Managing Fuel from SMRs: UK Framework and HTGR Gap Analysis

IAEA Technical Meeting on Back End of the Fuel Cycle Considerations for Small Modular Reactors
20 to 23 September 2022
1. Overview

National Strategy
National Strategy for net Zero

UK government white paper, 14 December 2020. Supportive of all forms of new nuclear energy

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**Large Nuclear**

We will aim to bring at least one large-scale nuclear project to the point of Final Investment Decision (FID) by the end of the parliament, subject to clear value for money and all relevant approvals.

Government "will examine the potential role of government finance during construction”

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**Advanced Nuclear**

We will provide up to £385 million on an Advanced Nuclear Fund for the next generation of nuclear technology aiming, by the early 2030s, to develop a Small Modular Reactor (SMR) design and to build an Advanced Modular Reactor (AMR) demonstrator.

“As the first major commitment of the programme, in 2021 we will open the Generic Design Assessment to SMR technologies”

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**Fusion**

We aim to build a commercially viable fusion power plant by 2040.

“The government has already committed over £400 million towards new UK fusion programmes”

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**Hydrogen**

We will publish a dedicated Hydrogen Strategy in early 2021 which positions the UK as a world leader in the production and use of clean hydrogen.

“A variety of production technologies will be required to satisfy the level of anticipated demand for clean hydrogen in 2050. This is likely to include methane reformation with CCUS, biomass gasification with CCUS and electrolytic hydrogen using renewable or nuclear generated electricity.”

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**Net Zero Innovation Programme (NZIP)**

£100 billion

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2. Status

Generation and Fuel Cycle
Advanced Nuclear (1)

- UKSMR, aims to deliver a first of a kind LWR-based (400+ MW) reactor in UK before 2030. Work is underway to prepare for GDA submission and siting, design and prepare for novel manufacturing and construction approaches.

- The UK government funded Advanced Modular Reactor competition has recently been completed. This funded early engineering (phase 2) development:
  - U-Battery: Prismatic HTGR micro reactor
  - Westinghouse: Generation IV lead-cooled fast reactor (LFR)
  - Tokamak Energy: High temperature superconducting magnets and divertor technologies

- Regulatory advice on the application of the Generic Design Assessment process to novel reactor designs has been issued.
The UK government has identified high temperature gas reactors as a technology that could contribute significantly to UK decarbonisation and is funding an R&D programme to have the options for HTGRs to contribute to the 2050 Net Zero target.

A three phase development program has been approved to accelerate concept development with a view to having an operational reactor in the early 2030s.

Evaluation of phase 1 bids is underway

An Advanced Nuclear Skills and Innovation Campus has been established to build capacity required to support anticipated nuclear build programmes.
Spent Fuel Management Policy

- Spent fuel management is a matter for the commercial judgement of its owners, subject to meeting the necessary regulatory requirements.

- The UK has transitioned to an Open Fuel Cycle, however the option for a future transition to a Closed Fuel Cycle remains open.

- The UK Geological Disposal Facility is intended to be capable of receiving all the spent fuel and vitrified waste from UK research and test reactors, closed Magnox reactors, current power reactors and 16 GWe of new power reactors.
Reprocessing

- Oxide fuel reprocessing ended in 2019, completing mission for which THORP was designed. ~20,000 tHM reprocessed.

- Magnox reprocessing ended in July 2022. ~ 55,000 tU metal fuel will have been reprocessed.

- Investment in reprocessing technology continues through BEIS Nuclear Innovation Programme to enable UK to restart reprocessing if domestic fuel use makes recycling attractive.

- Medium term energy strategy currently includes scenarios which include reprocessing.
Spent Fuel Storage (1)

Gas cooled reactors

- All Magnox reactors have been defueled and reprocessing has been completed. A small quantity of Magnox fuel remains in pond where it will be stored for several years before being moved to vented dry storage as higher priority legacy Magnox transfers to dry storage are completed.
- AGR fuel will continue to be consolidated and consigned to pond storage in an existing facility for at least 25 years, when a decision on longer term storage will be made. It is expected that this fuel will remain in pond storage until it is exported for disposal towards the end of the century.

Light water reactors

- Fuel at Sizewell continues to be consigned to DSCs for long term storage, pending disposal.
- HPC (and SZC) are being developed on the basis of an open cycle but recycle options are not precluded. Dry storage in DSCs is expected to be default option for long term storage.
Other fuels and SNM

- Exotic fuels will be consolidated at Sellafield for storage pending disposal. Storage arrangements will vary depending on fuel characteristics, but will use existing facilities as far as possible.
- Consolidation of Pu stocks at Sellafield is now complete. This material will remain in long-term safe and secure storage at Sellafield. NDA is working with the UK government to determine the right approach for putting this nuclear material beyond reach. Currently both reuse and disposal options are being considered.
Geological disposal of higher activity radioactive waste is UK Government policy, covering:
- High and Intermediate level waste
- Fuel declared as waste

Nuclear Waste Services (formerly RWM) will be the developer of the disposal facility.

GDF site selection is based on voluntarism and partnership - starting with local communities expressing an interest, with no commitment.

Expressions of interest period started December 2018 and four community partnerships have been established to date
- 3 in West Cumbria (Sellafield)
- 1 in Lincolnshire

Earliest spent fuel disposal expected ~2075

3. Regulation

Regulation of spent fuel management and disposal for Advanced Nuclear
Legal Framework

Justification

Legislation

Regulation

New reactors justified with open fuel cycle

Licenses
Permits
Modifications

Health and safety
Environmental
Transport
Security
UK Generic Design Assessment Process

• Generic design approval prior to site specific-licensing
• SNF management strategy, including -on-site storage -transport infrastructure -disposition
• Design and operational safety cases
• Integrated waste strategy
• 4 Stage application process reflecting design development
• Fuel cycle definition required at all stages of GDA process, with commensurate levels of detail
Advanced Nuclear

AMR Feasibility and Development Programme requirements included

- SNF management strategy
- SNF disposition option
- Demonstrate understanding of challenges for back-end management strategy, including
  - Storage (short & long term, on or off site)
  - Transport
  - Recycle (if appropriate)
  - Packaging
  - Disposability
- Generic Design Assessment to follow
Addressing Disposability

Disposability assessment process provides

- Stakeholder confidence that materials can be packaged in a manner that is compliant with GDF design assumptions.
- A route to adapt GDF concept/design if required.
- Integration with licensing/permitting processes

3. Summary

Regulating the back end of the fuel cycle for SMR
Summary

• UK remains committed to nuclear power as a key technology for meeting net zero commitments by 2050.

• New large LWR reactors are under construction and planned to replace existing reactors that are expected to cease generation by the end of this decade.

• The UK is supporting development of a range of SMR and advanced nuclear technologies, with anticipated implementation starting in the early 2030s.

• UK is now operating an open fuel cycle. Reprocessing remains an option if economically and environmentally attractive.

• Management of current fuels is mature and consistent with national strategy.

• The siting process for a deep geological disposal facility is underway with four candidate community partnerships having been established.

• UK regulation provides mechanisms that ensure appropriate consideration of the whole fuel cycle through development, licensing, operation and modification of reactors and fuels.
4. HTGR fuel management

Technological options and challenges
High Temperature Gas-cooled Reactor (HTGR)

Concept

- High temperature output: 700 °C - 950 °C
  - Heat used in other industrial processes
- Coolant: Helium
- Fuel: Coated Particles
  - Uranium oxycarbide or Uranium dioxide
  - Overcoated with carbon and silicon carbide
  - Tristructural-Isotropic (TRISO) particles
- HTGR core design:
  - Prismatic
  - Pebble bed
Considerations for baseline case

What needs to be managed?

Fuel components of a prismatic core

- Fuel kernel
- Fuel coating layers
- Fuel compacts
- Fuel rods
- Fuel element

High heat generating components
Intermediate heat generating components

How is it going to be stored/disposed of?

Fuel components in a dry sealed system as per LWR fuels.
The technological options

1. Non-dismantling: Co-disposal of fuel components and graphite materials.
   - Lower volumetric heat due to presence of graphite.

2. Dismantling: Core component separation.
   - Lower volume of material with a higher volumetric heat generation.

Qualitative assessments concluded that whole-element disposal have reduced environmental impact and reduced costs.
5. Gap analysis

Approach and findings
Methodology for evaluation of knowledge gaps

Baseline

- No dismantling
- Fuel behaviour only
- Dry Storage System as per LWR fuel

The importance of the research needs was evaluated and ranked
Example of evaluation process

SiC corrosion (aqueous)

Impact on safety function
- Criticality: 1
- Containment: 1
- Shielding: 0
- Thermal: 0
- Structural Integrity: 0

Impact on operational phase
- Normal Storage: 0
- Accident conditions during storage: 0
- Normal transport: 0
- Accident conditions during transport: 1
- Emplacement: 0
- Disposal: 2

Initiation: L
Propagation rate: L
Degradation or failure: L

Overall knowledge ranking: L
Gaps related to the fuel kernel

Low Priority:

- Oxidation (gaseous)
- Corrosion (aqueous)
- Fission gas release
- Helium release

Gaps related to the fuel containment layers

High Priority:
- PyC corrosion (aqueous)
- SiC corrosion (aqueous)

Medium Priority:
- Fission product migration
- Helium Pressurisation
- PyC oxidation (gaseous)
- SiC oxidation (gaseous)

Low Priority:
- Fission Product Attack on layers
- Propagation of existing flaws

Gaps related to the fuel compact and elements

Medium Priority:
- Oxidation (gaseous)

Low Priority
- Corrosion (aqueous)

Key knowledge needs to underpin storage and fuel disposal

Current priorities are associated with determining the conditions under which several degradation phenomena may be of concern, principally:

- Longevity of TRISO containment layers in groundwaters.
- Oxidation of TRISO containment layers and fuel graphite components.
- Effects of He pressurisation on the increase of failed fuel proportion during timescales relevant for long-term storage and disposal.
- The extent of fission product migration into and through TRISO containment layers.

It is anticipated that further research needs will be identified as the depth of assessment is developed.
Recommendations

• A research plan needs to be developed to support storage and (if necessary) disposal of HTGR spent fuel.

• Assessments on the degradation phenomena of HTGR components for pebble bed reactors (in the case these are to be deployed).

• Define research activities required to address the priority R&D topics.

• Integration of spent HTGR fuel in storage, transport and disposal into fuel qualification programmes to minimise overall costs.
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