Generation Environment Management

Report

Strategic Best Available Techniques (BAT) Assessment for the Management of Spent Advanced Gas-Cooled Reactor (AGR) Desiccant and Catalyst

Originated by:	[redacted] Environment Officer, Generation Environment Management	Date:	February 2023
Reviewed and Endorsed by:	[redacted] Accredited RadWaste Engineer Operational Radioactive Waste Management Group	Date:	March 2023
Approved by:	[redacted] Fleet Operational Radioactive Waste Management Group Head (Acting)	Date:	March 2023

Report Summary

Report title: Strategic BAT for the Management of Spent AGR Desiccant and Catalyst

Report Reference: ERO/REP/0185/GEN

Summary

The preferred option for management of spent Advanced Gas-cooled Reactor (AGR) desiccant was identified in 2018. This involves washing desiccant in an off-site facility, followed by incineration and final disposal of the secondary waste ash to landfill. However, direct incineration of AGR spent desiccant was identified as the second most favourable option, and it was recommended that further work should be undertaken to assess the viability of this option.

Additional work has been undertaken in the form of full-scale trials conducted by Tradebe on behalf of EDF and has led to a review of the strategic Best Available Techniques (BAT) / Best Practicable Means (BPM) for the management of spent AGR desiccant waste. These trials conducted at Tradebe's Fawley facility, on behalf of EDF, have proven the viability of the direct incineration of spent AGR desiccant, with the secondary waste ash being acceptable for disposal to landfill.

A strategic BAT / BPM assessment has been conducted to identify the preferred option for the management of spent AGR desiccant. Nine options underwent high-level screening, resulting in three options being taken forward for more detailed assessment. The three options assessed were:

1. Washing and encapsulation at Winfrith, disposal to the Low Level Waste Repository (LLWR)
2. Washing at Winfrith, incineration at Fawley, disposal of ash to landfill
7. Direct incineration at a Fawley, disposal of ash to landfill

Additional work was completed from 2018 to 2022 to demonstrate that spent AGR catalyst behaves in a similar manner to spent AGR desiccant when treated using the same methods. Results of the trials undertaken at Tradebe indicate that catalyst is a similar-enough waste to desiccant, and should therefore be included within the scope of this Strategic BAT Assessment. This is summarised in References 23, 24 and 25. This assessment has not been re-performed following the inclusion of catalyst waste, and therefore the arguments made reflect only the assessment of spent AGR desiccant. Additional information regarding catalyst and its inclusion within this strategic BAT/BPM assessment can be found in Appendix C – Inclusion of spent AGR catalyst within the scope of this Strategic BAT/BPM assessment.

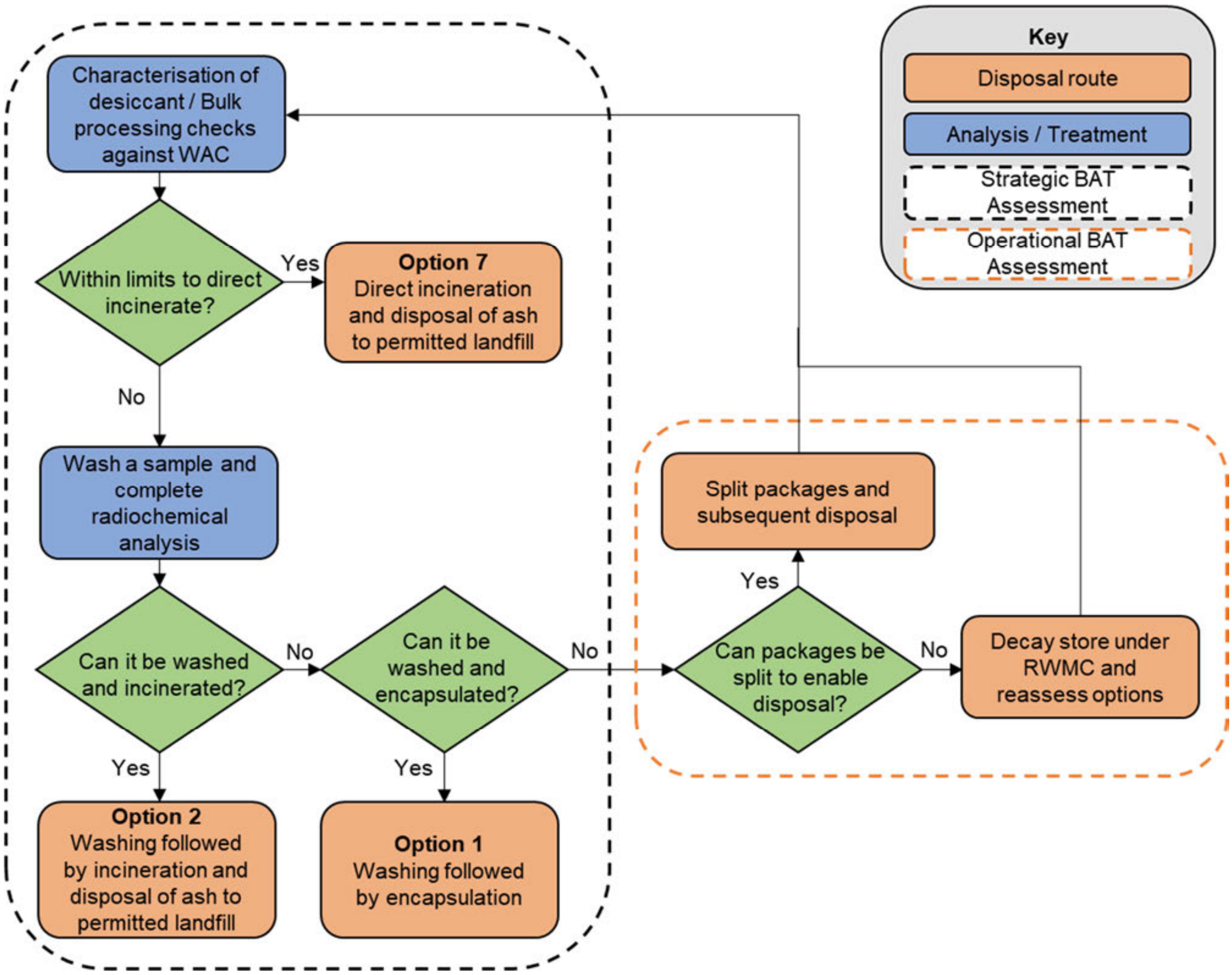
Conclusions

A summary of the pros and cons of each of the three options assessed is presented in the following Table. Option 7 (incineration and disposal to landfill), has been identified as the best performing option at a strategic level for all suitable AGR spent desiccant and catalyst. This option is much more closely aligned to the Waste Management Hierarchy (WMH) and the UK Strategy. It also avoids an additional processing step (washing) and yields significant cost benefits over those associated with Option 2.

Option	Pros	Cons
Option 1	• Lowest dose to the public (2.1E-04 μSv/TBq ^{3}H) • Technically underpinned	• Largest volume of waste disposed to the LLWR • Biggest conventional safety risk (washing, encapsulation) • Disposability risk associated with meeting the LLWR Waste Acceptance Criteria (WAC) is not removed

Option	Pros	Cons
		• Highest cost
Option 2	• No waste disposed to the LLWR • Removes LLWR disposability risk • Reduced conventional safety risk (washing, incineration) • Technically underpinned • Does not preclude Option 1 (retains contingency)	• Slight increase in public dose (when compared to Option 1) (indicative value of 1.49E-02 µSv/TBq ^{3}H from HYA R1 2013) – however, this dose does not differentiate the options
Option 7	• No waste disposed to the LLWR • Removes LLWR disposability risk • Lowest conventional safety risk (incineration) • Reduced cost (indicative 68% cost saving against Option 1). • Cost savings significant and will more than cover costs to maintain the washing plant as a contingency • Technically underpinned through trials • Fewest processing steps	• Highest dose to public (indicative value of 1.68E-02 µSv/TBq ^{3}H from HYA R1 2013) – however, this dose does not differentiate the options

A number of sensitivities have been considered through a sensitivity analysis and the robustness of the overall favourability of Option 7 has been demonstrated. Whilst Option 7 has been selected as the preferred option, there are cases where Option 7 would not be suitable due to the properties of the waste. This report provides the strategic direction for AGR spent desiccant and catalyst management, and provides a hierarchy of implementable options that can be demonstrated as BAT for an envelope of waste properties that are anticipated for AGR desiccant and catalyst waste. Where there are additional considerations to be made outside of the scope of this strategic BAT assessment, an operational BAT assessment should be conducted on a case by case basis. The figure overleaf provides an outline as to how this strategic BAT assessment should inform an operational BAT assessment should it be required. In keeping with the previous assessment, where Option 7 is unsuitable, use of Option 2 should be explored prior to Option 1.



Implementation Actions

The implementation of Option 7 as the preferred route for managing spent AGR desiccant will be subject to completion of the following actions:

- EDF to confirm whether amendments to station CEARs are required for the disposal of catalyst waste directly to Tradebe Fawley under EPR16. If required, EDF should seek the required amendments to the Compilation of Environmental Agency Requirements (CEAR) for the English AGR sites to allow transfer of Intermediate Level radioactive Waste (ILW) to the Fawley site, as appropriate. No changes to Permits are anticipated to be required for Scottish AGR sites. CEARs were updated to enable disposal of desiccant directly to Tradebe Fawley following publication of Revision 1 of this assessment.

In addition, the following requires consideration but does not prevent the implementation of Option 7 in the near-term:

- The Company Specification for the Storage, Processing and Disposal of Desiccant Waste will need to be revised in light of this strategic BAT assessment to include catalyst management.
- An assessment as to whether there are strategic and / or financial benefits associated with using another incinerator for spent AGR desiccant and catalyst management should be considered, given there may be benefits in terms of proximity for some sites.
- EDF should seek clarity from Tradebe on a WAC (or equivalent) for all options with regards to AGR spent desiccant and catalyst.

Report Issue

Date	Author	Revision	Amendment
16/02/2018	[redacted]	000	Issue 1
18/03/2020	[redacted]	001	Issue 2. Updated following desiccant direct burn trials.
March 2023	[redacted]	002	Issue 3. Updated to include catalyst following conclusion of incineration trials at Tradebe Fawley.

Glossary

Word, Phrase or Acronym	Description
AccRWE	Accredited Radioactive Waste Engineer
AGR	Advanced Gas-cooled Reactor
BAT	Best Available Technique
BPEO	Best Practicable Environmental Option
BPM	Best Practical Means
CEAR	Compilation of Environmental Agency Requirements
DNB	Dungeness B
EA	Environment Agency
EDF	EDF Energy Generation Ltd
GDF	Geological Disposal Facility
GEM	Generation Environment Management
FH ISO	Full-Height ISO Container
HAR	Hartlepool
HH ISO	Half-Height ISO Container
HNB	Hunterston B
HPB	Hinkley Point B
HYA	Heysham 1
HYB	Heysham 2
IBC	Intermediate Bulk Container
ILW	Intermediate Level radioactive Waste
IRAT	Initial Radiological Assessment Tool
LLW	Low Level Waste

Word, Phrase or Acronym	Description
LLWR	Low Level Waste Repository
MADA	Multi-Attribute Decision Analysis
OPEX	Operational Experience
REPs	Radioactive Substance Regulation Environmental Principles
SEPA	Scottish Environment Protection Agency
SQEP	Suitably Qualified and Experienced Person
TOR	Torness
VLLW	Very Low Level Waste
WAC	Waste Acceptance Criteria
WMH	Waste Management Hierarchy

Contents

List of Tables

List of Figures

1 Introduction

1.1 Background

1.1.1 Spent AGR Desiccant

EDF Energy Generation Ltd's (EDF's) Advanced Gas-cooled Reactors (AGRs) manage moisture within the reactor gas circuit through the utilisation of silica-based desiccant. Whilst a degree of regeneration is possible (for the last cycle desiccant is put on an extended regeneration cycle to minimise the moisture content), the effectiveness of the desiccant reduces over time; therefore, the desiccant has a limited operational life. The activity and characteristics of AGR spent desiccant is different at each AGR site, due to variations in plant design, operation (e.g. reactor gas chemistry and the efficiency of bypass and filtration systems) and the storage arrangements at each site. However, the typical envelope is found to have an approximate tritium (^{3}H) specific activity of 60-150 GBq tonne^{-1}. Other contaminating radioisotopes include: ^{14}C, ^{35}S, ^{36}Cl, ^{55}Fe, ^{63}Ni, with trace quantities of gamma-emitting radionuclides also present as contaminants [1]. Based on this, typically the spent desiccant is classified as Intermediate Level radioactive Waste (ILW).

Catalyst is used within the auxiliary gas system at AGR stations within the recombination unit. Catalyst recombines carbon monoxide with oxygen to produce carbon dioxide, which is used as the reactor coolant. The recombination unit is located on a separate leg of the Gas Bypass Plant after the Bypass Blowdown filters. Therefore catalyst experiences similar plant conditions to desiccant, and analytical data of catalyst samples from HYA and HAR has demonstrated that catalyst has similar radiochemical properties to desiccant. It is classified as ILW based upon tritium specific activity, and contains relatively low levels of other beta/gamma contaminants.

Catalyst is made from 0.1wt% platinum-coated, ceramic cylinders. It's physical and chemical properties do not preclude its disposal at either incineration facilities or LLWR.

The AGR fleet manage desiccant arisings in different ways, according to the Company Specification for the storage, processing and disposal of desiccant waste [2]. Some sites have been retrieving and managing desiccant for a number of years, whilst others have stored lifetime arisings on-site and are planning to dispose of some of those arisings at a future date. A summary of the storage arrangements is provided in Table 1, and further information in Appendix A. This strategic Best Available Techniques (BAT)[1] report will focus on all of the AGR sites and will consider the differing approaches and situations that each plant uses to manage spent desiccant.

[1] The use of BAT within this report is considered equivalent to Best Practicable Means (BPM), with the same obligations on waste producers, as recognised by Scottish Environment Protection Agency (SEPA) [3].

Table 1: High-Level Summary of the Management Strategy for AGR Spent Desiccant at each site

Site	Abbreviation	Summary of Management Strategy for Desiccant
Dungeness B	DNB	Storage of spent desiccant (mixed with catalyst) on-site in stainless steel Intermediate Bulk Containers (IBCs). DNB have completed characterisation of all stocks of desiccant and have commenced repackaging and disposal of desiccant from station. Catalyst is stored both separately and mixed with desiccant on site.
Hartlepool / Heysham 1 / Heysham 2 / Torness	HRA / HYA / HYB / TOR	Retrieve spent desiccant into 210 litre drums, decay store on-site for ~3 years, and then send off-site for treatment and disposal. Catalyst is stored in separate drums to desiccant at HRA and HYA and has not yet been produced at HYB or TOR.
Hinkley Point B / Hunterston B	HPB / HNB	Storage of desiccant (mixed with catalyst) on-site in Lifetime Vaults. Stored over site lifetime, although early retrieval and consignment for disposal being considered. HPB have consigned 120 drums of desiccant for disposal to previously enable on-going generation.

For the AGR sites, it is estimated that current stocks and future arisings of desiccant waste will total in the region of 850m^3 (as of January 2023). The volume of desiccant consigned per year varies depending upon site schedules and available funding. Catalyst volumes represent a much smaller volume of waste, totalling ~35m^3 across the AGR sites.

1.1.2 Assessments and Management Strategies

The management strategy for AGR spent desiccant has changed over the last two decades in response to changes in UK strategy (notably application of the WMH as per the UK Strategy for the Management of Low Level radioactive Waste (LLW) [4]) and the availability of new facilities to treat and dispose of radioactive waste. These changes are described in the following paragraphs and presented in Figure 1.

A Best Practicable Environmental Options (BPEO)[2] study, conducted in 2008, identified the best technique for managing spent AGR desiccant as off-site washing in water, encapsulation in cement and transporting to the Low Level Waste Repository (LLWR) for final disposal [5]. One of the assessment options considered the incineration (both pre and post-washing on-site) of spent desiccant. In 2008, this did not score favourably due to a lack of technical development to prove its viability.

In subsequent years, there were substantial changes to environmental regulations and spent desiccant from Magnox reactors was proven to be incinerable following washing [6]. This resulted in a full-scale service being provided to Magnox by Tradebe. This prompted EDF to undertake trials to test the viability of this option for AGR desiccant. Tradebe, on behalf of EDF, conducted three full-scale trials at their high temperature incinerator at Fawley. The three incineration trials were successful in proving that the resultant ash from the incineration of AGR desiccant met the specified requirements from Fawley's Environmental Permit for disposal to landfill [7].

In light of this evidence, a strategic BAT assessment was conducted in 2018 [8], which identified the best technique for managing spent AGR desiccant as off-site washing in water, repackaging and transportation of washed desiccant for incineration, followed by transportation of ash to an authorised landfill for final disposal. However, it was recognised that the option of direct incineration had a number of potential advantages, but as concluded in 2008 study [5], there

[2] BPEO is a methodology that can be used in Scotland to undertake the optioneering component of BPM.

remained a lack of technical evidence to prove the option's viability. Following this, EDF have worked with Tradebe to undertake trials to understand whether this option is suitably viable. This assessment is being conducted to re-assess the options accounting for the results of these trials.

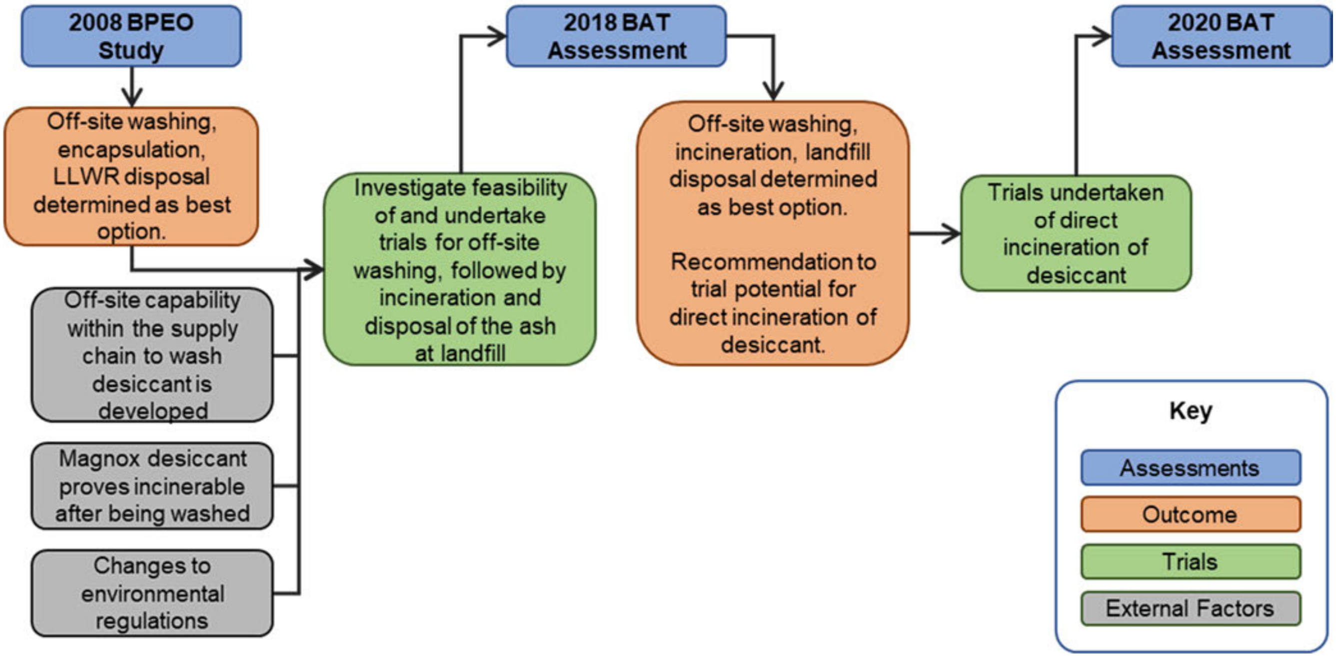


Figure 1: Schematic summarising previous assessment, trials and external factors, which have instigated changes in AGR desiccant management.

1.2 Objective

This report documents the review of EDF's strategic BAT assessment for the management of spent AGR desiccant, given new information on alternative waste management routes (i.e. trials for direct incineration of desiccant) since the last options assessment in 2018 [8]. Further considerations about the applicability of this assessment to catalyst were added in 2023, in Revision 002, and are documented within Appendix C – Inclusion of spent AGR catalyst within the scope of this Strategic BAT/BPM assessment.

1.3 Scope

1.3.1 Scope of Waste

This report covers spent desiccant and catalyst from the seven AGR sites. At some sites, their desiccant is mixed with catalyst, with the concentration of catalyst varying by site and also by batch. At some stations catalyst is stored and managed separately to desiccant.

1.3.2 Scope of Options Selection

For the initial scope of this study, only desiccant was considered. Knowledge of waste management options currently available for AGR spent desiccant was obtained through engagement with suppliers and a review of national Operating Experience (OPEX). Following review and a high-level assessment of these waste management options which have the potential to be implemented, three were identified for further consideration. The following three high-level waste management processes for the management of all suitable AGR spent desiccant were identified for consideration:

- Washing with water, encapsulation in cement and final disposal at the LLWR;

- Washing with water, incineration and final disposal of the resultant ash to landfill;
- Direct incineration and final disposal of the resultant ash to landfill; and
- Direct encapsulation in cement and final disposal at the LLWR.

These processes have been used to identify nine relevant waste management options for initial screening, as detailed in Section 3.

Following successful completion of direct incineration trials using catalyst, and given the similarities between desiccant and catalyst waste, it was determined that the assessment did not require completing again for the inclusion of catalyst within the scope of this assessment. Therefore the conclusions drawn from Revision 001 of this assessment are carried forward for catalyst.

1.4 Assumptions and Constraints

A number of assumptions have been made to bound the strategic assessment:

- It is assumed that the third-party treatment and disposal sites, along with associated plants within the scope of this study will be available for use for the next three years as a minimum. The required timescale for implementation of a selected option is assumed to be 12 months.
- Desiccant is disposed of in drums from AGR sites. This may require some of the desiccant to be repackaged on-site or off-site depending on how it is currently stored. This will need to be considered on a case by case basis and is not discussed in detail within this strategic BAT assessment.
- Desiccant is stored on AGR sites for a minimum of 3 years prior to transfer off-site, and can be stored on-site for considerably longer on some sites (refer to Appendix A for further information):
    - HRA, HYA, HYB and TOR sites store desiccant for a minimum of 3 years as a guidance period prior to transfer off-site, which aligns with the desiccant removal cycle and ensures that the volume of desiccant waste stored on-site at any one time is minimised. 3 year decay storage periods ensure significant decay of short-lived radionuclides (predominantly ^{35}S), resulting in reduced doses. The desiccant is assessed against characterisation data to determine if the levels of radionuclides and dose following decay storage are at an acceptable level to be able to transfer to waste for treatment and disposal, and a judgement is made on a case-by-case basis. In addition, the package lifetime of the drums containing the desiccant is ~5 years, and the 3 year time-period ensures the package remains certified for transport, although alternative arrangements could be made if package certification had expired (e.g. through use of IP-2 rated ISO containers).
    - The remaining AGR sites store desiccant on-site in lifetime vaults (HPB and HNB) or IBCs (DNB) for significantly longer time periods. The activity of this waste varies significantly, with some IBCs at DNB classified as LLW and other retrieved desiccant at HPB exceeding the typical activity envelope for gamma emitting nuclides (as determined from analysis of desiccant from other AGRs).
- Whilst the precise limits may vary for different incinerators, using the Fawley incinerator as an example, the incinerator is permitted to dispose of the following as per their environmental permit [7]:
    - Very Low Level Waste (VLLW) (40 MBq/t of tritium and 4 MBq/t of other radionuclides) to any place that holds an environmental permit for the disposal of non-radioactive waste of the same type as the VLLW. This is disposed of to the Pound Bottom landfill site in Wiltshire.
    - If the product is above this, and only for specific wastestreams, they can dispose of waste with an activity of 500 GBq (of any radionuclide) to a place holding a permit to

receive and dispose of LLW by on-site burial or via transport to Winfrith for treatment and disposal. This is not currently an option for AGR desiccant.

- Alternatively, the ash can be disposed to landfill as ‘out-of-scope’ of the Environmental Permitting Conditions if appropriate or to the LLWR if absolutely necessary.

- For radionuclide discharges arising from incineration, it is assumed that:
  - 100% of ^{36}Cl is retained on the solid ash (although it is likely that a significant proportion will be discharged as a liquid or a gas)[3]
  - ^{55}Fe, ^{63}Ni and gamma emitters such as ^{60}Co, ^{137}Cs and ^{241}Am are assumed to remain in the solid phase[3]
- Some sites (HYB and TOR) have steel ball bearings mixed in with the AGR spent desiccant and it is unclear whether these are acceptable under incinerator Waste Acceptance Criteria (WAC) (e.g. Fawley’s WAC [9]) for direct incineration (these are usually removed via the washing process). For the purposes of this assessment it is assumed that pre-treatment of this desiccant is not required, which would be tested with Tradebe should this option be implemented and a subsequent assessment completed to confirm disposals are BAT.
- Any aqueous discharges from washing treatments at Tradebe’s Winfrith site are discharged at Fawley. Arrangements to transport the aqueous discharges to Fawley are in place.
- EDF are currently the sole customer for Tradebe’s washing facilities. Tradebe have provided indicative cost for maintenance of this capability [10], which is further discussed in the assessment and sensitivity analysis.

1.5 Stakeholders and Team

The BAT assessment team consisted of the following representatives:

- [redacted] (GEM)
- [redacted] (Hydrock Consultants Ltd)
- [redacted] (Hydrock Consultants Ltd)
- [redacted] (DNB) – provided the dose assessment as detailed in Appendix B – Dose Estimates (based on HYA R1 2013 and HYB R7 2015 spent AGR desiccant).

Owing to a minor revision of this BAT assessment against the 2018 assessment [8], a smaller panel has been selected. The Environment Agency (EA) and the SEPA have been informed of this assessment, and are aware of the incineration trials and their on-going progress.

As stated previously, the assessment has not be re-conducted for the inclusion of catalyst within the scope of this Strategic BAT assessment, owing to the similarities between desiccant and catalyst waste. The detailed arguments for inclusion of catalyst within the initial scope of the assessment are detailed within Appendix C – Inclusion of spent AGR catalyst within the scope of this Strategic BAT/BPM assessment.

---

[3] EDF are aware this is the assumption used by incinerator operators to manage throughput and derive their WAC. For ^{36}Cl, data suggests that a significant proportion is discharged as a liquid or gas.

2 Approach to Assessment

The requirement to conduct a BAT assessment has been identified as per the relevant Company Specification [11], following evidence from trials to underpin the option to directly incinerate spent AGR desiccant. In accordance with the Company Specification which details the means for undertaking an assessment [12], a reasoned argument approach has been adopted for this assessment. This approach was selected over a more detailed multi-attribute decision analysis (MADA) as it is proportional to the level of risk and complexity of the limited range of options. Furthermore, arguments can be made with relative ease for and against the options using principles for radioactive waste management, as identified in the EA Radioactive Substance Regulation Environmental Principles (REPs) [13].

Initial options were selected that were considered to be reasonably accessible, reliable and robust. As well as being considered as achievable within the required implementation timeframe. These have been identified by reviewing; the available options which have been used previously by EDF; OPEX from other waste producers; and communication with suppliers to understand changes to their capability.

These were subjected to a high-level screening to screen-out whether any of the options were judged to be unsatisfactory, inappropriate and / or sub-optimal (Section 3.2). Those options taken forward (Section 3.2.2) were then subjected to further assessment using reasoned arguments against selected attributes (Section 5.1) to determine a BAT option. The results of this were subjected to a sensitivity analysis (Section 6.1) to test the outcome against the assumptions constraining this assessment (Section 1.4).

Reasoned arguments were formed using evidence based on the following sources of information:

- BPEO Option Study for the Management of Spent AGR Desiccant, carried out in 2008 [5] and the previous strategic BAT assessment carried out in 2018 [8].
- The report from AGR washing and incineration trials [1], which summarises the three washing and incineration trials carried out by Tradebe as commissioned by EDF in 2017.
- Radiological analysis from two direct incineration trials carried out by Tradebe commissioned by EDF in 2018 / 19 [14] [15].
- Communications with Tradebe regarding dose and water consumption (included within Table 3 and Appendix B).
- OPEX from Magnox Ltd and Tradebe.

3 Options

3.1 Initial options

The following nine initial options for the management of AGR desiccant have been identified for screening and were derived from the three high-level options outlined in Section 1.3:

1. Washing and encapsulation at Winfrith, disposal to the LLWR
2. Washing at Winfrith, incineration at Fawley, disposal of ash to landfill
3. Washing at Winfrith, incineration elsewhere, disposal of ash to landfill
4. Washing elsewhere, incineration at Fawley, disposal of ash to landfill
5. Washing elsewhere, incineration elsewhere, disposal of ash to landfill
6. Wash on-site, incineration at Fawley, disposal of ash to landfill
7. Direct incineration at Fawley, disposal of ash to landfill
8. Direct incineration at another permitted facility (or facilities), disposal of ash to landfill
9. Direct encapsulation at a permitted facility (or facilities), disposal to the LLWR

These options are described in further detail in the following sections.

3.2 High Level Screening of Options

A first stage assessment of the options was conducted to identify whether any were judged to be completely unsatisfactory, inappropriate and / or sub-optimal to take forward to the main assessment. The Company Specification [12] was used to define the following screening criteria to screen-out options:

- Options that would not conform with legal requirements or regulatory principles (excluding where a permit / Compilation of Environmental Agency Requirements (CEAR) variation can be sought).
- Options that would not meet the required objective (either on its own or in combination with another option(s)).
- Options that would not be achievable in the required timeframe (3 years).
- Options which would be considered to be sub-optimal to implement.

3.2.1 Options Screened Out

The following options have been screened out due to their accompanying disqualifying justifications.

Option 3 - Washing at Winfrith, incineration elsewhere, disposal of ash to landfill

It is considered unfavourable to use separate washing and incineration facilities that are not situated within a close distance. This would have proximity associated implications such as longer transport mileage and resulting greater environmental impact. Further trials would be required to support incineration at a facility other than Fawley (where incineration has been trialled) to ensure viability prior to use of this facility (e.g. trials to confirm that the resultant ash meets the WAC for landfill).

Option 4 - Washing elsewhere, incineration at Fawley, disposal of ash to landfill

There are not currently any other washing facilities available within the UK, and it would be sub-optimal financially to develop a new facility without any additional benefits (e.g. different end-point or increased viability). There are also technical risks associated with using other washing facilities as trials have not been carried out at these other facilities as technical viability is unknown.

It is also considered to be unfavourable to use separate washing and incineration facilities that are not situated within a close distance. This would have proximity associated implications such as longer transport mileage and resulting greater environmental impact.

Option 5 – Washing elsewhere, incineration elsewhere, disposal of ash to landfill

There are not currently any other washing facilities available within the UK, and it would be sub-optimal financially to develop a new facility without any additional benefits (e.g. different end-point or increased viability). There are also technical risks associated with using other washing and incineration facilities (including abroad) as trials have not been carried out at these other facilities as technical viability is unknown. There would also be additional requirements for transferring waste to incineration facilities abroad (e.g. transfrontier shipment agreement), which may delay implementation past the required timeframe.

Option 6 – Wash on EDF site, incineration at Fawley, disposal of ash to landfill

EDF do not currently have the facilities available on-site to wash spent desiccant. Significant infrastructure and process development would be required, which would be unlikely to be implemented within the required timescales (outlined in Section 1.4). Washing using the facilities at Winfrith has been proven to be a viable route and thus, provides the same endpoint with improved viability and lower development costs. Furthermore, the BPEO study [5] previously identified that using a central washing facility was the best option which remains valid.

Option 8 – Direct incinerate at another permitted facility (facilities), disposal of ash to landfill

There is only one other facility suitable for the incineration of desiccant waste within the UK, and trials would need to be completed to ensure viability prior to use of this facility (e.g. trials to confirm that the resultant ash meets the WAC for landfill). There would need to be financial and technological benefits in pursuing use of an additional facility, which are not currently apparent.

Option 9 – Direct encapsulation at a permitted facility (or facilities), disposal to the LLWR

Direct encapsulation has been screened out as it would not produce a product that is compliant with the LLWR WAC for the majority of desiccant. The desiccant must have a specific activity of <19.6 GBq $tonne^{-1}$ to ensure the radioactivity requirements of the LLWR WAC are met post encapsulation. In the absence of the washing process and with the typical envelope having an approximate tritium (^{3}H) specific activity of 60-150 GBq $tonne^{-1}$, the desiccant would far exceed the 12 GBq $tonne^{-1}$ beta / gamma radionuclide limit for LLWR disposal. Therefore, this option would not conform with regulatory requirements and principles, does not meet the required objective and is considered sub-optimal.

3.2.2 Final Options for Assessment

The three options (Options 1, 2 and 7) that remain following this preliminary stage have been taken forward to the final assessment. The following sections provide a short justification for their inclusion and further description of the option.

Option 1: Washing, encapsulation and disposal to LLWR

Option 1 was the strategy for disposal of desiccant waste from a number of AGR sites up until 2018, having been identified as the BPEO in 2008 [5].

The spent desiccant is transported to Winfrith, where it is washed in water, removing bulk tritium by isotopic dissolution and a small proportion of radionuclides other than tritium. Very little ^{14}C is removed during the washing process, and this is retained in the final product. The effluent from washing is containerised for transport from Winfrith to Fawley for discharge. The washed desiccant is then encapsulated in cement at Winfrith before being transported to the LLWR for final disposal.

Option 2: Washing at Winfrith, incineration at Fawley, disposal to landfill

Option 2 is the preferred option for disposal of desiccant waste from a number of AGR sites, having been identified as the BAT option in 2018 [8].

This option involves the transportation of the desiccant to Winfrith, where it is washed in water, removing bulk tritium by isotopic dissolution and a small proportion of radionuclides other than tritium. The washed desiccant is then repackaged in UN-approved drums for liquids and transported to Tradebe Fawley where it is incinerated. The remaining tritium and ^{14}C is discharged via either the aqueous phase or gaseous phase during the incineration process. The effluent from washing is containerised for transport from Winfrith to Fawley for discharge. It is assumed that all the ^{36}Cl is retained on the resulting secondary waste ash. The secondary waste ash is transported for final disposal to landfill as VLLW.

Option 7: Direct incineration at Fawley, disposal of ash to landfill

This option involves the transportation of the desiccant to Tradebe Fawley, where it is incinerated before the secondary waste ash is transported for final disposal to landfill. Successful trials (two using desiccant from HYB and TOR [14] [15]) have been conducted in 2018 / 2019 to test the viability of this option. The trials demonstrate the resultant secondary ash has significantly reduced tritium content and there is a reduction in ^{14}C and other radionuclides making it suitable for disposal to landfill as VLLW.

4 Options Assessment

4.1 Attributes and BAT Principles

The options were assessed against the attributes listed and defined in Table 2. These are the same as those used in the 2018 BAT Assessment [8], as all attributes were considered still relevant, and able to differentiate between criteria.

Table 2: Attributes definitions

High level criteria	Attribute	Definition
Safety	Public Dose	The dose to the public arising from operations. This includes exposure due to discharges, waste transport and disposal.
	Operator dose	The dose received by workers for all operations, including transport and disposal. This extends to workers on-site and workers at any off-site facilities.
	Radiological safety / risk	Addresses the radiological consequences and risks of an accident during implementation and operation, including public and operator dose on or off-site.
	Conventional safety	Involves the risk to operators and to the public from accidents during implementation and operation, including transport on and off-site.
Technical	Development Status	Involves consideration of the strategic disadvantages to adopting plant designs or ideas which require further development work before they can be implemented. *Note. Ease of Deployment was not included, as the relative ease is similar for all remaining options and it was not considered differentiating.*
	Project / Implementation time	The anticipated implementation time, including option development and design; authorisation and Regulatory consultation; construction and commissioning etc.
	Compatibility with existing plant / processes	Compatibility and potential competition for assets with existing and future systems, Dependency of an option on external factors is perceived to be a disadvantage.
	Process flexibility	The ability to process wastes etc. where the condition and composition of the waste may vary significantly from that predicted.
	Waste form disposability	Relates to the waste being in an acceptable state to be finally disposed to meet disposal criteria.
Environmental	Radiological disposals: gaseous, aqueous or solid	Performance in relation to radiological disposals, whether of airborne, liquid, or solid wastes; includes judgements on waste minimisation. Must include secondary wastes.
	Non-radiological discharges: gaseous, aqueous or solid	Performance in relation to physical and chemical properties of disposals, whether as airborne, liquid or solid materials.
	Resource use	Evaluation of the performance of each option in relation to material and energy use.
	Transport	Consideration of the environmental and social impacts of transport of waste. It does not include safety as this is addressed in 'Conventional Safety'.

High level criteria	Attribute	Definition
Regulatory	Impact on regulatory permissions	Involves consideration of the requirements for, and the potential complexity of securing, EA(S)R18, EPR permits, EIADR99 consents, planning permissions, Article 37 Opinion etc.
Social and economic	Lifetime costs	The total cost, in current monetary values; including capital, operating, decommissioning, storage and waste disposal.
	Financial risks	Relates to potential difficulties associated with facility or plant construction, commissioning and operation, and uncertainties in storage and disposal costs.

The following environmental / waste management principles, as defined in the EA REPs [13], were considered and applied as follows:

- Application of the WMH: options that make use of waste management options higher up the WMH are assessed as more favourable.
- Sustainable development: options that promote sustainability (e.g. through use of fewer resources) are considered more favourable.
- Precautionary principle: options that are proven and well-understood, with limited environmental risk were viewed favourably.
- Proximity and self-sufficiency: options that utilise facilities near to the waste-producing site are considered favourable.
- Concentrate and contain: the remaining options cannot be distinguished using this principle. Concentrate and contain would likely result in a waste product that would require disposal in a Geological Disposal Facility (GDF), which is generally considered to have a higher environmental impact than those disposal options proposed.
- Passive safety: options that produce a wasteform that is passively safe and does not present a significant environmental risk from secondary wastes are viewed favourably.
- Whole lifecycle approach: options that enable effective management of waste from arising through to disposal are viewed favourably.
- Characterise and segregate for effective management: all desiccant waste is / will be characterised prior to processing. Options where effective segregation of other associated wastes (e.g. steel ball bearings) can be achieved are considered on a case by case basis.
- Minimise waste requiring disposal to a GDF / maintain capacity of the LLWR: options that reduce the amount of waste disposed to the LLWR are considered favourable.
- Ensure future manageability / disposability: options that ensure the on-going treatability of desiccant waste are assessed as more favourable.

4.2 Assessment Data

Data from a consignment of HYA R1 desiccant in 2013 (following a three year decay storage period) was used as a representative consignment. This was also used in the previous assessment [8] and ensures consistency when evaluating the options. Additional information as required from other desiccant discharges, including HAR R1 2016 and HYB R7 2015, were also used as applicable. Data used to support this assessment is summarised in Appendix B and in referenced documentation. The dose assessment assesses the dose from all radionuclides associated with desiccant from HYA R1 2013 and HYB R7 2015, in order to give representative total doses associated with different options for desiccant with different radiochemical properties.

5 Reasoned Arguments

5.1 Assessment of options against attributes

Table 3: Summary of arguments (and associated assumptions) against the attributes

High level criteria	Attribute	Option 1 (washing, encapsulation, LLWR)	Option 2 (washing, incineration, landfill)	Option 7 (direct incineration, landfill)
Safety	Public Dose *(Data used to support this assessment is discussed in Appendix B).*	• All doses must be within permit limits for each treatment and disposal facility. • The data presented in Appendix B, Table 7 (2.10E-04 µSv/TBq ^{3}H), demonstrates that this is within permit limits for the treatment and disposal facilities used. The dose is lower relative to the other options, however this is not distinguishing. • There are no discharges to the air from desiccant washing, whilst there are aqueous discharges of tritium. • There is minimal public dose during encapsulation and from residual activity once encapsulated. • There are negligible doses associated with discharges from disposal at the LLWR, as the majority of radionuclides are relatively short-lived and will significantly decay prior to public exposure from the repository due to coastal erosion (estimated to be in ~300 years). These doses have not been quantitatively assessed.	• All doses must be within permit limits for each treatment and disposal facility. • The data presented in Appendix B, Table 8 using an example consignment (HYA/R1 2013, 1.49E-02 µSv/TBq ^{3}H) demonstrates that this is within permit limits for the treatment and disposal facilities used. The relative dose is lower than Option 7 but higher in comparison to Option 1, however this is not distinguishing. • There are no discharges to the air from desiccant washing, whilst there are aqueous discharges of tritium. • There are both aqueous and gaseous discharges contributing to public dose from incineration. • Minimal public dose is associated with residual activity of secondary waste once incinerated.	• All doses must be within permit limits for each treatment and disposal facility. • The data presented in Appendix B, Table 8 using an example consignment (HYA/R1 2013, 1.68E-02 µSv/TBq ^{3}H) demonstrates that this is within permit limits for the treatment and disposal facility. The dose is higher relative to the other options; however, this is not distinguishing. • There are both aqueous and gaseous discharges contributing to public dose from incineration. These are higher than for Option 2 as there is no reduction in tritium contamination through washing prior to incineration. • Minimal public dose is associated with residual activity of secondary waste once incinerated.
	Operator dose	• Dose per drum typically <20 µSv/h prior to any treatment. • Repackaging may be required on-site prior to consignment, which will incur operator dose. • Operator dose is dependent on handling time, which is comparable to Option 2, but more than for Option 7: - Dose to workers during the washing process are managed by Tradebe's procedures that control doses to workers and repackaging is not required following washing. - Dose to workers during the cementation process are managed by Tradebe's procedures that control doses to workers.	• Dose per drum typically <20 µSv/h prior to any treatment. • Repackaging may be required on-site prior to consignment, which will incur operator dose. • Operator dose is dependent on handling time, which is comparable to Option 1, but more than for Option 7: - Dose to workers during the washing process are managed by Tradebe's procedures that control doses to workers, however repackaging at Winfrith may be required after washing to allow desiccant / liquid mixes to be transported for incineration, which may incur a higher dose than for Option 1. However, no significant increase in dose is expected when compared to the cementation process. - Handling required to incinerate drums and handling of secondary waste containing residual activity following incineration. •	• Dose per drum typically <20 µSv/h prior to any treatment. • Repacking may be required on-site prior to consignment, which will incur operator dose. • Operator dose is dependent on handling time, which is shortest for Option 7, than for Options 1 and 2. Handling required to incinerate drums and handling of secondary waste containing residual activity following incineration.

High level criteria	Attribute	Option 1 (washing, encapsulation, LLWR)	Option 2 (washing, incineration, landfill)	Option 7 (direct incineration, landfill)
	Radiological safety / risk	• Radiological risk associated with mobile activity in the effluent from the washing process. • Radiological risks are reduced after each treatment stage. Ultimately, the desiccant (and radiological content) is immobilised using an encapsulant (cementitious grout).	• Radiological risk associated with mobile activity in the effluent from the washing process. • Radiological risks are reduced after each treatment stage, the final ash waste meets the WAC of Pound Bottom Landfill.	• No radiological risks associated with mobile activity in the washing process. • There are no preceeding treatment steps and therefore the desiccant has a higher activity and subsequently risk at the incinerator, however this is the same as for desiccant in Options 1 and 2 at the washing step (and relatively low at (<20 μSv/h per drum prior to any treatment). • Fewer processing steps.
	Conventional safety	• Option is considered to have the most handling steps. • Risk associated with manual handling for some steps in the cementation process (tipping of drums to allow loading of half height ISO (HHISO) containers used for disposal). • Wet cement is alkaline and can cause significant skin irritation. • There are two transport legs associated with this option: To Winfrith for washing and encapsulation, and to the LLWR for disposal.	• Option has fewer handling steps than Option 1. • There are fewer conventional safety risks than for Option 1, as those risks associated with the cementation process are removed. • Conventional safety risks associated with high temperatures for incineration. • There are three transport legs associated with this option: to Winfrith for washing, to Fawley for incineration, and to Pound Bottom Landfill for disposal.	• Option has fewer handling steps than Options 1 and 2. • There are fewer conventional safety risks than for Options 1 and 2, as those risks associated washing and cementation processes are removed. • Conventional safety risks associated with high temperatures for incineration. • There are two transport legs associated with this option: to Fawley for incineration, and to Pound Bottom Landfill for disposal.
Technical	Development Status	• This route has been used previously by EDF as the disposal option for management of spent AGR desiccant. It is a tried and tested route.	• This route is currently routinely used by EDF as the disposal option for the management of AGR desiccant following the outcome of the previous BAT assessment [8]. It is a tried and tested route. • This route has also been tried and tested by another waste producer, as Magnox have previously used this route to dispose of their reactor desiccants.	• Trials have been conducted [14] [15], which provide confidence that the route is fully developed for the typical envelope of spent AGR desiccant. • In particular, these trials have confirmed that the resultant ash meets the WAC for Pound Bottom Landfill for disposal.
	Project / Implementation time	• This route has been used previously by EDF as the disposal option for management of AGR desiccant. • It would require minimal implementation time to use this option again. • No regulatory permissions are required.	• Route has been implemented since 2018 and used relatively frequently. • All of the AGR sites have a permit that allows transfer of ILW to Winfrith and therefore no additional regulatory permissions are required.	• Trials have been conducted to prove the viability of the route for the typical envelope of the spent AGR desiccant. • Additional regulatory permissions are required for some AGR spent desiccant. Where the desiccant is ILW, permit / CEAR variations will be required to allow the consignment of the desiccant to Fawley (a non-nuclear licensed site). • This will require regulatory and stakeholder engagement. • The implementation time for this is considered reasonable and estimated to take 12 months.
	Compatibility with existing plant / processes	• This route has been used previously by EDF as the disposal option for management of AGR desiccant. • The retrieval and consignment process for each option is similar, and therefore is compatible with existing plant and processes.	• This route has been used previously by EDF as the disposal option for management of AGR desiccant. • The retrieval and consignment process for each option is similar, and therefore is compatible with existing plant and processes.	• The retrieval and consignment process for this option is similar to Options 1 and 2, which have previously been or are implemented, and therefore this option is considered compatible with existing plant and processes.

High level criteria	Attribute	Option 1 (washing, encapsulation, LLWR)	Option 2 (washing, incineration, landfill)	Option 7 (direct incineration, landfill)
	Process flexibility	• Has been used previously as the management strategy for spent AGR desiccant and throughput through the washing and encapsulation plant was manageable. Thought that this could be managed effectively again. • Can be used to treat AGR desiccant waste with gamma contribution and elevated dose rates that may be unsuitable for incineration. • Final product must be compatible with the LLWR WAC, which may limit flexibility / disposal in some cases. The desiccant must have a specific activity of <19.6 Gbq tonne^{-1} post washing to ensure the activity requirements are met post encapsulation. Some AGR desiccant has previously challenged this limit following washing.	• Currently used and throughput through the washing equipment and the incinerator is efficiently managed. • Can be used to treat a broader envelope of AGR desiccant waste than Option 1, as the product does not need to meet the LLWR WAC, but can be managed through the incinerator to ensure a disposable product. • Comparable to Option 7, although there may be limited cases where Option 2 can be used to treat and dispose of desiccant, which Option 7 is not suitable for. This is as the washing process removes a small proportion of radionuclides other than tritium.	• Can be used to treat the typical envelope of AGR desiccant, but may not be suitable for desiccant with higher gamma contribution and elevated dose rates that may be unsuitable for incineration. • The same number of drums (3-6 drums per trial) have been trialled as were for Option 2 previously. The results suggest that the throughput can be managed similarly to Option 2. There are some radionuclides which may be removed via washing (e.g. ^{36}Cl), however their inclusion for direct incineration should not challenge permit limits. • Generally comparable to Option 2, although there may be limited cases where Option 2 can be used to treat and dispose of desiccant, which Option 7 is not suitable for. This is as the washing process removes a small proportion of radionuclides other than tritium.
	Waste form disposability	• Waste form is disposable and well understood. • However, there is the potential for the LLWR WAC to be exceeded (12 GBq tonne^{-1}) if not enough tritium is removed in the washing process.	• Waste form is disposable and well understood. • Incinerator can manage throughput to meet the landfill WAC. • Operating controls ensure secondary waste ash does not exceed discharge limits and is disposed of within the limits of their permit.	• Waste form is disposable and well understood. • Evidence from trials indicate that the Fawley incinerator can manage the throughput to ensure activity levels in ash meet the landfill WAC. Trials have confirmed that, as with Option 2, no desiccant beads are visible in the ash. • Operating controls ensure secondary waste ash does not exceed discharge limits and is disposed of within the limits of their permit.
Environmental	Radiological disposals: gaseous, aqueous or solid	• Waste volume is increased due to the addition of cement and containerisation within a Half-Height ISO (HHISO) container. • Final disposal at the LLWR is considered to have a high environmental impact, as per the WMH. • Uses finite capacity at the LLWR. • 2.45 - 2.72 m^3 of effluent is generated per m^3 of desiccant during washing [16] [17]. This is transported from Winfrith to Fawley and discharged. • Generation of secondary waste in the form of filters from the washing process.	• Final waste volume for disposal is less than Option 1 as there in no requirement for cementation or an HH ISO container to facilitate disposal. • Incineration and final disposal of ash at landfill is considered to have a lower environmental impact than Option 1, as per the WMH. There is reduced activity in the final waste product. • 2.45 - 2.72 m^3 of effluent is generated per m^3 of desiccant during washing [16] [17]. This is transported from Winfrith to Fawley and discharged. • There are also gaseous and aqueous discharges associated with incineration. • Generation of secondary waste in the form of filters from the washing process. Filters at incinerators are routinely changed and it is not thought additional waste will arise from desiccant incineration.	• Final waste volume for disposal is less than Option 1 as there in no requirement for cementation or an HH ISO container to facilitate disposal. • Incineration and final disposal of ash at landfill is considered to have a lower environmental impact than Option 1, as per the WMH. There is reduced activity in the final waste product. • Aqueous and gaseous discharges from incineration are managed within the facility permit limits. • There are no aqueous discharges associated with a washing process. • Filters at incinerators are routinely changed and it is not thought additional waste will arise from desiccant incineration.
	Non-radiological discharges: gaseous, aqueous or solid	• Aqueous discharges associated with cementation.	• No aqueous discharges associated with cementation. Increased non-radiological discharges (gaseous and aqueous) in comparison to Option 1 from the incineration of desiccant.	• No aqueous discharges associated with cementation. • Increased non-radiological discharges in comparison to Option 1 from the incineration of desiccant.
	Resource use	• Use of 50-55 m^3 of water to wash a single desiccant discharge. • Additional drums for repackaging washed desiccant and effluent are not required. • Use of cement required. • Disposal of Half-height ISO containers required.	• Use of 50-55 m^3 of water to wash a single desiccant discharge. • Use of additional drums required for repackaging washed desiccant and effluent for transfer to Fawley. • No requirement for Half-height ISO container disposal. • Drums are incinerated with the spent AGR desiccant.	• There is no washing stage and therefore water is not required. • Additional drums for repackaging washed desiccant and effluent are not required. • No requirement for Half-height ISO container disposal. • Drums are incinerated with the spent AGR desiccant.

High level criteria	Attribute	Option 1 (washing, encapsulation, LLWR)	Option 2 (washing, incineration, landfill)	Option 7 (direct incineration, landfill)
	Transport	• Additional transport mileage required from Winfrith to the LLWR in comparison to other options. This will be a heavy load due to cementation of the waste. • Additional transport mileage also associated with transfer of effluent from the washing process to Fawley for discharge.	• Transport mileage is less than for Option 1, as transport to the LLWR is not required. • Washed desiccant and effluent will require transport from Winfrith to Fawley for incineration and discharge respectively. • The resultant ash from incineration is transported to Pound Bottom landfill.	• Transport mileage is less than Options 1 and 2, as desiccant is transferred directly to Fawley. • The resultant ash from incineration is transported to Pound Bottom landfill.
Regulatory	Impact on regulatory permissions	• Disposal route has previously been operational. • Route is available under current AGR permits, and no additional permits or variations are required. • Effluent discharge from wash water at Fawley is managed within permit limits. This uses a proportion of the permitted daily and yearly allowance.	• Disposal route is currently operational and fully implemented. • Route is available under current AGR permits, and no additional permits or variations are required. • Effluent discharge from wash water at Fawley is managed within permit limits. This uses a proportion of the permitted daily and yearly allowance.	• Disposal route can be managed within Fawley's permitted gaseous and aqueous discharge limits. • The transfer of ILW desiccant directly to Fawley (a non-nuclear licensed site) will require a permit / CEAR variation for all AGR sites. This will require regulatory engagement and additional permissions. • Scottish HAW Policy will need to be considered (e.g. ensuring ILW is not returned to Scottish sites) and engagement with SEPA will be required to ensure this option aligns with policy should it be implemented.
Social and economic	Lifetime costs *(Rates are those in pending desiccant contract and are documented in [18]. This is explored further in the sensitivity analysis in Section 6.1.3).*	• The cost for the treatment and disposal of the desiccant discharge from HYA R1 2013 is the most expensive option under the current contractual arrangement [16].	• The Tradebe estimate for the treatment and disposal of the desiccant discharge from HYA R1 2013 via Option 2 demonstrates a cost saving of 3% against Option 1 [16].	• The Tradebe estimate for the treatment and disposal of the desiccant discharge from HYA R1 2013 via Option 7 suggests a potential cost saving of between 65-80% over Option 1 [16].
	Financial risks	• The costs are understood and there is limited financial risk. • There is a risk that washing capability could be lost as it is understood that EDF are the only company to use this facility. Some of the costs of maintaining this capability are incorporated into the rates, however, if the frequency of consignments is low, there may be additional costs.	• The costs are understood and there is limited financial risk. • There is a risk that washing capability could be lost as it is understood that EDF are the only company to use this facility. Some of the costs of maintaining this capability are incorporated into the rates, however, if the frequency of consignments is low, there may be additional costs.	• The costs are understood and there is limited financial risk. There may be an opportunity to use different framework rates (those of the generic Radioactive Waste Management Services Contract [19]), which would further reduce costs. Using the HYA R1 2013 data, this would result in a cost saving of 80% over Option 1. • There is a risk that washing capability could be lost as it is understood that EDF are the only company to use this facility. • This capability may be required for desiccant in the future (depending on its characteristics), and there may be additional costs associated with maintaining this capability. This would be more so than for Options 1 and 2, where some of the costs would be recovered through use of the route.

5.2 Key arguments

The key arguments for the determination of the BAT were developed from the summary of option statements under each high-level criteria presented in Table 2. These arguments are tested and explored further in the sensitivity analysis undertaken in Section 6.1.

5.2.1 Safety

The safety performance of each option is a key principle in determining the best performing option. No option assessed within this study presents any major conventional or radiological safety hazards, and so no options are ruled out on safety principles.

Using data from two desiccant discharges (HYA R1 2013 and HYB R7 2015), a robust dose assessment for each option was undertaken (Appendix B). Further explanation of the dose assessment can be found in Appendix B. In summary, it is assumed for each option that the difference in dose between options comes from differences in the amount of ^{3}H to be discharged through aqueous and gaseous routes, as the amount of “other radionuclides” removed during the washing process is known to be small. Using data from HYA R1 2013 as an example, Option 1 was the best performing option, resulting in 2.1×10^{-4} μSv of additional dose per TBq ^{3}H discharged. Option 7 resulted in 1.68×10^{-2} μSv additional dose per TBq ^{3}H discharged, and whilst this is higher than the best performing option for this attribute, this is a minor dose. Doses of this magnitude and the differences between the estimated public doses do not differentiate between options. Dose is highly dependent upon the nuclide mix of the AGR desiccant, such that desiccant with higher contributions from other radionuclides (specifically ^{14}C, ^{36}Cl and gamma emitting nuclides such as ^{60}Co) will yield larger public doses than batches of desiccant with smaller contributions from these other nuclides.

The operator dose is proportional to the handling time of the drums, which is shortest for Option 7 due to a reduced number of handling steps. Doses to operators at different facilities are likely to be different, as the WAC at Fawley does not enable waste with significantly elevated dose rates to be processed. Therefore dose to operator is likely to be higher for wastes processed at Winfrith (Options 1 and 2); however, it is important to note that this is as a result of the waste properties, and not as a result of the process being sub-optimal.

All options will require the use of equipment and vehicle (e.g. Forklifts) to move packages, and therefore the associated conventional safety risks are comparable for all options. Manual handling risks are identified as part of the processes employed at the washing facility but have been suitably assessed and mitigated to ensure operator safety. Option 7 represents the safest option from a manual handling perspective, as drums will be transferred directly from the producing site to an incinerator, with reduced need for manual handling. Option 2 requires some additional manual handling to enable the transfer of desiccant into liquid rated drums for onward transport from Winfrith to the incinerator. However, this is considered to be less onerous than the manual handling risks introduced by Option 1, which requires encapsulation of washed desiccant into HH ISO containers.

5.2.2 Technical

Spent AGR desiccant will continue to be generated throughout the service life of the AGR fleet, thus it is important that the preferred option is viable for near-immediate implementation, in order to reduce the potential for accumulation of spent desiccant on-site. This ensures compliance with Licence Condition 32, provided sites are able to complete disposals in accordance with the required processes and within funding constraints.

Options 1 and 2 are considered fully developed having been used previously, or currently implemented. Recent full-scale trials conducted by Tradebe at Fawley have demonstrated the viability of direct incineration, Option 7. A desktop study comparing the HYA R1 2013 desiccant against the Fawley WAC has shown that a batch of desiccant can be directly incinerated and two test batches were incinerated and shown to meet the disposal requirements of the Pound Bottom landfill. The retrieval process is essentially the same for all three options and therefore all options are considered compatible with the existing plant / process. Options 1 and 2, having been previously implemented or being currently used, have the shortest implementation times. It is expected that Option 7 will take 12 months to implement to allow time to seek and secure the required permit / CEAR variations, it is not thought that these timescales will challenge the ability of any site to comply with Licence Condition 32.

For an option to be used, the desiccant must meet the relevant WAC to ensure a disposable product is produced. There are some occasions where waste outside of the WAC may be accepted with prior written agreement and / or additional measures established. Generally, Options 1 and 2 are considered to yield the most flexibility in terms of the envelope of wastes that can be disposed of, however for Option 1 the final product must be compatible with the LLWR WAC (i.e. meeting the 12GBq $tonne^{-1}$ βγ limit at the LLWR has proved technically challenging on occasion). The option for direct incineration, Option 7, may not be suitable to incinerate desiccant that has a high concentration of radionuclides other than tritium, or drums with elevated dose rates. This is considered comparable to Option 2, although there may be limited cases where Option 2 can be used to treat and dispose of desiccant, which Option 7 is not suitable for. This is as the washing process can remove a small proportion of radionuclides other than tritium. In these cases, it is possible that Option 2 could be used, as this reduces the concentration of tritium (reducing the activity) and may also remove some other radionuclides in the process, which may then facilitate incineration. Should the desiccant be deemed unsuitable for incineration following washing, Option 1 could be employed, provided the final product was capable of meeting the LLWR WAC.

The flexibility of the process beyond disposing what it considered the typical envelope of spent AGR desiccant is considered further in the sensitivity analysis in Section 6.1.

5.2.3 Environmental

Discharges and Disposals

In terms of discharges, both gaseous and aqueous discharges can be managed for all three options at the respective facilities. Option 2 has higher discharges in comparison to Option 1 as it yields both discharges to the air and to water. The quantity of tritium contaminated effluent is much lower for Option 7 than Option 2 as there is no associated washing process. However, the quantity of tritium discharged to the air via incineration from Option 7 is likely to be much higher. Overall, however, the discharges associated with each option (similarly with the equivalent dose, as discussed in Section 5.1) are not considered a differentiating factor.

The washing process employed in Options 1 and 2 results in effluent discharge, which cannot be discharged at the Winfrith site. This is instead containerised and transported to the Fawley site for discharge, which must be carefully managed and could be regarded as sub-optimal. Direct incineration avoids the use of the washing process and hence management of this effluent. The washing process also uses filters which require disposal as secondary waste.

In terms of application of the WMH (key to the UK Strategy for the Management of Solid Low Level Waste (UK National Strategy) [4] and more recently to the Nuclear Decommissioning Authority Radioactive Waste Strategy [20]), the reduction of the volume and / or activity of waste requiring disposal is considered preferable. Furthermore, the routing of treatable wastes away from the LLWR through robust and sustainable waste management infrastructure is a key objective of the UK strategy.

Option 1 is considered the poorest performing option with respect to the WMH. The disposal volume is the highest following the addition of cementitious grout, which requires disposal at the LLWR. Options 2 and 7 are consistent with these strategies and divert suitable wastes away from disposal at the LLWR by using alternative treatment and disposal facilities. The washing and/or incineration processes reduce both the activity and volume of the final waste product requiring disposal, which then facilitates disposal of the final product to landfill.

Resource Use and Transport

Option 1 is the most resource intensive of the options requiring the use of water, additional drums for repacking, cement and HH ISO containers for disposal. Option 7 uses the least resources as pre-treatment to incineration is not utilised and desiccant is disposed of in the drums into which it is retrieved.

On average across the AGR sites, Option 1 will yield the highest mileage. Firstly, AGR desiccant must be transported to the Winfrith site, before being transported to the LLWR, which is not an inconsequential distance. Furthermore, the effluent generated during the desiccant washing process is transported from Winfrith to Fawley before being discharged, this increases the transport mileage associated with Option 1 by an additional 52 miles.

Option 2 has reduced travel mileage as Winfrith, Fawley and Pound Bottom Landfill are located within fairly close proximity. The distance from Winfrith to Pound Bottom Landfill, via Fawley, is approximately 70 miles. Option 7 yields the lowest transport mileage as the waste is transported directly to Fawley and onwards for disposal. This could be further optimised in the future by considering the use of incinerators other than Fawley, which may be closer to some of the AGR sites. This would support the use of the Proximity Principle, but would potentially require further trials to support demonstration of viability.

5.2.4 Regulatory

It is imperative that the selected option does not compromise the ability of the site to comply with its regulatory requirements. Options 1 and 2 do not impact on regulatory compliance, having been previously or are currently being used. To implement Option 7 Permit / CEAR variations will be required to allow transfer of any desiccant classified as ILW direct to the Fawley site. However, should this option be deemed justifiably BAT, it is not thought that a permit / CEAR variation would be withheld and this should not discriminate against this option.

Scottish HAW Policy will also need to be considered (e.g. ensuring ILW is not returned to Scottish sites) and engagement with SEPA will be required to ensure this option aligns with policy should it be implemented.

5.2.5 Social and Economic

The cost associated with disposal of AGR desiccant employing each of the final options was compared using the consignment of HYA R1 2013 as an example consignment [18]. This demonstrated that Options 1 and 2 are broadly comparable in cost (within 10% of each other), whilst Option 7 was considerably less expensive (an estimated 68% cost saving over Option 1). The washing process makes up a significant portion of the overall cost of Options 1 and 2, and there may be the ability to drive down the costs of Option 7 further, depending on the commercial rates agreed.

There is also the potential with direct incineration to explore the use of other incinerators, which could introduce inter-facility competition and further drive down costs. This would likely require additional trials to ensure the desiccant can be appropriately managed at a facility other than Fawley. In some cases, costs could increase due to the dissipation of cost-savings that may arise when sending the total quantity to one facility (e.g. uniform packaging requirements). Therefore, opportunities to use alternative facilities should only be pursued if deemed strategically and financially beneficial.

The financial risks associated with each option are well understood. As stocks of spent desiccant on some sites have been significantly reduced, and should Option 7 be deemed BAT, security of supply to TI for washing of desiccant may be difficult to guarantee. This could cause contractual liabilities and incurrence of maintenance costs on washing equipment that is not regularly utilised. This could mean that desiccant requiring washing (where direct incineration is not suitable) no longer has an available disposal route or that there would be additional costs associated with assembling and maintaining the plant. The risk for Options 1 and 2 is lower as they utilise the washing process and TI's costs associated with maintaining this plant can be recuperated. This risk is greater for Option 7, however, given there may be a future need for this capability for waste management during decommissioning. EDF may choose to pay for the maintenance of this capability regardless. TI have provided an indication of this cost and it is estimated to be around ~15% of the cost of Option 1 for one representative consignment. Therefore, even with these potential additional costs, Option 7 proves far more cost effective.

The cost associated with disposing of desiccant with a higher activity (outside of the typical envelope) is discussed further in the sensitivity analysis in Section 6.1.3.

5.3 Identification of BAT

Based on the assessment of the options against attributes, particularly the key arguments detailed in Section 5.2, Option 7 is considered to be the most favourable BAT option.

This option implements the principles of the WMH more effectively than Option 1, and conforms to the UK Strategy [4] [20] of diversion of wastes away from the LLWR via alternative waste treatment suppliers. Where the nature and quantity of the spent AGR desiccant permits, it also avoids an additional processing step in the form of desiccant washing in Option 2. This reduces the manual handling required, the additional transportation required, and generation of additional volumes of effluent which require discharge at an alternative facility from which they are generated.

Desk based studies and two trials have been conducted to prove the viability of this option, and these have demonstrated that the typical envelope of spent AGR desiccant can be managed via this route to produce a final product that meets the WAC of disposal to landfill. It is recognised that some desiccant may have properties which preclude the use of Option 7 or make it sub-optimal, and this is discussed further in the sensitivity analysis in Section 6.1.1. The projected savings in costs associated with this option (65-80% savings against Options 1 and 2 for a single consignment), and minimal implementation time, show that this option is worth pursuing even if there is only a proportion of desiccant that can be treated. This remains true even when costs associated with maintaining Tradebe's capability to wash desiccant are included.

Where Option 7 cannot be used to treat the desiccant, Option 2 would be considered the most favourable option due to application of the WMH and UK Strategy. This may be applicable where the removal of a proportion of radionuclides other than tritium through the washing process may facilitate incineration. However it is unclear what proportion of different radionuclides are removed and these cases may be limited. Should desiccant be deemed unsuitable for disposal via Options 7 and 2, Option 1 may be used provided the final product will meet the LLWR WAC. Further reasoning for selection of Option 2 over Option 1 can be found in the previous version of this assessment [8]. Table 4 provides an indication of when an option may become preferable dependent on the properties of the desiccant.

Table 4: Indication of which option may be suitable for desiccant with different characteristics

Preference	Option	Description	Suitable Desiccant
Higher Preference	Option 7	Direct incineration at Fawley, disposal of ash to landfill to landfill	Suitable for standard desiccant with a low contact dose rate and a low concentration of radionuclides other than tritium. Suitable for desiccant with high concentrations of tritium.
Medium Preference	Option 2	Washing at Winfrith, incineration at Fawley, disposal of ash to landfill to landfill	Suitable for standard desiccant with a low contact dose rate and a low concentration of radionuclides other than tritium. There may be limited cases where Option 2 can be used to treat and dispose of desiccant, which Option 7 is not suitable for, in which the washing process removes a small proportion of radionuclides other than tritium to facilitate incineration. Suitable for desiccant with high concentrations of tritium.
Lower Preference	Option1	Washing and encapsulation at Winfrith, disposal to the LLWR	Suitable for desiccant with a higher contact dose rate and a high concentration of radionuclides other than tritium. Specific activity concentration must be reduced to <19.6 GBq $tonne^{-1}$ following washing to ensure compliance with LLWR WAC, which has previously proven problematic for some washed desiccant.

6 Sensitivity Analysis and Uncertainties

6.1 Sensitivity Analysis

It is essential that the approach to demonstrating the BAT provides a sufficient degree of robustness. A sensitivity analysis allows the main factors and judgements that have led to the identification of the BAT to be subjected to an appropriate level of scrutiny and investigation to determine the impact of possible risks and uncertainties.

Based on the key arguments in Section 5.2 and qualitatively, it can be considered that Option 7, on balance, performs comparably to the other options in relation to Safety Criteria. Option 7 performs worse across Technical and Regulatory Criteria, owing to a potentially less flexible process and the need to gain regulatory approvals, which are discussed further in Section 6.1.1 and 6.1.2. However, the performance of Option 7 across the Technical and Regulatory Criteria is not considered to be significantly worse than the performance of Options 1 and 2 across these criteria.

Option 7 scores better in Environmental Criteria owing to its reduced environmental impact, as per the WMH, which is not challenged by possible risks and uncertainties. Option 7 also performs significantly better on cost, for which the underpinning assumptions are tested in Section 6.1.3.

6.1.1 Process Flexibility and Properties of Desiccant

Activity and Particulate Content of Desiccant

Trials to test the viability have demonstrated that Option 7 is a viable disposal route for routine spent AGR desiccant. As documented in Appendix A, the activity and characteristics vary across the different AGR sites. Option 7 has been determined as the BAT option and should be utilised where the waste is within the range demonstrated as suitable. However there may be AGR desiccant for which Option 7 is not suitable.

An example is the desiccant retrieved, sampled and characterised from the HPB vault in 2019 [21]. Whilst a proportion of this desiccant may have been stored for a significant period of time, the reactor gas drying system does not have By-Pass Blow Down filters prior to the desiccant towers, and therefore the desiccant can be contaminated with a higher proportion of particulate and gamma emitting radionuclides. Within a batch, some desiccant drums may be suitable for disposal via Option 7, whilst others may not be.

The following characteristics of this type of desiccant waste may make use of Option 7 sub-optimal:

- The contact dose rate of some of the drums of the spent AGR desiccant are considerably higher than have been observed previously (several are over 30 μSv/h due to the Cobalt-60 and other gamma emitting radionuclides content). Even with a period of radioactive decay, it may not be suitable to consign these to Fawley (a non-nuclear licensed site) prior to pre-treatment in the form of washing.
- The total activity could breach package and consignment limits within the WAC should a large quantity of high activity desiccant be consigned. Should a consignment of spent desiccant exceed the 2 TBq Fawley monthly tritium activity limit [9], the consignment may need to be divided and sent in multiple batches, potentially increasing contact time, manual handling and storage requirements on-site as well as transport costs.
- There is considerable particulate contamination of the desiccant, resulting in increased activity levels of radionuclides other than tritium. This may challenge the discharge limits of the incinerator. The washing process may remove some of the particulate and therefore may facilitate incineration, although the extent to which this occurs has not been assessed in great detail. If incineration is still not viable following washing, encapsulation (Option 1) could be used provided it was assured the final product would meet the LLWR WAC.

Where Option 7 is deemed sub-optimal, use of Option 2 would be appropriate. Similarly, Option 1 could be used in cases where Option 2 is deemed inappropriate. Alternatively, and if the desiccant cannot be treated via Options 7, 2, and 1 as currently packaged, other options should be explored on a case by case basis and a decision reached by performing an operational BAT assessment. For example, the desiccant could be distributed over a greater number of packages and disposed of over a greater period of time to allow use of these options. .

Inclusion of Steel Ball Bearings

Desiccant discharges from HYB and TOR contains approximately 500 kg of steel ball bearings and ceramic beads. In Options 1 and 2, these are removed via the washing process and disposed of separately. For Option 7, the ceramic beads are suitable for incineration, however it is unclear whether the steel ball bearings are permitted within the Fawley WAC, and further clarity should be sought from Tradebe about their acceptability. Should it be deemed that the steel ball bearings need to be removed prior to incineration, a further exploration of options (including whether washing is most suitable) would be required to determine whether it is BAT to remove the steel ball bearings prior to incineration or whether another option is more suitable (e.g. separation of the steel ball bearings and treatment via another route).

Following implementation of this BAT assessment in 2020, it has been determined that where drums contain mostly steel ball bearings, these drums should be transferred for onward treatment and disposal through recycling, as opposed to inclusion within the disposals made to an incinerator.

Decay Storage Period

It is assumed that the AGR desiccant is stored on-site for a minimum of 3 years prior to transfer off-site to allow for decay of short-lived radionuclides, predominantly ^{35}S. This storage period also reduces the activity of the tritium within the desiccant by almost 1/8th of the total tritium activity (which contributes over 90% of the total desiccant activity). Some desiccant, for example the desiccant stored in lifetime vaults at HPB and HNB, is stored for a significantly longer period of time. Significant mixing of the desiccant has not occurred, and therefore the desiccant towards the top of the vault may not have had as significant a decay period as that towards the bottom of the vault. The properties of the desiccant throughout the vault may not be consistent, as plant properties may have changed over time.

The decay storage period for each batch of desiccant should be reviewed on a case by case basis. To enable disposal of waste that has been decayed for less than 3 years, an operational BAT (or similar) will be required to justify the disposal. Decay periods of greater than 3-5 years are not thought to yield significant benefits in terms of the decay of radionuclides, unless extended for long periods. This is not thought to affect the implementation of Option 7.

6.1.2 Permits and Regulatory Considerations

The implementation of Option 7 will require permit / CEAR variations for AGR sites to allow transfer for ILW desiccant to the Fawley incineration. There is always a risk that this variation will not be granted, however the risk is thought to be minimal given implementation of Option 7 is underpinned by optimisation of WMH application. This should be further mitigated through early engagement. As mentioned previously, Scottish HAW Policy will also need to be considered (e.g. ensuring ILW is not returned to Scottish sites) and engagement with SEPA will be required to ensure this option aligns with policy should it be implemented.

It has been anticipated that this will take 12 months to implement, which was deemed acceptable. This figure is based on OPEX of the implementation time of permit / CEAR variations to allow the incineration of tritiated oils (also classified as ILW). If direct transfer from an AGR site to an incinerator cannot be undertaken because the necessary Permits and CEARs are not in place, other options for the management of desiccant will be considered, in line with the findings of this strategic BAT report.

In addition, should the facility at Fawley be the only incinerator used to dispose of spent desiccant via direct incineration, the management of consignments between sites would need consideration to ensure the desiccant can be managed within monthly acceptance limits. There is potential that incineration of third-party customers' tritium waste could also significantly impact consignment scheduling. Consignments should be planned in advanced and early engagement through the EDF-TI contract management monthly meetings is recommended.

6.1.3 Cost Data

Cost data is presented in Table 6, based on one consignment of HYA R1 2013 desiccant, which is considered to be a typical sample. A cost analysis was also undertaken with HAR R1 2016 data, as this desiccant had a higher gamma activity. Option 7 is anticipated to yield cost savings of approximately 50-80% over Option 1. Cost savings from Option 2 compared to Option 1 are negligible.

The price savings vary depending on the contract used, and EDF will need to confirm these rates and the most appropriate contract for the route prior to implementation of Option 7. A bespoke desiccant contract is agreed with TI, which is separate to the Radioactive Waste Management Services contract [19]. The data using different rates for both consignments is summarised in Table 5.

Table 5: Cost data based on HYA R1 2013 and HAR R1 2016 desiccant.

Option	Contract Used	Cost Saving against Option 1 / %
		LLWR rates based on volume
HYA R1 2013		
1	Bespoke Desiccant Contract	0
2		3
7		66
	Radioactive Waste Management Services	79
HAR R1 2016		
1	Bespoke Desiccant Contract	0
2		1
7		54
	Radioactive Waste Management Services	71

The following should be noted when comparing cost data:

- Additional processing steps (e.g. for removal of steel ball bearings) have not been taken into account. Additional processing will lead to cost increases, and will therefore reduce cost savings.
- Different desiccant batches contain different amounts of tritium and other radionuclides. The cost for disposal through incineration will change depending upon how much activity is contained with the desiccant, and so all potential cost savings presented here must be taken as indicative.

The data above makes no consideration of which route the desiccant would be (or would have been) disposed through. It therefore cannot be said with certainty that the HAR R1 2016 desiccant can be disposed of for 29% of the cost of Option 1 through use of direct incineration, as it is unclear whether this desiccant would meet the Fawley WAC. This study assumes that all third-party treatment and disposal sites as well as all associated plants within the scope of this study are available, are adequately maintained and have sufficient capacity. In terms of Option 7, should the Fawley incinerator become unable to accept EDF desiccant waste (e.g. prolonged shutdown or throughput capacity), there are other incinerators in the UK and abroad who could potentially accept this waste. The future availability of the washing plant has already been discussed in Section 5.2.5, and it is recommended that EDF further engage with TI to understand costs associated with keeping Options 1 and 2 available, should Option 7 be unsuitable for disposal of desiccant with some properties (examples are provided in Section 6.1.1). Across the fleet, the cost savings associated with implementation of Option 7 will be substantial and only be reduced by a small proportion should EDF incur costs associated with maintaining washing capability.

6.2 Uncertainties and Data Gaps

Quantitative operator (treatment and disposal facilities) doses are not available for the processes considered in this study, as these are controlled in accordance with Tradebe's procedures. Whilst it is assumed these doses are managed within the required limits, it may be beneficial to compare, quantitatively, the doses received to workers from each process. Given that doses associated with desiccant are typically very low (often <20 μSvh^{-1}), it is not anticipated that this would be a determining factor in any option being selected as BAT. This may become more significant for desiccant with higher dose rates (e.g. the desiccant recovered from the HPB vault as discussed in Section 6.1.1) and may require assessment via an operational BAT assessment, as necessary. This desiccant may fall outside of Tradebe's processing WAC and may require additional arrangements and controls for managing such waste, which will limit operator dose. Doses to the environment would also need to be considered for each option. However, as discussed above, given the typically low doses associated with the desiccant, it is not expected that dose to the environment would be a determining factor.

As discussed in Section 6.1.1, there is uncertainty regarding the direct incineration of steel ball bearings in the HYB and TOR desiccant, which should be further discussed with Tradebe. Whilst a requirement for an additional processing step to remove the steel ball bearings does not change the outcome of this strategic BAT assessment, the preferred option for HYB and TOR may be one other than Option 7 and may need to be determined through an operational BAT assessment.

There is some uncertainty surrounding the proportion of radionuclides other than tritium that are removed from the desiccant via the washing process. For desiccant like that retrieved from HPB in 2019, this may need to be understood should use of Option 2 be pursued, to ensure this waste can be incinerated to produce an ash that can be disposed of to landfill. Whilst the Fawley incinerator has a defined WAC for incineration, it is not currently clear whether this WAC would be suitable for desiccant to be disposed of through Option 7. It has been determined that the Fawley WAC is not suitable for desiccant disposed of through Option 2, due to increased water content and the impact this has on incinerator operation. An updated WAC could be useful in providing clarity as to which route is most suitable for different batches of desiccant.

7 Conclusions

A summary of the pros and cons of each of the three options assessed is presented in Table 6. Option 7 (incineration and disposal to landfill), has been identified as the best performing option at a strategic level for all suitable AGR spent desiccant. This option yields significant benefits over those associated with currently implemented preferred Option 2. These benefits include reduced industrial safety risk, reduced transport, reduced resource use, and significant cost savings. Full-scale trials undertaken by Tradebe have successfully demonstrated the viability of Option 7 and there are no technical uncertainties which prevent use of this option.

A number of sensitivities have been considered and the robustness of the overall favourability of Option 7 has been demonstrated. As highlighted throughout this report, there may be AGR spent desiccant with properties (e.g. activity or particulate content), which make Option 7 unpracticable and / or sub-optimal. This report provides the strategic direction for AGR spent desiccant management, and provides a hierarchy of implementable options that can be demonstrated as BAT for an envelope of waste properties that are anticipated for AGR desiccant waste. Where there are additional considerations to be made outside of the scope of this strategic BAT assessment, an operational BAT assessment should be conducted on a case by case basis. Figure 2 provides an outline as to how this strategic BAT assessment should inform an operational BAT assessment should it be required.

Table 6: Summary of pros and cons for each of the options

Option	Pros	Cons
Option 1	• Lowest dose to the public (2.1E-04 μSv/TBq ^{3}H) • Technically underpinned	• Largest volume of waste disposed to the LLWR • Biggest conventional safety risk (washing, encapsulation) • Disposability risk associated with meeting the LLWR Waste Acceptance Criteria (WAC) is not removed • Highest cost
Option 2	• No waste disposed to the LLWR • Removes LLWR disposability risk • Reduced conventional safety risk (washing, incineration) • Technically underpinned • Does not preclude Option 1 (retains contingency)	• Slight increase in public dose (when compared to Option 1) (indicative value of 1.49E-02 μSv/TBq ^{3}H from HYA R1 2013) – however, this dose does not differentiate the options
Option 7	• No waste disposed to the LLWR • Removes LLWR disposability risk • Lowest conventional safety risk (incineration) • Reduced cost (indicative 68% cost saving against Option 1). • Cost savings significant and will more than cover costs to maintain the washing plant as a contingency • Technically underpinned through trials • Fewest processing steps	• Highest dose to public (indicative value of 1.68E-02 μSv/TBq 3H from HYA R1 2013) – however, this dose does not differentiate the options

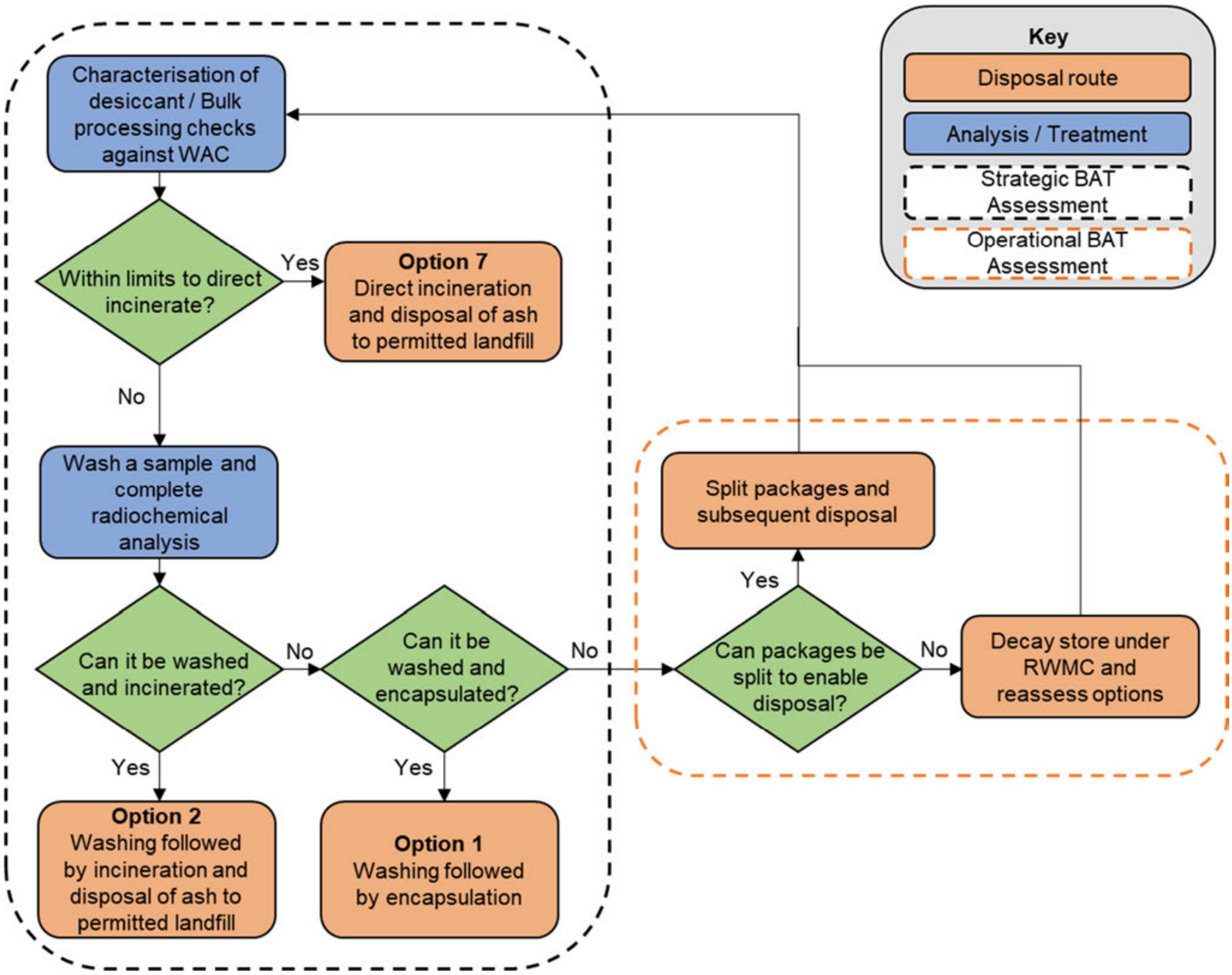


Figure 2 **Interface between this strategic BAT assessment and an operational BAT assessment.**

8 Implementation

The implementation of Option 7 as the preferred route for managing spent AGR desiccant and catalyst will be subject to completion of the following actions:

- EDF to confirm whether amendments to station CEARs are required for the disposal of catalyst waste directly to Tradebe Fawley under EPR16. If required, EDF should seek the required amendments to the Compilation of Environmental Agency Requirements (CEAR) for the English AGR sites to allow transfer of Intermediate Level radioactive Waste (ILW) to the Fawley site, as appropriate. No changes to Permits are anticipated to be required for Scottish AGR sites. CEARs were updated to enable disposal of desiccant directly to Tradebe Fawley following publication of Revision 1 of this assessment.

In addition, the following requires consideration but does not prevent the implementation of Option 7 in the near-term:

- The Company Specification for the Storage, Processing and Disposal of Desiccant Waste will need to be revised in light of this strategic BAT assessment to include catalyst management.
- An assessment as to whether there are strategic and / or financial benefits associated with using another incinerator for spent AGR desiccant and catalyst management should be considered, given there may be benefits in terms of proximity for some sites.
- EDF should seek clarity from Tradebe on a WAC (or equivalent) for all options with regards to AGR spent desiccant and catalyst.

9 References

Ref.	Document Identifier	Document Title
1.	N/A (saved in file on V: Drive)	Tradebe, AGR Desiccant Washing and Incineration Trial: Final Report. INUTEC(17)P014 Issue 1, 2017
2.	BEG/SPEC/SHE/ENVI/009 /02	Company Specification for the Storage, Processing and Disposal of Desiccant Waste, Rev 002, 2022
3.	Scottish Environment Protection Agency, RS-POL-001	Satisfying the optimisation requirement and the role of Best Practicable Means
4.	N/A	Department of Energy & Climate Change, UK Strategy for the Management of Solid Low Level Waste from the Nuclear Industry, February 2016
5.	ENL/REP/0055/AGR/08	Best Practicable Environmental Option Study for the Management of Spent AGR Desiccant. Dungeness B, Hartlepool, Heysham 1, Heysham 2 and Torness
6.	N/A	Problematic Waste IPT, Problematic Waste Management Case Study: Treatment and Disposal of ILW Desiccant. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/695290/PWIPT-Case-Study-ILW-Dessicant.pdf Web link last accessed 21/07/2020
7.	N/A (saved in file on V: Drive)	Fawley High Temperature Incinerator, Environmental Permit, EPR/PP3593SE/V007
8.	ERO/REP/0185/GEN	Strategic BAT for the Management of Spent AGR Desiccant, Rev 000, 2018
9.	N/A	Tradebe Fawley, Code of Practice: Conditions for Acceptance of Radioactive Waste Issue 7, January 2015
10.	Email correspondence between Tradebe and [redacted]	Personal Communication (email) from [redacted]: 'RE: Desiccant Framework Returnable Schedule Issue 3' – Received 24/12/19
11.	BEG/SPEC/SHE/ENVI/021	Company Specification for The Application of Best Available Techniques and Best Practical Means, Rev 008, May 2020
12.	BEG/SPEC/SHE/ENVI/021 /02	Company Specification for Undertaking a Strategic BAT / BPM Assessment, Rev 001, March 2020
13.	N/A	Environment Agency, Radioactive Substances Regulations – Environmental Principles. Regulatory Guidance Series, No RSR 1, 2010
14.	N/A (saved in file on V: Drive)	Tradebe Test Report, Radiochemical Characterisation of Direct Incineration Trial Torness R2 2015 Desiccant Samples, 2018
15.	N/A (saved in file on V: Drive)	Tradebe Test Report, The Radiochemical Analysis of Ash Sample from the Heysham 2 R7 2015 Desiccant Direct Incineration Trial, 2019
16.	Email correspondence between Tradebe and [redacted]	Personal Communication (email) from [redacted]: 'Price Comparison for LLWR disposal and Fawley disposal for AGR desiccant for the strategic BAT review' – Received 30/11/2017

Ref.	Document Identifier	Document Title
17.	Email correspondence between Tradebe and [redacted]	Personal Communication (email) from [redacted]: 'Strategic BAT review – water use for desiccant washing and water disposal' – Received 25/10/2017
18.	N/A (saved in file on V: Drive)	V:Drive Task File Reference: ERO-REP-0185-GEN Cost Comparison Data V1, 2020
19.	Contract 4600077403	Framework agreement between EDFE NGL and TI for the provision of radioactive waste management services. File may be provided (if required, and on a need-to-know basis) by EDF Supply Chain or FORM.
20.	N/A	Nuclear Decommissioning Authority, Radioactive Waste Strategy: Integrated Waste Management, 2019
21.	N/A (saved in file on V: Drive)	V:Drive Task File Reference: Inventory HPB Desiccant drums 2019 vault empty - For EDF, 2020
22.	N/A (saved in file on V: Drive)	Personal Communication (email) from [redacted]: 'Tradebe desiccant info' – Received 15/01/2018
23.	N/A (saved in file on V: Drive)	V:Drive Task File Reference: Inutec(18)P016 Issue 2 - Wash and incineration trial Heysham 1 and Hartlepool catalyst FINAL
24.	N/A (saved in file on V: Drive)	V:Drive Task File Reference: Inutec(21)P003 Issue 2 - Wash and incineration trial Heysham 1 R2 2016 catalyst
25.	N/A (saved in file on V: Drive)	V:Drive Task File Reference: Inutec(22)P019 Issue 1 - Direct incineration trial Hartlepool catalyst

10 Distribution List

Name	Position / Location	User ID
[redacted]	Environment Officer / Generation Environment Management	[redacted]
[redacted]	Environment Officer / Generation Environment Management	[redacted]
[redacted]	Group Head / Fleet Operational Radioactive Waste Management (Acting)	[redacted]
[redacted]	Fleet Environment Manager/ Nuclear Generation Environment Management	[redacted]
[redacted]	Radwaste Engineer / Environmental Safety Group - DNB	[redacted]
[redacted]	Radwaste Engineer / Environmental Safety Group - DNB	[redacted]
[redacted]	Accredited Radwaste Engineer / Environmental Safety Group - HAR	[redacted]
[redacted]	Radwaste Engineer / Environmental Safety Group - HAR	[redacted]
[redacted]	Accredited Radwaste Engineer / Environmental Safety Group - HAR	[redacted]
[redacted]	Accredited Radwaste Engineer / Environmental Safety Group - HYA	[redacted]
[redacted]	Accredited Radwaste Engineer / Environmental Safety Group - HYA	[redacted]
[redacted]	Radwaste Engineer / Environmental Safety Group - HYB	[redacted]
[redacted]	Accredited Radwaste Engineer / Environmental Safety Group - HPB	[redacted]
[redacted]	Radwaste Engineer / Environmental Safety Group - HPB	[redacted]
[redacted]	Radwaste Engineer / Environmental Safety Group - HNB	[redacted]
[redacted]	Radwaste Engineer / Environmental Safety Group - TOR	[redacted]
[redacted]	Accredited Radwaste Engineer / Environmental Safety Group - TOR	[redacted]
[redacted]	Environmental Safety Group Head / Environmental Safety Group - TOR	[redacted]

Appendix A – Desiccant Characteristics at each AGR site

Site	Estimated Average Tritium Activity (after decay period) (Bq/g)	Steel Ball Bearings present	Storage of spent AGR desiccant waste	Packaging for Transport	Volume of desiccant stored on-site (as of Jan 2020) (m^3)	Volume of Lifetime Arisings (as of Jan 2020) (m^3)
HRA	60-150	N	On-site for a minimum of 3 years	210 Litre steel drums (with a packaging lifetime of 5 years)	35.6	0.8
HYA	60-150	N	On-site for a minimum of 3 years	210 Litre steel drums (with a packaging lifetime of 5 years)	0	30
HYB	60-150	Y	On-site for a minimum of 3 years	210 Litre steel drums (with a packaging lifetime of 5 years)	0	56
TOR	60-150	Y	On-site for a minimum of 3 years	210 Litre steel drums (with a packaging lifetime of 5 years)	0	27
HPB[4]	Generally >60-150	N	On-site (for significantly longer than 3 years) in lifetime vaults	Removal from lifetime vaults into 210 Litre steel drums	198 (mixed catalyst and desiccant)	16.8
HNB[4]	Generally >60-150	N	On-site (for significantly longer than 3 years) in lifetime vaults	Removal from lifetime vaults into 210 Litre steel drums	260 (mixed catalyst and desiccant)	0
DNB	Generally <60-150	N	On-site (for significantly longer than 3 years) in IBCs	210 litre steel drums or IBCs in FH ISO	120 (mixed catalyst and desiccant)	None planned

[4] HNB and HPB lifetime vaults will contain limited amounts of steel ball bearings associated with the catalyst disposals – volumes of these are expected to be very small due to limited historic disposals to the vault. The method of desiccant retrieval employed at HPB in 2019 appears to indicate that these steel ball bearings preferentially stay within the vault and are not readily retrieved.

Appendix B – Dose Estimates (based on HYA R1 2013 and HYB R7 2015 spent AGR desiccant)

Information about the HYA Reactor 1 (HYA R1) 2013 and HYB Reactor 7 (HYB R7) 2015 spent desiccant were used to provide realistic and indicative values for a detailed dose assessment, allowing direct comparison between each of the options.

For the purposes of this dose assessment, and in keeping with the assumptions previously stated in this report, it is assumed that the only radionuclide to be removed during the washing process is tritium. All other nuclides are assumed to stay at constant levels during the washing process. Therefore any differences in the doses between options can be attributed solely to the route via which the ^{3}H is discharged. For Option 7 – Direct Incineration, more tritium will be discharged via the gaseous route, as none has been removed through a washing process.

For Option 1 – Washing and Encapsulation, it was determined that dose to public following washing would be negligible, as the majority of radionuclides associated with the desiccant would have decayed to very low levels by the time the LLWR is expected to be affected by coastal erosion. Therefore these doses have not been formally assessed. The expected dose to a member of the public from 1 TBq ^{3}H discharged as a result of the washing process is 0.00021 µSv.

Table 7: Public dose from 1 TBq of tritium processed by washing or incineration [16].

Route	Public dose (air) µSv/TBq	Public dose (water) µSv/TBq	Public dose (total) µSv/TBq
Washing	0	2.1E-04	2.1E-04
Incineration	5.8E-04	1.7E-04	7.5E-04

For Option 2 – Washing and Incineration, and Option 7 – Direct Incineration, the dose assessment was carried out using the Initial Radiological Assessment Tool (IRAT). The assessment considers the dose impact for a number of nuclides other than ^{3}H, including ^{14}C, ^{36}Cl, ^{55}Fe, ^{60}Co, ^{63}Ni, ^{134}Cs and ^{137}Cs. ^{35}S is excluded as it will have decayed to very low levels for most desiccant waste. The partitioning of the radionuclides through the incinerator and associated abatement processes ave been considered as part of this dose assessment. Some assumptions have been made when developing the models (e.g. “other beta/gamma” nuclides have been assigned to ^{55}Fe and ^{63}Ni where these nuclides were not assessed for HYA).

Data from the HYA R1 2013 and HYB R7 2015 desiccant discharges were used to develop two dose assessments, presented in Table 8 and Table 9. More detailed information on the radionuclide mixes for the HYA R1 2013 and HYB R7 2015 desiccant batches used to produce these dose assessments can be found in Table 10 and Table 11.

Table 8: Public dose from discharges for HYA R1 2013

Public dose (µSv / TBq ^{3}H)	Option 2		Option 7	
	0.0149		0.0168	
	Gaseous	Liquid	Gaseous	Liquid
	0.0140	0.00085	0.0160	0.00084

The difference between Option 2 – Washing and Incineration and Option 7 – Direct Incineration is 0.0019 µSv per TBq of ^{3}H.

Table 9: Public dose from discharges for HYB R7 2015

Public dose (μSv / TBq ^{3}H)	Option 2		Option 7	
	0.00336		0.00465	
	Gaseous	Liquid	Gaseous	Liquid
	0.0030	0.00036	0.0043	0.00035

The difference between Option 2 – Washing and Incineration and Option 7 – Direct Incineration is 0.0013 μSv per TBq of ^{3}H.

Table 10: HYA R1 2013 dose assessment data

% contribution	Activity	"other activity" Excluding ^{3}H	Option 2		Option 7	
			Gaseous dose	Liquid dose	Gaseous dose	Liquid dose
^{3}H	99.301	-	7.23	24.38	14.98	23.79
^{14}C	0.168	24.85	27.39	23.27	25.1	23.45
^{60}Co	0.001	0.15	0	0.03	0	0.03
^{36}Cl	0.243	35.95	64.79	0.03	59.37	0.03
^{54}Mn	0.001	0.15	0	0	0	0
^{55}Fe	-	-	0.01	0	0.1	0
^{63}Ni	-	-	0	0	0	0
^{65}Zn	-	-	0	0	0	0
^{75}Se	-	-	0	0	0	0
^{134}Cs	-	-	0	0.01	0	0.01
^{137}Cs	0.004	0.59	0.59	52.27	0.54	52.67
Other beta/gamma*	0.259	38.31	-	-	-	-

*for "other beta/gamma" the doses were apportioned to ^{55}Fe and ^{63}Ni.

Table 11: HYB R7 2015 dose assessment data

% contribution	Activity	"other activity" Excluding 3H	Option 2		Option 7	
			Gaseous dose	Liquid dose	Gaseous dose	Liquid dose
3H	99.928	-	34.66	58.14	54.62	57.35
14C	0.0325	45.275	57.18	24.04	39.7	24.49
60Co	0.000001	0.001	0.03	0.6	0.02	0.61
36Cl	0.00269	3.735	7.73	0	5.39	0
54Mn	0.0283	39.257	0	0	0	0
55Fe	0.00493	6.851	0.02	0	0.01	0
63Ni	0.00000	0.000	0	0	0	0
65Zn	-	-	0	0	0	0
75Se	0.00006	0.086	0	0	0	0
134Cs	0.00000	0.000	0	0.11	0	0.11
137Cs	0.00000	0.000	0.37	16.58	0.26	16.9
Other beta/gamma*	0.00319	4.428	0	0.52	0	0.53

*Other beta/gamma includes contribution from detectable ^{110m}Ag

It is clear from the above data that whilst tritium accounts for a significant proportion of the contamination associated with AGR desiccant, it is the "other" radionuclide inventory that more significantly affects the dose when compared to its proportion of the total activity. Doses are impacted in particular by contributions from ^{14}C and ^{36}Cl. However, no doses associated with any option detailed within this Appendix present an unacceptable risk to the public, and differences between the options are not significant enough to differentiate options.

Appendix C – Inclusion of spent AGR catalyst within the scope of this Strategic BAT/BPM assessment

Introduction

Catalyst is used within the auxiliary gas system at AGR stations within the recombination unit. Catalyst recombines carbon monoxide with oxygen to produce carbon dioxide, which is used as the reactor coolant. The recombination unit is located on a separate leg of the Gas Bypass Plant after the Bypass Blowdown filters. Therefore catalyst experiences similar plant conditions to desiccant, and analytical data of catalyst samples from HYA and HAR has demonstrated that catalyst has similar radiochemical properties to desiccant. It is classified as ILW based upon tritium specific activity, and contains relatively low levels of other beta/gamma contaminants.

Catalyst is made from 0.1wt% platinum-coated, ceramic cylinders. It's physical and chemical properties do not preclude its disposal at either incineration facilities or LLWR.

Given the above similarities to desiccant waste, it has been concluded that spent AGR desiccant and catalyst represent similar enough waste streams, such that they can be considered under the scope of the same strategic BAT/BPM assessment.

Catalyst incineration trials

The full scope of catalyst incineration trials is detailed within Refs 23, 24 and 25 and is summarised below.

Washing and incineration trials

Washing and incineration trials were completed on HYA catalyst in November 2018. The catalyst used in these trials was removed from the plant in 1994/95, and had therefore undergone significant decay prior to the trial being completed. The results from this trial indicated that a disposable ash product could be produced through the incineration process (Ref 23).

A similar washing and incineration trial was completed on HAR catalyst in February 2019. Similarly to the trial conducted using HYA catalyst, the catalyst from HAR had undergone significant decay, having been retrieved from the recombination unit in 1997 (Ref 23).

To further demonstrate the capability of the washing and incineration, an additional washing and incineration trial was undertaken using 4 drums of catalyst from HYA R2 2016 that had not decayed for as long as the catalyst used in other trials. This was performed to demonstrate that the process could be used for catalyst with higher levels of tritium and other beta/gamma contaminants, such as those that will be removed from the recombination units at EoG (Ref 24).

Analysis of samples from all washing and incineration trials demonstrated that the ash waste product met the conditions for disposal to landfill. The results of the washing and incineration trials are presented within Table 12.

Direct incineration trials

Following the completion of the washing and incineration trials, direct incineration trials were undertaken. Initially these used 4 drums of catalyst from HAR which was removed from the plant in 2018. It later transpired that whilst this catalyst was removed from the plant in 2018, it was actually removed from the recombination unit in 2011, and was erroneously kept in another part of the system until it was discovered at a later date (Ref 25).

Initial analysis of the catalyst samples indicated very elevated levels of Cl-36, but re-analysis of the waste prior to incineration indicated that this was likely a spurious result that was not representative of the entire waste population.

The direct incineration trial was completed in March 2022, and samples of ash taken during the trials were analysed at Tradebe Inutec shortly afterwards. Only one bulk sample (comprised of 33 sub-samples) was analysed at Tradebe. Most radionuclides were detected at levels to be expected within the ash, however Ni-63 (which had not been detected at particularly elevated levels in the initial pre-incineration analyses) was detected at levels that meant the waste would not have been suitable for disposal as VLLW.

Following discussion with Tradebe, it was determined that the best available option would be to re-sample the ash skip (which had been quarantined in line with the process for undertaking trials using desiccant and catalyst until such time that the analysis determines that it can be disposed of). A sampling plan was developed to produce two new samples for analysis (comprised of 12 sub-samples – see Figure 1 in Ref 25). Samples were taken in line with the sampling plan, and analysed in line with previous analytical requirements. All results from the direct incineration trial are reported in Table 13.

A disposable ash product was produced following analysis of the ash after incineration had been completed, although in some instances this was more difficult to prove than for desiccant waste. As discussed above, there were some instances where initial analysis of the ash indicated that the radionuclide levels exceeded the limits for VLLW disposal – these exceedances were later proven to be not representative of the entire waste population through re-sampling and re-analysis.

Conclusions

Catalyst waste is demonstrated to fall within the envelope of spent AGR desiccant because the waste is dominated by tritium, and its physical and chemical properties do not preclude its treatment using similar techniques to those used to dispose of spent AGR desiccant. The arguments made in the assessment for spent AGR desiccant therefore apply to spent AGR catalyst.

Given the similarities between the radiochemical properties of desiccant and catalyst waste, and the evidence from substantial trials conducted to prove the viability of the incineration route for catalyst waste, it has been determined that spent AGR catalyst can be included within the scope of this strategic BAT/BPM assessment. Given the similarities between the two waste types, and the controls in place at the incinerator, it has been determined that there is no need to re-assess the options presented within this study previously, as it is not credible that the preferred option for catalyst would be different to desiccant.

It is recommended that EDF engage with regulators to determine whether any regulatory controls require updating to enable the disposal of catalyst waste direct to holders of an environmental permit without a nuclear site licence (i.e. an update to English AGR CEARs to include catalyst), or whether this is already covered by the scope of the existing station CEARs.

Table 12: Radiochemical properties of washed catalyst and resultant ash following washing and incineration

Catalyst batch	Sample I.D.	Specific Activity (Bq.g^{-1})						
		H-3	C-14	S-35	Cl-36	Fe-55	Ni-63	Co-60
HYA R1 1994/95		Post-washing analysis						
	AA0355	4600	2.3	-	8.3	<0.52	4.2	<0.13
	AA0356	1530	3.2	-	25.0	<0.47	3.4	<0.055
		Post-incineration ash analysis						
	AA0778-1	10.3	1.6	-	<0.031	<0.24	<0.054	<0.15
	AA0778-2	10.9	1.8	-	-	-	-	-
HAR R1&R2 1997		Post-washing analysis						
	AA0775	3080	3.7	-	1.15	<0.42	3.79	<0.18
		Post-incineration ash analysis						
	AA0068-1	0.11	<0.02	-	<0.28	<0.028	<0.097	<0.054
	AA0068-2	0.20	<0.02	-	-	-	-	-
HYA R2 2016		Post-washing analysis						
	AC0275	17600	2.6	9.66	0.62	<0.88	10.2	0.161
		Post-incineration ash analysis						
	AA0346 Bulk 1	<0.04	<0.03	<0.057	<0.14	<0.0045	<0.20	<0.10
	AA0346 Bulk 2	<0.04	<0.03	-	-	-	-	-

Table 13: Radiochemical properties of untreated catalyst and resultant ash following direct incineration

Catalyst batch	Sample I.D.	Specific Activity ($Bq.g^{-1}$)						
		H-3	C-14	S-35	Cl-36	Fe-55	Ni-63	Co-60
HAR R1 2018		Pre-incineration analysis						
	AD0713-1	69000	7.4	0.15	478*	3.3	9.56	1.22
	AD0709	-	-	-	44	-	-	-
	AD0710	-	-	-	2.61	-	-	-
	AD0711	-	-	-	16.3	-	-	-
	AD0712	-	-	-	10.5	-	-	-
	AD0713-2	-	-	-	28.9	-	-	-
		Post-incineration ash analysis						
	AE0085	0.46	<0.06	<0.15	<0.029	<0.33	4.2*	0.259
	AE0259	<0.11	<0.15	<0.077	0.057	<0.6	0.39	0.309**
	AE0260	1.2	<0.07	<0.076	<0.024	0.8	0.69	0.196**

*results considered to be non-representative of overall waste, confirmed through reanalysis

**analysis of as-received ash sample