowly          | Water top-up         | Slow evaporation results in increased acid concentration in the vessel. Water must be topped up every few months to control the corrosion rate of the vessel.                                             |                                                                                                                                                                                     |
|           |                                                                                      |                     |                                                                              | Material containment | Inspection for pin-hole leaks required. Although this is continuous, inspection monthly would be expected to be adequate to prevent bulk loss of activity though small losses may occur during this time. |                                                                                                                                                                                     |
|           |                                                                                      | Flammable           | No                                                                           |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |
|           |                                                                                      | Corroding           | No                                                                           |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |
|           |                                                                                      | Secondary           | Hydrogen is evolved due to radiolysis; liquor evaporates due to self-heating | Ventilation          | Provided to sweep out hydrogen. In the absence of forced ventilation, free ventilation is provided and adequate for this purpose.                                                                         |                                                                                                                                                                                     |
|           |                                                                                      | React water         | No                                                                           |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |
| React gas | No                                                                                   |                     |                                                                              |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |
| Other     | No                                                                                   |                     |                                                                              |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |
| 2         | Vitrified high level waste in stainless steel containers in a passively cooled store | Heat                | The material is self heating, but can withstand high temperatures            | Cooling              | Passive cooling is adequate; active cooling is not required                                                                                                                                               | Loss of all storage features would have no impact for decades.<br><br>Control Factor = decades                                                                                      |
|           |                                                                                      | Corrosive           | No                                                                           |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |
|           |                                                                                      | Flammable           | No                                                                           |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |
|           |                                                                                      | Corroding           | No                                                                           | Material containment | Infrequent inspection of the containers will be required to ensure they are not corroding                                                                                                                 |                                                                                                                                                                                     |
|           |                                                                                      | Secondary           | No                                                                           |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |
|           |                                                                                      | React water         | No                                                                           |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |
|           |                                                                                      | React gas           | No                                                                           |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |
| Other     | No                                                                                   |                     |                                                                              |                      |                                                                                                                                                                                                           |                                                                                                                                                                                     |

|           | Storage mode                                                                                                                | Material Properties |                                                                                                                                                                                                                                                    | Storage Features     |                                                                                                                                                                                                               | Control Factor                                                                                                                                                                                                                                                                                                                                                                   |
|-----------|-----------------------------------------------------------------------------------------------------------------------------|---------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3         | PuO <sub>2</sub> product in stainless steel containers in a secure, passively cooled store with outlet filtration           | Heat                | Material is self-heating                                                                                                                                                                                                                           | Cooling              | Passive cooling is adequate; active cooling is not required                                                                                                                                                   | Limiting storage feature is the requirement for inspection.<br><br>Control Factor for product with PVC liners = years<br><br>Control Factor for product with no PVC liner = decades<br><br>In practice, the two types of packages may be co-located. Since failure of one package does not affect any others, it is appropriate to score the two types of packages individually. |
|           |                                                                                                                             | Corrosive           | No                                                                                                                                                                                                                                                 |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |
|           |                                                                                                                             | Flammable           | No                                                                                                                                                                                                                                                 |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |
|           |                                                                                                                             | Corroding           | No                                                                                                                                                                                                                                                 |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |
|           |                                                                                                                             | Secondary           | Radiolysis of residual moisture will produce gases which may overpressurise containers<br><br>Some containers contain PVC liners which may be degraded by radiolysis; such degradation releases hydrochloric acid which may corrode the container. | Material containment | For those containers with PVC liners annual inspection is required to ensure that the container is not holed. For the remaining containers, less frequent inspection to check for pressurisation is adequate. |                                                                                                                                                                                                                                                                                                                                                                                  |
|           |                                                                                                                             | React water         | No                                                                                                                                                                                                                                                 |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |
|           |                                                                                                                             | React gas           | No                                                                                                                                                                                                                                                 |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |
| 4         | Untreated waste, including organics and metals, stored loose in mild steel containers in a store with no ventilation system | Heat                | No                                                                                                                                                                                                                                                 |                      |                                                                                                                                                                                                               | Limiting storage feature is the requirement for inspection of the container<br><br>Control Factor = years                                                                                                                                                                                                                                                                        |
|           |                                                                                                                             | Corrosive           | No                                                                                                                                                                                                                                                 |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |
|           |                                                                                                                             | Flammable           | Organic components of the waste are flammable                                                                                                                                                                                                      |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |
|           |                                                                                                                             | Corroding           | Containers corrode slowly if exposed to unconditioned (moist) air.<br><br>Organics and metals corrode slowly is exposed to unconditioned (moist) air.                                                                                              | Material containment | Inspection of container required annually to detect corrosion of the container                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                  |
|           |                                                                                                                             |                     |                                                                                                                                                                                                                                                    | Material condition   | Inspection of the material itself is not required since degradation is not expected to affect dispersion of the material                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                  |
|           |                                                                                                                             | Secondary           | No                                                                                                                                                                                                                                                 |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |
|           |                                                                                                                             | React water         | No                                                                                                                                                                                                                                                 |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |
| React gas | No                                                                                                                          |                     |                                                                                                                                                                                                                                                    |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |
|           | Other                                                                                                                       | No                  |                                                                                                                                                                                                                                                    |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                  |

|   | Storage mode                                                                                                               | Material Properties |                                                                                                                                                       | Storage Features     |                                                                                                                                                                            | Control Factor                                                                                                                                      |
|---|----------------------------------------------------------------------------------------------------------------------------|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| 5 | Untreated waste, including organics and metals, stored loose in mild steel containers in a store with a ventilation system | Heat                | No                                                                                                                                                    |                      |                                                                                                                                                                            | Limiting storage feature is the requirement for inspection of the container<br><br>Control Factor = years                                           |
|   |                                                                                                                            | Corrosive           | No                                                                                                                                                    |                      |                                                                                                                                                                            |                                                                                                                                                     |
|   |                                                                                                                            | Flammable           | Organic components of the waste are flammable                                                                                                         |                      |                                                                                                                                                                            |                                                                                                                                                     |
|   |                                                                                                                            | Corroding           | Containers corrode slowly if exposed to unconditioned (moist) air.<br><br>Organics and metals corrode slowly if exposed to unconditioned (moist) air. | Ventilation System   | Controls moisture in air. Loss of Ventilation system will allow moisture to build in the store air in a few days but corrosion of package cannot happen quicker than years |                                                                                                                                                     |
|   |                                                                                                                            |                     |                                                                                                                                                       | Material containment | Inspection of container required infrequently to detect corrosion of the container                                                                                         |                                                                                                                                                     |
|   |                                                                                                                            |                     |                                                                                                                                                       | Material condition   | Inspection of the material itself is not required since degradation is not expected to affect dispersion of the material                                                   |                                                                                                                                                     |
|   |                                                                                                                            | Secondary           | No                                                                                                                                                    |                      |                                                                                                                                                                            |                                                                                                                                                     |
|   |                                                                                                                            | React water         | No                                                                                                                                                    |                      |                                                                                                                                                                            |                                                                                                                                                     |
|   |                                                                                                                            | React gas           | No                                                                                                                                                    |                      |                                                                                                                                                                            |                                                                                                                                                     |
|   |                                                                                                                            | Other               | No                                                                                                                                                    |                      |                                                                                                                                                                            |                                                                                                                                                     |
| 6 | Organic ion exchange resins stored under water in closed stainless steel tanks                                             | Heat                | No                                                                                                                                                    |                      |                                                                                                                                                                            | The limiting storage feature is the inspection of the containment required to ensure the material remains in place.<br><br>Control Factor = decades |
|   |                                                                                                                            | Corrosive           | No                                                                                                                                                    |                      |                                                                                                                                                                            |                                                                                                                                                     |
|   |                                                                                                                            | Flammable           | No                                                                                                                                                    |                      |                                                                                                                                                                            |                                                                                                                                                     |
|   |                                                                                                                            | Corroding           | Tank corrodes slowly due to exposure to aqueous contents<br><br>Resin degrades slowly due to exposure to radiation                                    | Material condition   | Inspection of the material itself is not required since degradation is not expected to affect dispersion of the material                                                   |                                                                                                                                                     |
|   |                                                                                                                            |                     |                                                                                                                                                       | Material containment | Infrequent inspection required to assess degradation of the tank                                                                                                           |                                                                                                                                                     |
|   |                                                                                                                            | Secondary           | No                                                                                                                                                    |                      |                                                                                                                                                                            |                                                                                                                                                     |
|   |                                                                                                                            | React water         | No                                                                                                                                                    |                      |                                                                                                                                                                            |                                                                                                                                                     |
|   |                                                                                                                            |                     |                                                                                                                                                       | React gas            | No                                                                                                                                                                         |                                                                                                                                                     |
|   |                                                                                                                            | Other               | No                                                                                                                                                    |                      |                                                                                                                                                                            |                                                                                                                                                     |

|       | Storage mode                                                                                                                                        | Material Properties |                                                                                               | Storage Features         |                                                                                                                                                                                                                                                                                        | Control Factor                                                                                                       |
|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|-----------------------------------------------------------------------------------------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| 7     | Encapsulated ion exchange resin in stainless steel containers in a passively cooled, watertight store                                               | Heat                | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        | Limiting factor is requirement for inspection of the stainless steel containers<br><br>Control Factor = decades      |
|       |                                                                                                                                                     | Corrosive           | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | Flammable           | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | Corroding           | Containers will corrode very slowly if exposed to water                                       | Material containment     | Infrequent inspection of the containers required to ensure containment                                                                                                                                                                                                                 |                                                                                                                      |
|       |                                                                                                                                                     | Secondary           | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | React water         | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | React gas           | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
| 8     | Sludge (primarily magnesium hydroxide, but with some organics, wind-blown debris and uranium corrosion products) stored underwater in an open pond. | Heat                | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        | Inspection of pond structure and cover water top-up are the limiting control features.<br><br>Control Factor = years |
|       |                                                                                                                                                     | Corrosive           | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | Flammable           | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | Corroding           | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | Secondary           | Sludge will become dry if water cover is lost. The resulting powder may be dispersed by wind. | Provision of water cover | Annual inspection of pond required to ensure water cover is retained<br><br>Water top-up required to replace evaporative losses. Evaporation is expected to be slow. Annual top-up required.                                                                                           |                                                                                                                      |
|       |                                                                                                                                                     | React water         | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | React gas           | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
| 9     | Magnox fuel stored underwater in a pH controlled, concrete, open pond.                                                                              | Heat                | Fuel stored in skips may self heat sufficiently to ignite if stored in air                    | Provision of water cover | Annual inspection of pond required to ensure integrity is retained                                                                                                                                                                                                                     | The limiting storage feature is the control of pond water chemistry<br><br>Control Factor = months                   |
|       |                                                                                                                                                     | Corrosive           | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | Flammable           | Magnox cladding is flammable                                                                  |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | Corroding           | Magnox cladding reacts with water to evolve hydrogen                                          | Pond water chemistry     | pH control reduces corrosion rate. Loss of dosing might result in corrosion of some rods in a number of months.<br><br>A pond purge is provided to control temperature in the pond. Fuel is not expected to raise pond water temperature enough to cause unacceptable corrosion rates. |                                                                                                                      |
|       |                                                                                                                                                     | Secondary           | see "corroding"                                                                               | Control of temperature   |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | React water         | see "corroding"                                                                               |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
|       |                                                                                                                                                     | React gas           | No                                                                                            |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |
| Other | No                                                                                                                                                  |                     |                                                                                               |                          |                                                                                                                                                                                                                                                                                        |                                                                                                                      |

|       | Storage mode                                                                                                          | Material Properties |                     | Storage Features     |                                                                                   | Control Factor                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|-------|-----------------------------------------------------------------------------------------------------------------------|---------------------|---------------------|----------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10    | Miscellaneous steel waste stored underwater in a pH controlled, concrete, open pond.                                  | Heat                | No                  |                      |                                                                                   | Since surface contamination of the items is negligible, no storage features are required to maintain control of this waste. Water cover is provided only to protect plant operators in daily operations.<br><br>Control Factor = decades                                                                                                                                                                                                                                                                                                                                                                                                                |
|       |                                                                                                                       | Corrosive           | No                  |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | Flammable           | No                  |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | Corroding           | Very slow corrosion |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | Secondary           | No                  |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | React water         | see "corroding"     |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | React gas           | No                  |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Other | No                                                                                                                    |                     |                     |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 11    | Contaminated water containing soluble active species in a pH controlled, concrete, open pond.                         | Heat                | No                  |                      |                                                                                   | Inspection of the pond structure is the controlling storage feature.<br><br>Control Factor = years.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|       |                                                                                                                       | Corrosive           | No                  | Material containment | Annual inspection of the pond required to ensure that small leaks do not develop. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | Flammable           | No                  |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | Corroding           | No                  |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | Secondary           | No                  |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | React water         | No                  |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | React gas           | No                  |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Other | No                                                                                                                    |                     |                     |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 12    | Mixed materials stored underwater in a pH controlled, concrete, open pond<br><br>(combination of examples 8-11 above) | Heat                | see 8-11 above      | see 8-11 above       |                                                                                   | The Control Factor for a group of wastes will typically be the shortest Control Factor of any of the wastes considered individually.<br><br>In this case the Control Factor is that for control of pH to prevent fuel corrosion (months). However, pH control does not affect the other wastes and so this Control Factor is not appropriate for these materials. Both sludge and water require annual inspection of the pond and so this is the Control Factor for these materials. However, the loss of water does not affect the steel wastes and so this factor should not be applied to them. Steel wastes retain their Control Factor of decades. |
|       |                                                                                                                       | Corrosive           | see 8-11 above      |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | Flammable           | see 8-11 above      |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | Corroding           | see 8-11 above      |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | Secondary           | see 8-11 above      |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | React water         | see 8-11 above      |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|       |                                                                                                                       | React gas           | see 8-11 above      |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Other | see 8-11 above                                                                                                        |                     |                     |                      |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

|    | Storage mode                                                           | Material Properties |                                                                                                                              | Storage Features     |                                                                                                                                                               | Control Factor                                                                                                     |
|----|------------------------------------------------------------------------|---------------------|------------------------------------------------------------------------------------------------------------------------------|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| 13 | Magnesium hydroxide sludge underwater in an ullaged concrete silo.     | Heat                | No                                                                                                                           | Material containment | Annual inspection of the silo is required to ensure that small leaks capable of passing sludge do not develop.                                                | Provision of ventilation to control hydrogen release is the limiting storage feature<br><br>Control Factor = hours |
|    |                                                                        | Corrosive           | No                                                                                                                           |                      |                                                                                                                                                               |                                                                                                                    |
|    |                                                                        | Flammable           | No                                                                                                                           |                      |                                                                                                                                                               |                                                                                                                    |
|    |                                                                        | Corroding           | No                                                                                                                           |                      |                                                                                                                                                               |                                                                                                                    |
|    |                                                                        | Secondary           | The sludge contains held up hydrogen resulting from the corrosion of magnox. Disturbing the sludge may release the hydrogen. | Ventilation          | Forced ventilation is provided to remove hydrogen. If the ventilation failed, build up of hydrogen would be rapid in the event of a gaseous release.          |                                                                                                                    |
|    |                                                                        | React water         | No                                                                                                                           |                      |                                                                                                                                                               |                                                                                                                    |
|    |                                                                        | React gas           | No                                                                                                                           |                      |                                                                                                                                                               |                                                                                                                    |
|    |                                                                        | Other               | No                                                                                                                           |                      |                                                                                                                                                               |                                                                                                                    |
| 14 | Magnox swarf and uranium fines underwater in an ullaged concrete silo. | Heat                | Heat is evolved by the corrosion of swarf.                                                                                   | Cooling              | If cooling is lost there is the potential that swarf could reach temperatures great enough to threaten the silo integrity with a few weeks.                   | Provision of ventilation to control hydrogen levels is the limiting storage feature.<br><br>Control Factor = days. |
|    |                                                                        | Corrosive           | No                                                                                                                           | Material containment | Swarf is sufficiently large that small leaks will not allow it to pass from the silo. Inspection for leaks is not required to maintain containment of sludge. |                                                                                                                    |
|    |                                                                        | Flammable           | Swarf is flammable in air                                                                                                    | Water cover          | Annual inspection of the building is required to prevent small leaks removing water cover from the swarf.                                                     |                                                                                                                    |
|    |                                                                        | Corroding           | Magnox swarf corrodes to evolve hydrogen                                                                                     |                      |                                                                                                                                                               |                                                                                                                    |
|    |                                                                        | Secondary           | see "Corroding"                                                                                                              | Ventilation          | Forced ventilation is provided to remove hydrogen. Build up of hydrogen to reach flammable levels in the ullage would take days if ventilation were lost.     |                                                                                                                    |
|    |                                                                        | React water         | see "Corroding"                                                                                                              |                      |                                                                                                                                                               |                                                                                                                    |
|    |                                                                        | React gas           | No                                                                                                                           |                      |                                                                                                                                                               |                                                                                                                    |
|    |                                                                        | Other               | No                                                                                                                           |                      |                                                                                                                                                               |                                                                                                                    |

|    | Storage mode                                                                      | Material Properties |                    | Storage Features   | Control Factor                                                                                                                                                                                                                                                                               |
|----|-----------------------------------------------------------------------------------|---------------------|--------------------|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15 | Mixed materials (from examples 13 and 14) underwater in an ullaged concrete silo. | Heat                | see examples 13-14 | see examples 13-14 | <p>The limiting storage features taken from examples 13-14 is the provision of ventilation to remove hydrogen. A hydrogen fire could potentially affect the containment of all materials, so this Control Factor is applied to all materials in the silo.</p> <p>Control Factor = hours.</p> |
|    |                                                                                   | Corrosive           | see examples 13-14 |                    |                                                                                                                                                                                                                                                                                              |
|    |                                                                                   | Flammable           | see examples 13-14 |                    |                                                                                                                                                                                                                                                                                              |
|    |                                                                                   | Corroding           | see examples 13-14 |                    |                                                                                                                                                                                                                                                                                              |
|    |                                                                                   | Secondary           | see examples 13-14 |                    |                                                                                                                                                                                                                                                                                              |
|    |                                                                                   | React water         | see examples 13-14 |                    |                                                                                                                                                                                                                                                                                              |
|    |                                                                                   | React gas           | see examples 13-14 |                    |                                                                                                                                                                                                                                                                                              |
|    |                                                                                   | Other               | see examples 13-14 |                    |                                                                                                                                                                                                                                                                                              |

|    | Storage mode                                                                          | Material Properties |                                                           | Storage Features    |                                                                                                                                                                                                                                                                                                                                                                                               | Control Factor                                                                                                                                          |
|----|---------------------------------------------------------------------------------------|---------------------|-----------------------------------------------------------|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| 16 | Magnox fuel stored underwater in a cooled, pH controlled, stainless-steel lined pond. | Heat                | Fuel may heat to ignition if stored in air.               | Water cover         | Annual inspection of pond required to ensure slow leaks are not removing water cover.<br><br>Top up required to replace evaporative losses. Top up required monthly.                                                                                                                                                                                                                          | The limiting storage features are the control of pond temperature and water chemistry and the provision of water top up.<br><br>Control Factor = months |
|    |                                                                                       | Corrosive           | No                                                        |                     |                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                         |
|    |                                                                                       | Flammable           | Magnox cladding is flammable                              | Water cover         | as above                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                         |
|    |                                                                                       | Corroding           | Magnox corrodes to evolve hydrogen when stored in water   | Pondwater chemistry | Control of pH reduced corrosion rate. Loss of pond water chemistry control would be expected to result in accelerated corrosion resulting in a bulk release to the pond within months.<br><br>Chilled Pond purge controls temperature in the pond and reduces corrosion rate. A temperature rise would result in accelerated corrosion resulting in a bulk release to the pond within months. |                                                                                                                                                         |
|    |                                                                                       | Secondary           | see "Corroding"                                           | Ventilation         | Free ventilation is adequate to remove hydrogen.                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                         |
|    |                                                                                       | React water         | see "Corroding"                                           |                     |                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                         |
|    |                                                                                       | React gas           | No                                                        |                     |                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                         |
|    |                                                                                       | Other               | Criticality possible if fuel is inappropriately arranged. | Spacing             | Fuel is stored in a safe geometry in steel racks. These racks require infrequent inspection to ensure their integrity.                                                                                                                                                                                                                                                                        |                                                                                                                                                         |

|    | Storage mode                                                                                         | Material Properties |                                                                                       | Storage Features     |                                                                                                                           | Control Factor                                                                                                         |
|----|------------------------------------------------------------------------------------------------------|---------------------|---------------------------------------------------------------------------------------|----------------------|---------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| 17 | LWR fuel underwater in a purged, temperature controlled, stainless steel lined pond.                 | Heat                | Fuel evolves heat, but is able to withstand the resulting high temperatures           |                      |                                                                                                                           | Infrequent inspections of rods and pond furniture are the limiting storage mechanisms.<br><br>Control Factor = decades |
|    |                                                                                                      | Corrosive           | No                                                                                    | Material containment | The fuel rods should be inspected infrequently to ensure that containment is being maintained                             |                                                                                                                        |
|    |                                                                                                      | Flammable           | No                                                                                    |                      |                                                                                                                           |                                                                                                                        |
|    |                                                                                                      | Corroding           | No                                                                                    |                      |                                                                                                                           |                                                                                                                        |
|    |                                                                                                      | Secondary           | No                                                                                    |                      |                                                                                                                           |                                                                                                                        |
|    |                                                                                                      | React water         | No                                                                                    |                      |                                                                                                                           |                                                                                                                        |
|    |                                                                                                      | React gas           | No                                                                                    |                      |                                                                                                                           |                                                                                                                        |
|    |                                                                                                      | Other               | Criticality possible if fuel is inappropriately arranged.                             | Spacing              | Fuel is stored in a safe geometry in steel racks. These racks require infrequent inspection to ensure their integrity.    |                                                                                                                        |
| 18 | Mixed solid waste (including graphite and magnox swarf) in a dry, passively ventilated, inerted silo | Heat                | Heat may be released by release of Wigner energy from graphite or corrosion of swarf. |                      |                                                                                                                           | The limiting storage feature is the need for the ongoing provision of inerting.<br><br>Control Factor = weeks.         |
|    |                                                                                                      | Corrosive           | No                                                                                    |                      |                                                                                                                           |                                                                                                                        |
|    |                                                                                                      | Flammable           | Both graphite and magnox are flammable                                                | Inerting             | The silo is inerted. Loss of inerting would be expected to allow an atmosphere capable of supporting combustion in weeks. |                                                                                                                        |
|    |                                                                                                      | Corroding           | Magnox corrodes in water. This corrosion evolves hydrogen.                            | Material containment | Annual inspections will be required to ensure that the silo has remained waterproof.                                      |                                                                                                                        |
|    |                                                                                                      | Secondary           | See "Corroding"                                                                       | Ventilation          | Passive ventilation is available and adequate.                                                                            |                                                                                                                        |
|    |                                                                                                      | React water         | See "Corroding"                                                                       |                      |                                                                                                                           |                                                                                                                        |
|    |                                                                                                      | React gas           | No                                                                                    |                      |                                                                                                                           |                                                                                                                        |
|    |                                                                                                      | Other               | Release of Wigner energy from graphite possible.                                      |                      |                                                                                                                           |                                                                                                                        |

|    | Storage mode                                                                       | Material Properties |                                                                                       | Storage Features     |                                                                                                                                                                                                               | Control Factor                                                                                                                                                                                                                                                                                                                   |
|----|------------------------------------------------------------------------------------|---------------------|---------------------------------------------------------------------------------------|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 19 | Mixed solid waste (including graphite and magnox swarf) in a dry, ventilated vault | Heat                | Heat may be released by release of Wigner energy from graphite or corrosion of swarf. |                      |                                                                                                                                                                                                               | The limiting storage feature is the need for the hydrogen monitoring of the vault.<br><br>Control Factor = days.                                                                                                                                                                                                                 |
|    |                                                                                    | Corrosive           | No                                                                                    |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | Flammable           | Both graphite and magnox are flammable                                                |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | Corroding           | Magnox corrodes in water. This corrosion evolves hydrogen.                            | Material containment | Annual inspections will be required to ensure that the vault has remained waterproof.<br><br>Daily inspection will be required to ensure that the concentration of hydrogen in the vault is sufficiently low. |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | Secondary           | See "Corroding"                                                                       | Ventilation          | In addition to active ventilation, passive ventilation is available but is not considered adequate to remove the quantities of hydrogen that may be formed.                                                   |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | React water         | See "Corroding"                                                                       |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | React gas           | No                                                                                    |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | Other               | Release of Wigner energy from graphite possible.                                      |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                  |
| 20 | Uranium hexafluoride in mild steel containers on outdoor rafts                     | Heat                | No                                                                                    |                      |                                                                                                                                                                                                               | Limiting storage feature is the requirement for annual inspection of the outside surface of the container.<br><br>Control Factor = years<br><br>If the containers were stored indoors in a dry atmosphere, the limiting storage feature would be inspection for internal corrosion. In this case<br><br>Control Factor = decades |
|    |                                                                                    | Corrosive           | No                                                                                    |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | Flammable           | No                                                                                    |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | Corroding           | Containers may corrode due to exposure to rainwater                                   | Material Containment | Annual inspection of the outside surface required to ensure that containment is maintained<br><br>Infrequent inspection of the containers to ensure internal corrosion is acceptable is required.             |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | Secondary           | No                                                                                    |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | React water         | Reaction with water is fast releasing HF                                              | Material containment | as above                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | React gas           | Reaction with moist air releases HF                                                   | Material containment | as above                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                  |
|    |                                                                                    | Other               | No                                                                                    |                      |                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                  |

|    | Storage mode                                                    | Material Properties |                              | Storage Features     |                                                                                                                                | Control Factor                                                                                             |
|----|-----------------------------------------------------------------|---------------------|------------------------------|----------------------|--------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| 21 | NaK in gas inerted storage in a stainless steel reactor circuit | Heat                | No                           |                      |                                                                                                                                | The limiting storage feature is the need for monitoring material containment<br><br>Control Factor = hours |
|    |                                                                 | Corrosive           | No                           |                      |                                                                                                                                |                                                                                                            |
|    |                                                                 | Flammable           | NaK is flammable             | Material containment | Hourly inspection of the reactor loop is required to ensure that containment is maintained to prevent ingress of air and water |                                                                                                            |
|    |                                                                 |                     |                              | Inerting             | Inerting is required to prevent reactions with air. If inerting supply is lost then air concentrations may build within days.  |                                                                                                            |
|    |                                                                 | Corroding           | NaK is corrosive             | Material Containment | see above                                                                                                                      |                                                                                                            |
|    |                                                                 | Secondary           | No                           |                      |                                                                                                                                |                                                                                                            |
|    |                                                                 | React water         | Reaction with water is rapid | Material containment | see above                                                                                                                      |                                                                                                            |
|    |                                                                 | React gas           | NaK Reacts with air          | Material Containment | see above                                                                                                                      |                                                                                                            |
|    |                                                                 | Inerting            | see above                    |                      |                                                                                                                                |                                                                                                            |
|    | Other                                                           | No                  |                              |                      |                                                                                                                                |                                                                                                            |