wnti

# Good Practice Guide

## Spent Nuclear Fuel Safe Storage

# Contents



01

# Executive Summary

## Introduction

The Nuclear Decommissioning Authority (NDA) provides contractual spent fuel management services to EDF Energy (EDFE) for the lifetime arisings of spent fuel, this is from a fleet of 7 Advanced Gas-cooled Reactor (AGR) power stations which operate within the UK. The NDA discharges this contract through Sellafield Ltd.

As interim storage at the reactor sites is limited, once fuel is removed from the reactor a timely transfer to Sellafield is crucial in preventing a backlog and enabling continued reactor operation. Approximately 200te of AGR fuel is presently received at Sellafield each year.

In 2012 the NDA's Senior Strategy Committee with the regulator (ONR) and EDFE endorsed a 7 to 10-year extension to the lifetime of AGR reactors. Due to this extension the current projection is that planned Schedule Closure Dates (SCD's) will begin in 2022, running until 2030. Following each station closure bulk defueling will begin, with fuel being transported to Sellafield for wet interim storage.

As a result of the strategic intent of the 2012 NDA Oxide Fuel Strategy all AGR fuel not reprocessed on the cessation of the Thermal Oxide Reprocessing Plant (THORP) must be interim wet stored in the THORP Receipt and Storage Pond (TR&S) at Sellafield under its 2003 Single Pond Strategy.

Due to the station lifetime extensions, the amount of spent AGR fuel which requires storage in TR&S has increased from the pre-extension forecast of 4,000te to circa 5,000te. As this increased fuel volume cannot be accommodated under the current pond furniture configuration there is now a storage capacity gap in TR&S.

In order to accommodate demand in line with planned SCD's and meet the NDA's contractual obligations three key strategic changes (see below) must be delivered, this document will focus on the third point "Safe Storage of SNF".

- **Receipt rate:** The ability to manage and maintain receipt volumes that meet demand and current unknowns such as the potential for earlier than planned station closures.

- **Storage capacity:** Provision of high-density pond furniture to close the TR&S storage capacity gap.

- **Safe storage of SNF:** Resolution of the >1.7MW heat loading constraint within TR&S and the provision of failed fuel management (although failed fuel is not expected). This is to ensure non-foreclosure of future NDA options.

## 1.1 Fuel Process at Sellafield

The import of AGR fuel into the Fuel Handling Plant (FHP) requires a regular movement of fuel between FHP, AGR Storage Pond (AGRSP) and Thorp Receipt & Storage Pond (TR&S). This is to preserve space in FHP for future fuel imports and protect the TR&S pond for significant heat generation (1.7MW limit) as the pond is loaded with AGR fuel for long term interim storage. Figure 1 shows the proximity and location of these facilities.

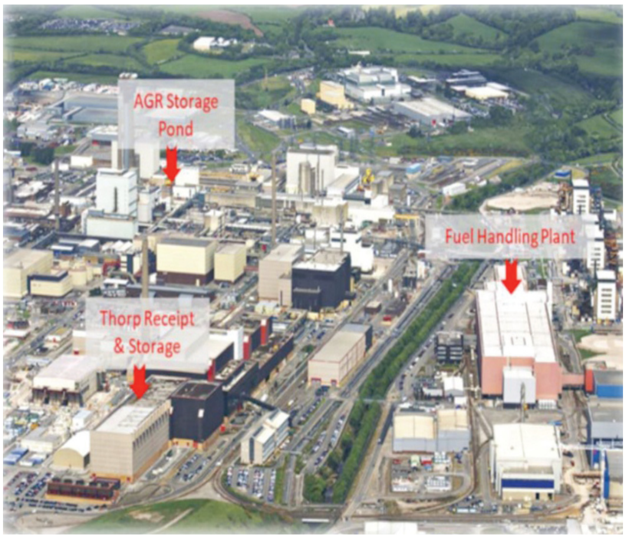


***Figure 1:*** *Illustration of the key areas on the Sellafield site utilised by the Single Pond Strategy Programme.*

**Fuel Handling Plant:** AGR SNF in A2 flasks are received from EDFE and fuel transferred to the storage pond. Empty A2 skips are emptied and returned to EDFE. Fuel is then dismantled, and pins repacked in higher density storage cans and skips. The graphite sleeve and stainless- steel bracing material are segregated for waste disposal.

**AGR Storage pond:** ARG SNF is received from FHP for short term cooling. Fuel cooling was initially to support THORP reprocessing however, its main function is to help control the heat load and potential leaking fuel on TR&S Pond.

**Thorp Receipt and Storage Pond (TR&S):** Fuel is received from the FHP (direct move) or AGRSP (triangular move) for long term interim storage of AGR fuel. TR&S is the long-term interim store for AGR and LWR fuel to support the NDA Oxide Fuel & Single Pond Strategies. Fuel is not classed as waste and will be interim stored in TR&S until the UK Geological Disposal Facility is available or other future options are taken e.g. dry storage, repurpose of fuel.

## 1.2 Single Pond Strategy Programme

A licence instrument was granted in November 2018 to interim store AGR fuel in TR&S. The license limited the storage of fuel within TR&S to a total heat load of 1.7MW due to issues substantiating un- interruptible / sufficiently redundant cooling at higher heat loads. The intent is to target projects and improvements that resolve the heat load constraint. These range from operational improvements to transformational projects.

The single pond programme will pursue the opportunities that will resolve the heat load limitation in TR&S pond which will ultimately allow safe storage of all receipted AGR fuel whilst promoting risk reduction.

Table 1 highlights hard and soft projects that are required to deliver the AGROP strategy

### Table 1

| Change required from the Programme | | | Value Proposition |
|---|---|---|---|
| Potential scope | Core | Replacement of current aged and degraded cooling system asset | Provides long term cooling system resilience<br>Prerequisite to securing TR&S<br>>1.7MW heat load licence instrument |
| | | Permanent caustic dosing system | Provides long term stable pond chemistry to pH11.4<br>Provides reduced risk of failed fuel<br>Prerequisite to securing TR&S<br>>1.7MW heat load licence instrument |
| | | Failed fuel management strategy | Provides protection, detection, identification and management of failed Fuel |
| | | | Prerequisite to securing TR&S<br>>1.7MW heat load licence instrument |
| | | TR&S roof replacement | Provides long term stable pond chemistry to pH11.4<br>Prerequisite to securing TR&S<br>>1.7MW heat load licence instrument |
| | | Import of 'other' oxide fuels into TR&S. E.g. LWR, AGR PIE, Difficult fuels | Implements single pond strategy for oxide fuels |
| Key Services Requirement | Ability to not foreclosure on future NDA strategic decisions | | |

# 02

# Safety case requirements for storage of SNF in TR&S

### Table 2

| SNF conditions for acceptance | |
|---|---|
| Units | • Internal LWR Transport flasks.<br>• Multi Element Bottles (MEBs).<br>• AGR storage/transport flasks.<br>• B560 AGR storage containers.<br>• AGR skips and 8.5” inner diameter cans.<br>• 5” PIE cans. |
| Material:<br>AGR fuel – excluding Post Irradiated Examination (PIE) | • Maximum average skip irradiation 40,000 MWd/tU.<br>• Maximum pin irradiation 48,000 MWd/tU.<br>• Maximum rating 21 MW/tU.<br>• Maximum pre irradiation enrichment 3.82 w/o U235.<br>• Minimum cooling 3 years.<br>• Maximum weight per fuel container 2.7 TeU. |
| Material:<br>Light Water Reactor fuel (LWR) | • Maximum average skip irradiation 60,000 MWd/tU.<br>• Maximum rating 60 MW/tU.<br>• Maximum pre irradiation enrichment 4.0 w/o U235.<br>• Minimum cooling 1 Year.<br>• Maximum weight per fuel container 3.3 TeU. |

Future fuels to be stored in TR&S will be subject to further assessments and safety case review.

03

## Sustainability of TR&S pond structure.

There is a requirement within the AGROP project to confirm the long-term use of the TR&S building/ ponds and their adequacy for the continued receipts of fuel until circa 2080. One of the key areas that has been reviewed within the AGROP project is the pond structure. Previous work has identified the requirement to have a solution available should repair to the pond movement joint be required. Injection grouting (resin) of the water bar arrangement was identified as the preferred solution.

This assessment identified the probable life of the water bars and seals, noting that the mechanical properties of the PVC water bars can degrade when irradiated. It was also noted that the performance characteristics of polysulphide sealant material can also become affected when irradiated, leading to the possibility of pond water entering the joint and proceeding to the water bar locations.

Once the possible failure mechanism was identified a repair strategy was developed and proven through trials.

### Repair trial.

The mock-up trial joint had the following attributes:

- Scaled model (a 1:1 scale model would be 24m long).
- Transparent Perspex viewing panels.
- Representative joint widths.
- Similar joint infill material.
- Sealed ends of joints.
- The model should be sat on a flat surface which is sealed to prevent liquid leakage through the base.

Trial works using the proposed injection technique with vacuum assistance was conducted on the model and proved successful, this developed and verified the final methodology of repair if required.

***Figure 2:*** *This shows one of the TR&S pond expansion joints with stress and measurement gauges used during an annual engineering system health review. The stub to the left-hand side is a leak detection route that can also be used as part of the repair methodology.*

04

# Pond chemistry in support of long-term storage of SNF

In 2004 the single pond strategy was identified as the UK answer to the interim storage of national SNF, in 2012 the intention was that all fuel not reprocessed on the cessation of THORP would therefore be interim wet stored in TR&S.

This can be broken down into several topic areas:

- Understanding fuel failure mechanism
- Chemical makeup control.
- Pond heat generation and pond water movement.
- Safe storage of the SNF

## 4.1 Understanding fuel failure mechanism

During standard operations in an AGR core, the lattice structure of the stainless-steel fuel pins can be deformed by the constant bombardment of neutrons. For those pins in the hottest part of the reactor, this deformation is temporary with the lattice structure springing back into place. For other pins, this deformation is permanent, leaving the pin with a weakness in the lattice structure that can be targeted by corrosion. Fuel that is susceptible to corrosion through this process is called 'sensitised' and the corrosion mechanism that targets this fuel and can cause fuel failure is Inter-Granular Attack (IGA).

Of interest were chlorides, as they were known to accelerate the corrosion of the stainless-steel cladding of AGR fuel rods. At the time, chloride levels were sampled and still appeared to be manageable at 0.2ppm, as the fuel was expected to be safe unless levels exceeded 0.5ppm.

Fuel failures are typically detected by elevated levels of caesium – 137 in the storage pond water but products such as cobalt and nickel, both originating from the cladding if the pins themselves are also trended to give some early warning of corrosion.

## 4.2 Lead container trials

To determine the optimum pond conditions for storing fuel in TR&S long term a trial was performed on three containers of known failed fuel where a specific amount of chloride was injected into fuelled containers to encourage IGA.

Low levels of nitrate and sodium hydroxide were added to the separate containers to identify which condition stemmed the fuel failure rate. This was done by sampling each of the containers over a 2-year period, the results clearly showed that sodium hydroxide (caustic) was far the most effective and became the preferred option. On competition of the trail the failed fuel was processed through THORP.

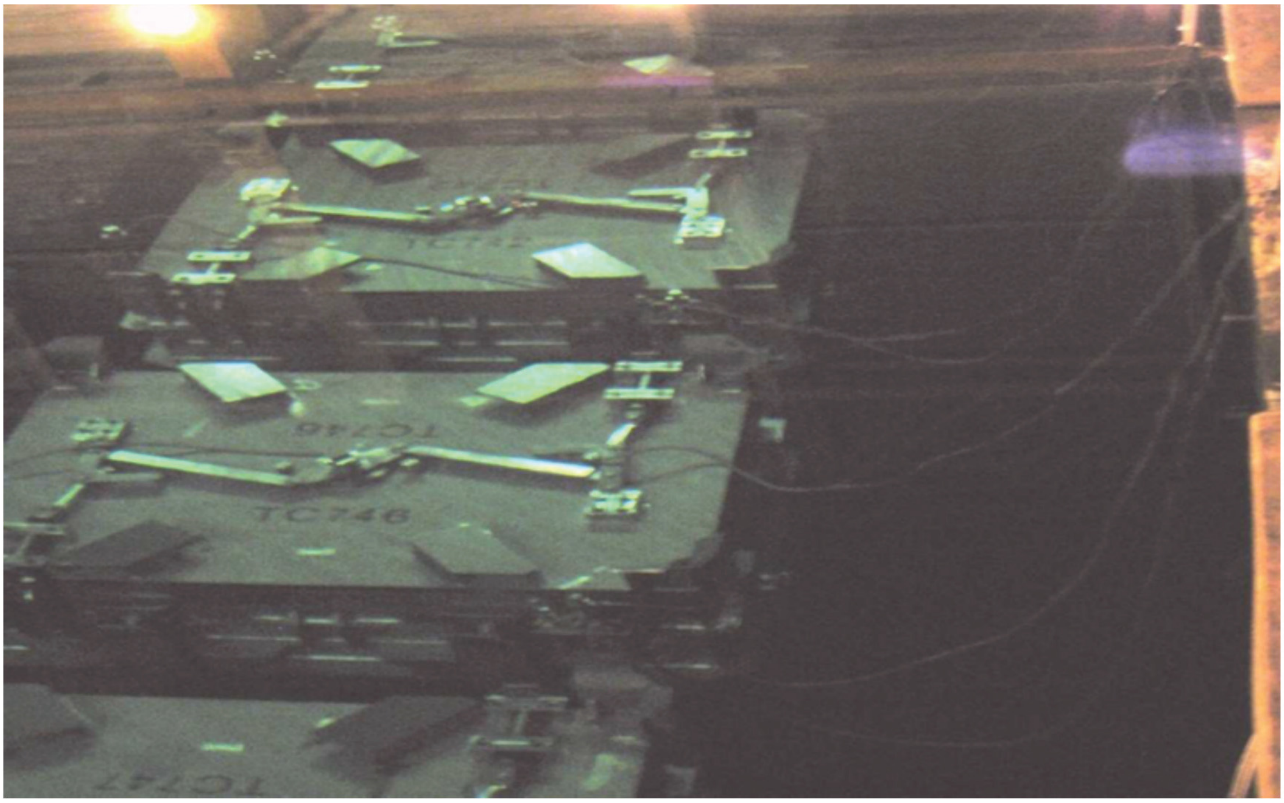


***Figure 3:** Shows the AGR Containers used in the lead trial with sampling hoses attached, these hoses lead to the rig shown in the next figure.*


***Figure 4:** The manual sampling rigs extracts the liquor from the trial containers and sent to the site laboratories for analysis for Cs137, nickel and cobalt.*

## 4.3 Chemical makeup

On completion of the trials, the technical justification and development of the nuclear safety case the plant operators progressed to change the pond chemistry from pH7 demineralised water, to a low dosed Caustic pH9. This was the interim position and gave the opportunity to implement LFE (learning from experience) prior to the final increase to pH11.4.

Areas of LFE included:

- Initial increase of pond water activity due to release of thin films of algae from the pond walls and pond furniture.
- The time to increase from pH7 to pH9 was much longer than anticipated.
- The sampling regime identified the importance of pond water movement required to evenly disperse the caustic.
- The importance an efficient water treatment facility that can purge, discharge and recycle filtered pond purge with fresh water, filtered recycled and discharge was noted.

The successful transition to pH11.4 required the build and commission of a purpose-built caustic dosing rig.

***Figure 5:** Phase 1 of the Caustic dosing rig with an initial design life initially 10 yrs. Phase 2 will be designed for the life of the facility, is presently in study.*

## 4.4 Pond heat generation and water movement

Circa 2040 the TR&S pond starts to reach its capacity of approximately 5000 tonnes the calculated heat loading will be between 6 - 9MW, presently the storage pond is bounded by its safety case to 1.7 MW. This is due to the present cooling tower complex being an aging asset and only designed to support the short-term storage of SNF, it could not be substantiated to anything greater than 1.7 MW. This has initiated a project for the replacement cooling tower facility that will meet all conventional and nuclear safety requirements, this enables a safety case to be developed in support of the licence instrument to operate up to 9MW heat loading in the TR&S pond.

The control of the pond temperature is not only required for the optimum fuel storage conditions but also to manage the expansion and contraction of the main pond structure. Previous temperature sampling has shown that without good water movement there can be a differential of up to 10 degrees C from the surface level to the lower level, this can increase the leak rate of the pond and potentially its longevity.

Temperature modelling for TR&S based on the following assumptions:

- The cooling effect of the recirculation is independent of pond temperature (0.6°C cooling effect).
- There is no change to the relative humidity outside the building (85%).
- Temperature of the environment is assumed to be the average for the month based on past 14-year data.
- Temperature of the feed water is the same as the environment, this is a simplification based on information from the Water Treatment Plant that the demineralised water temperature varies through the year (range given 4°C to 18°C).
- Past heat loads have been calculated every 3 months, to generate a heat load for the months where it has not been calculated, it has been interpolated (interpolated values indicated by green cell in figure 6).
- Future heat load of the pond has been assumed to increase linearly, 20 kW per month (based on trend during 2020), predicted heat loads indicated by grey cell in the table.

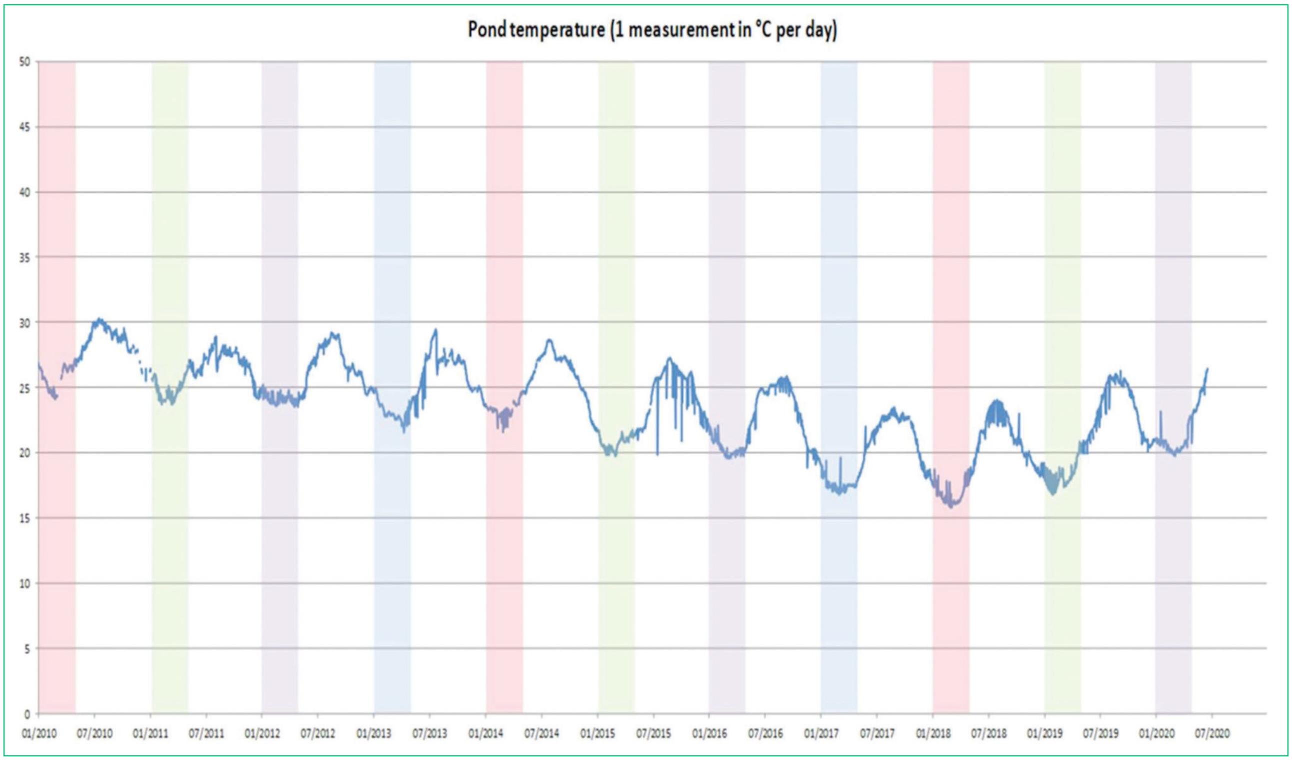


***Figure 6:*** *The graph shows the temperature behaviour of the pond water from 2010. The peaks are during the summer months when the ambient temperature increases, and the troughs are the winter months the general trend shows the lowest temperature to be in the winter of 2018, this trend aligns with the caseation of THORP reprocessing (Nov 2018). As you can see the decreasing trend has now reversed as quantities of fuel in the pond increase, this will require close management as the pond inventory increases.*

For simplicity the value starting from November 2020 has been rounded up.

- Temperature taken for a given heat load is based on a 30-day model. As such, the modelled result for April should be compared against the measured value for May of that year.
- The measured pond temperature given is based on an average of the pond temperature values from 3 days before and to 3 days after the 1st of the month
- Purge/discharge remains steady at 400m3

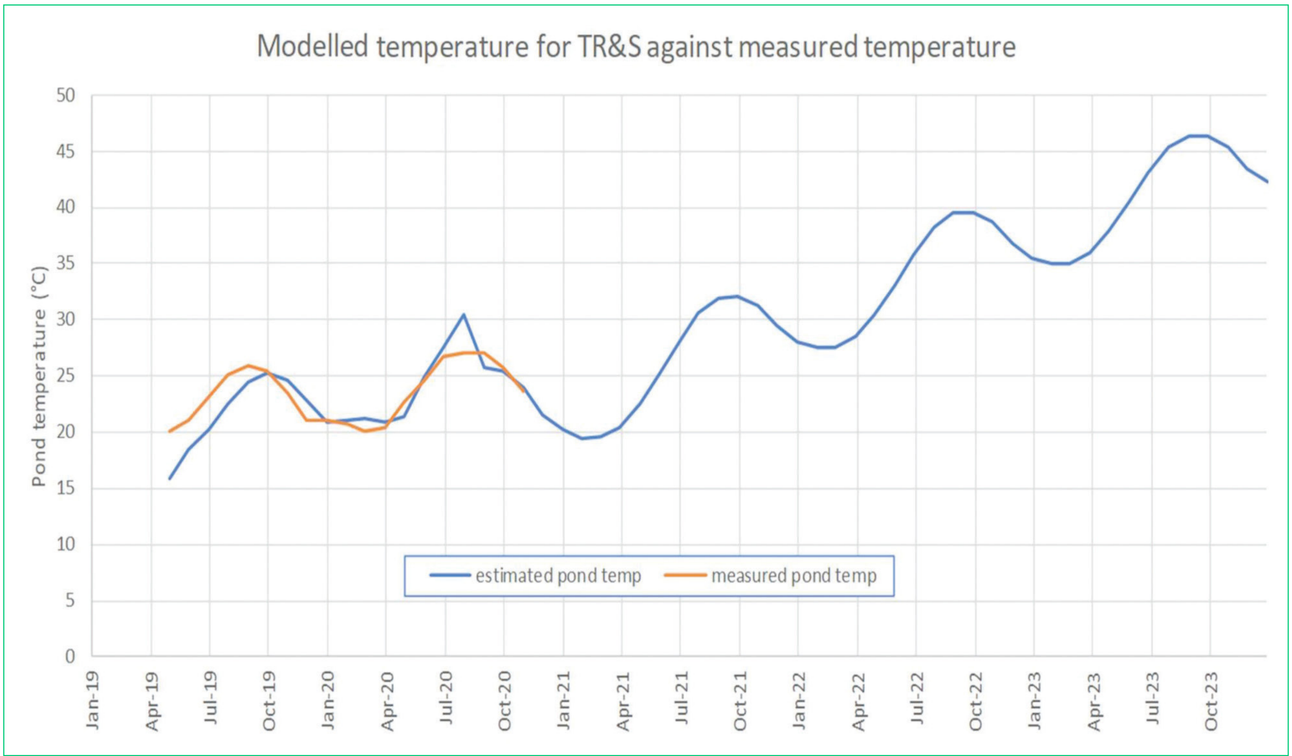


***Figure 7:*** *It can be seen that the pond temperature is estimated to rise above 30°C, the top end of the operating envelope, by the end of July 2021 at an estimated heat load of 750kW, if no additional cooling is introduced to the pond and the increase in heat load seen during 2020 is maintained.*

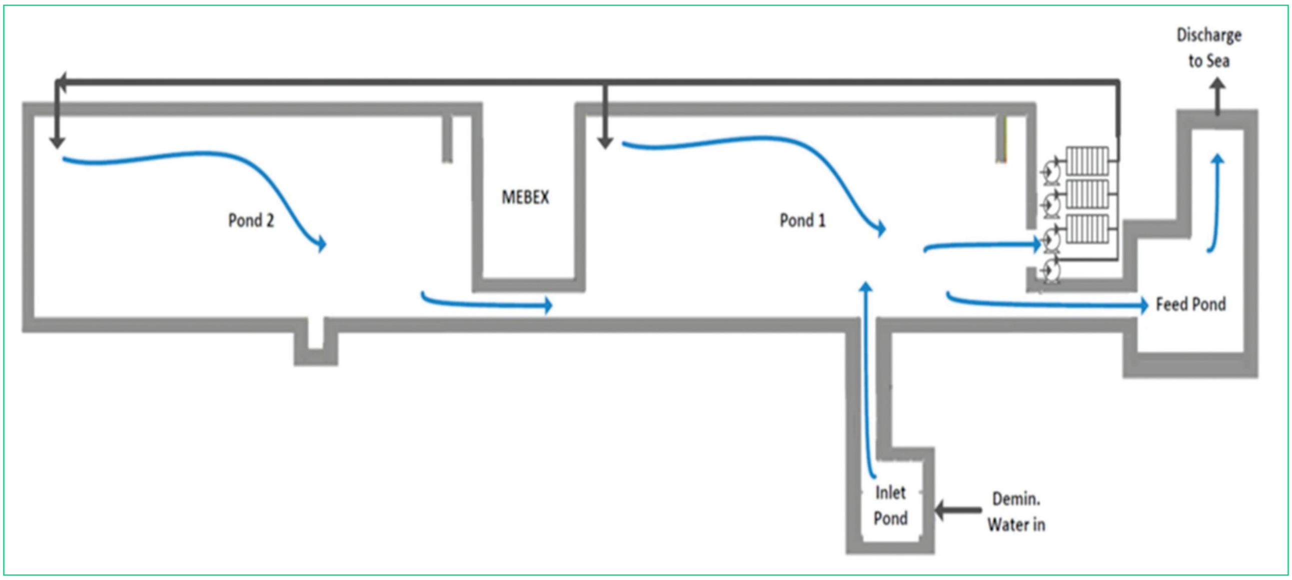


***Figure 8:*** *As previously mentioned, the pond water circulation ensures that the temperature and chemical parameters give an even distribution throughout for optimum storage conditions.*

- *The blue lines represent the water movement of the pond water*
- *The black lines highlight the pond recirculation system*

***Figure 9:*** *Shows the water flow from the corner of pond 2 through the access isle into pond 1*

## 4.5 Safe Storage of SNF

Projects that will support the storage, future pre-conditioning and export to the Geological Disposal Facility are now being developed. These include:

- Storage in the new racks will enable enough storage capacity for all remaining AGR fuel; resulting in > 75% of the UKs SNF inventory residing in TR&S pending GDF availability.
- Active temperature modelling. This work is to ensure that the models that have been built to date bound the temperatures seen in pond to understand the level of safety margin that we have in the system.
- A study is underway to understand corrosion of fuel pins in more detail over longer timescales and at higher heat loads. This will out turn in 2024 and give re-assurance that fuel is tolerant to experiencing conditions outside the normal operating range of the pond and continue to retain integrity until 2084 when fuel is scheduled for removal to GDF. climate change study and effects on assets and fuel storage.
- A climate change study has been undertaken and confirms that storage conditions are resilient to anticipated ranges of sea level rise.
- When a conditioning facility will be required prior to be available to precondition the fuel.


***Figure 10:*** *This is the most recent picture of a 63c rack being imported into TR&S preparation area, on completion of quality checks it will be transported to the pond for fuel handling trials.*

# Conclusion

The national AGROP program covers receipt rate of SNF to Sellafield in support of EDFE defueling, the storage capacity requirements for all EDFE SNF and the continued safe storage of the fuel until the GDF is available circa 2080.

This document covers the approach Sellafieldhas taken as we condition TR&S for the next 60 years of safe spent nuclear fuel storage. The information shared within this, whilst technically underpinned for Sellafi eld LTD, should only be used as guidance.

As part of our continued collaboration with WNTI, Sellafi eld are keen to share future learning of SNF and look forward to engagement within the membership.

Alan Moses
Business Change Authority
Spent Fuel Services
Sellafi eld LTD
Alan.w.moses@sellafi eldsites.com
Mob. 07814822954

Whilst the WNTI will use all reasonable efforts to ensure that the information in this Good Practice Guide is accurate, we cannot guarantee the accuracy of all information and we will accept no liability for any loss or damages incurred, howsoever caused, and cannot be held liable for any use or reliance you may make of or put on it. The WNTI also cannot be held liable for your use or inability to use the site or the information or services that it contains. Errors and Omissions Accepted.

The WNTI offers the use of this Good Practice Guide freely to members and non-members of the transport community. Where any interpretation of the information has been made, it has been done so with the interests of the wider transport community. Although the standard has been extensively reviewed by industry experts, if you have any issues in use or content, please contact the WNTI so we can rectify the issues and conflicts in systems etc.

Aviation House
125 Kingsway
London, WC2B 6NH
United Kingdom

Tel: +44 (0)20 7580 1144
Fax: +44 (0)20 7580 5365

Web: www.wnti.co.uk
Email: wnti@wnti.co.uk

WNTI Good Practice Guide
Spent Nuclear Fuel Safe Storage

World Nuclear Transport Institute
5th Floor Aviation House,
125 Kingsway,
London, WC2B 6NH
020 7580 1144
info@wnti.co.uk
www.wnti.co.uk