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

NATIONAL NUCLEAR LABORATORY

1. Overview

National Strategy

National Strategy for net Zero

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

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"

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"

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"

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 of nuclear generated electricity."

https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

Net Zero Innovation Programme (NZIP)

£100 billion

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.

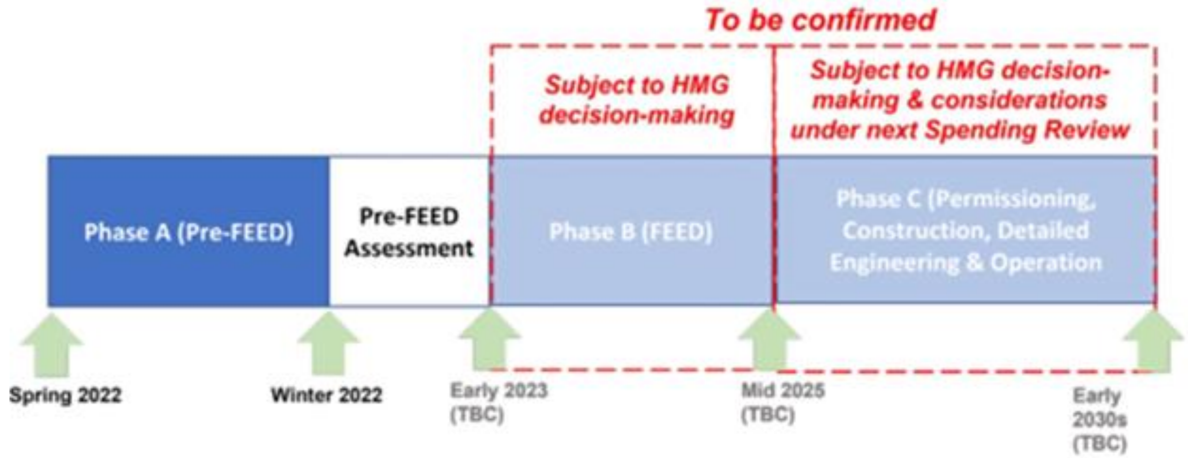
- The UK government funded Advanced Modular Reactor competition has recently been completed. This funded early engineering (phase 2) development :

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.

Advanced Nuclear (2)

- 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



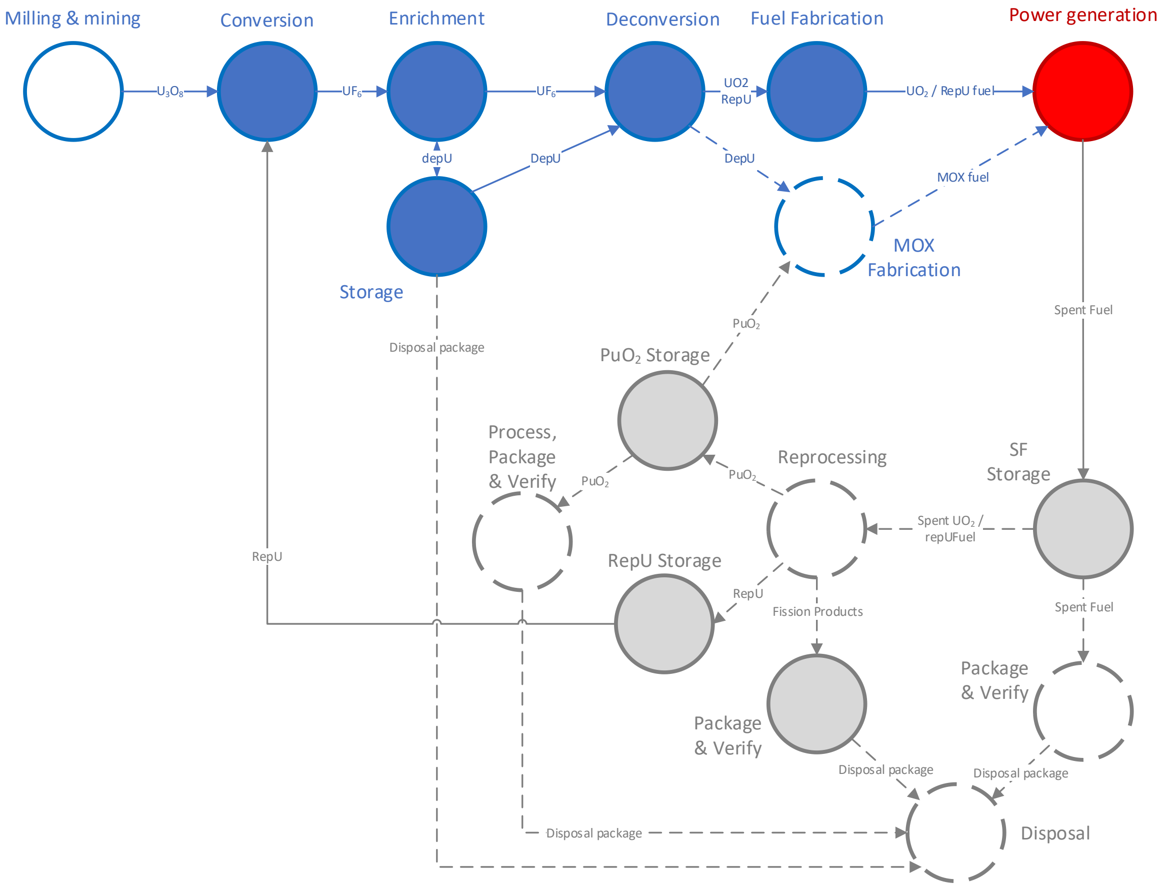
- An Advanced Nuclear Skills and Innovation Campus has been established to build capacity required to support anticipated nuclear build programmes.

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.



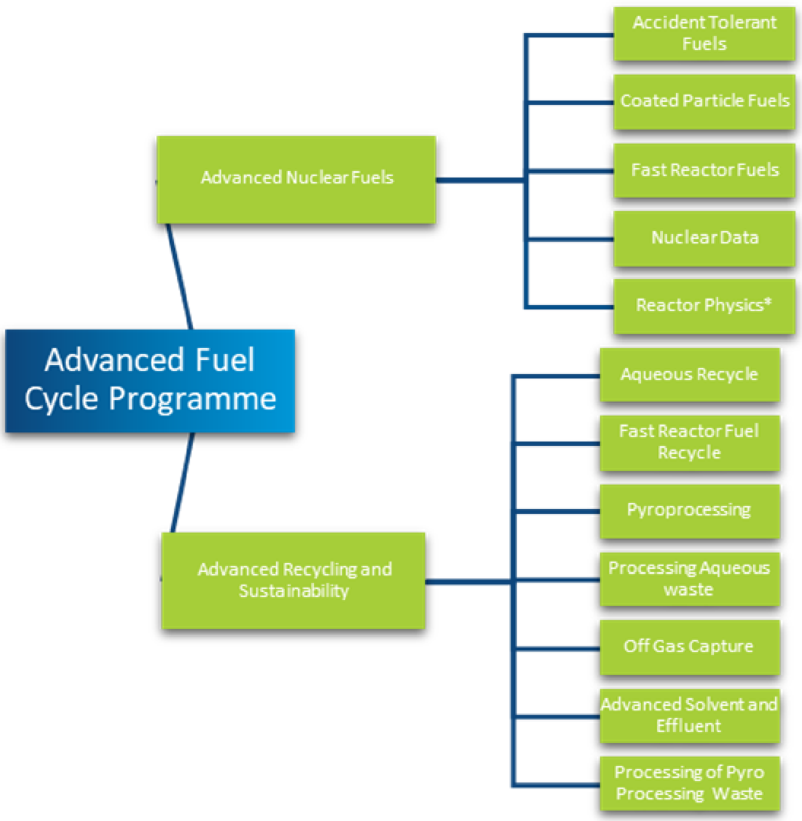
Reprocessing

- 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)

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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.

Spent Fuel Storage (2)

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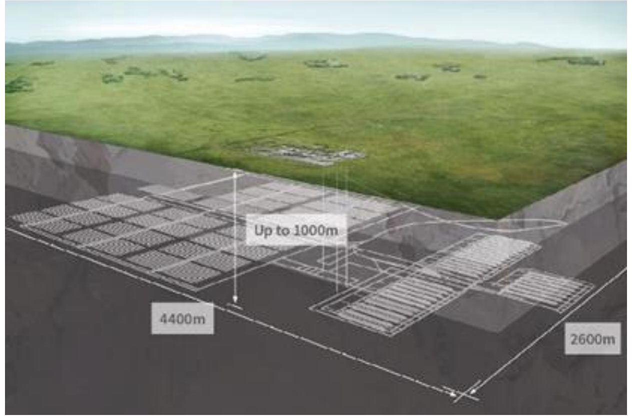
Other fuels and SNM

- 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

Disposal

- 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

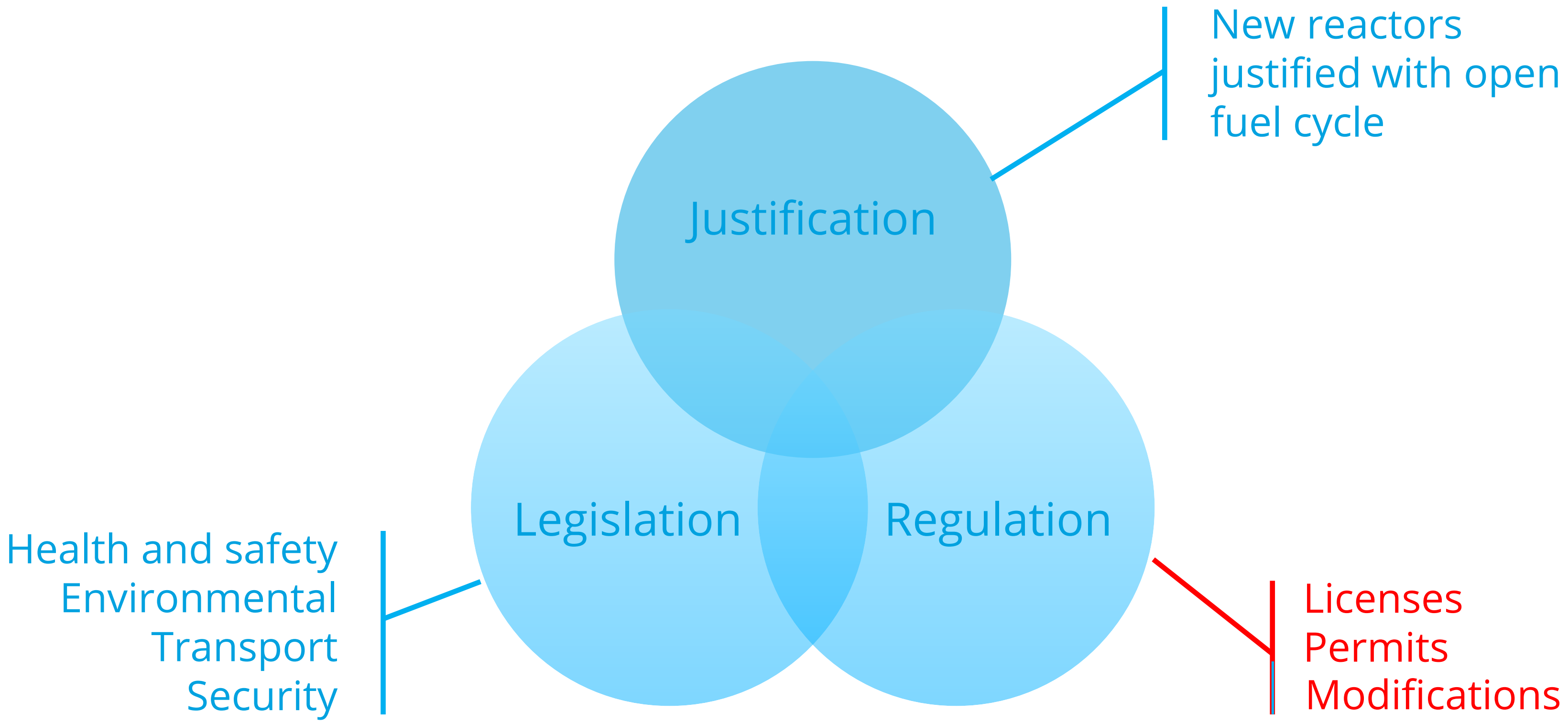


(Ref: Nuclear Decommissioning Authority. Geological Disposal - Steps towards implementation, Executive Summary March 2010, ISBN 978 1 84029 402 6)

3. Regulation

Regulation of spent fuel management and disposal for Advanced Nuclear

Legal Framework



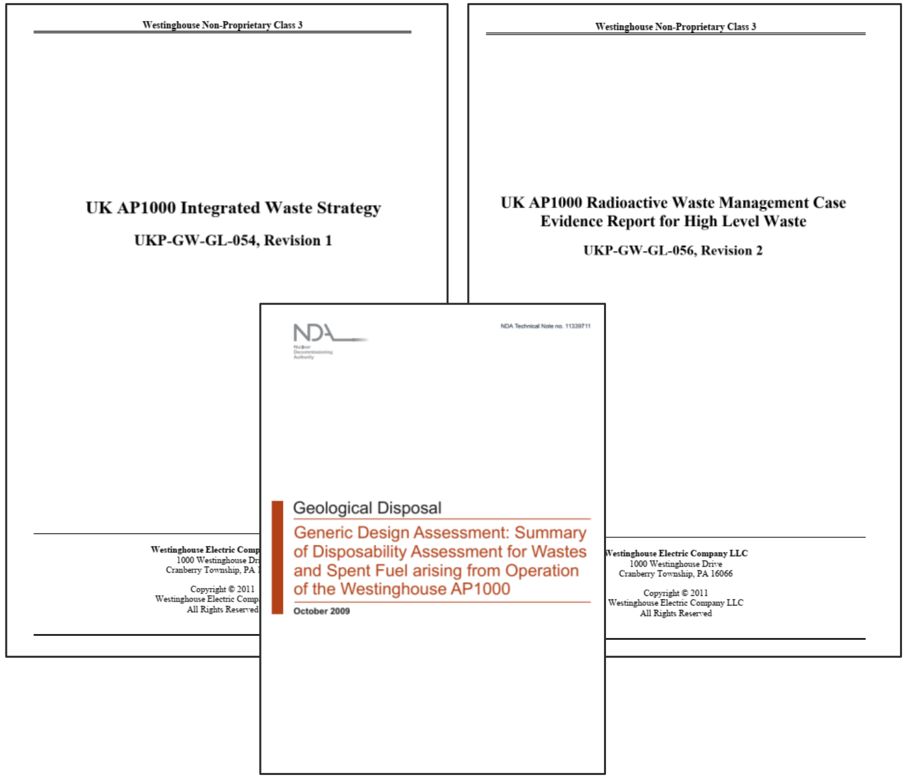
Not protectively marked

Large Nuclear

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


ONR Office for Nuclear Regulation

SAFETY ASSESSMENT PRINCIPLES FOR NUCLEAR FACILITIES
2014 EDITION, REVISION 1 (JANUARY 2020)

ONR Office for Nuclear Regulation

New Nuclear Power Plants: Generic Design Assessment Technical Guidance

ONR-GDA-GD-007 Revision 0
May 2019

ONR Office for Nuclear Regulation · Cyfoeth Naturiol Cymru Natural Resources Wales · SEPA Scottish Environment Protection Agency · Environment Agency

The management of higher activity radioactive waste on nuclear licensed sites

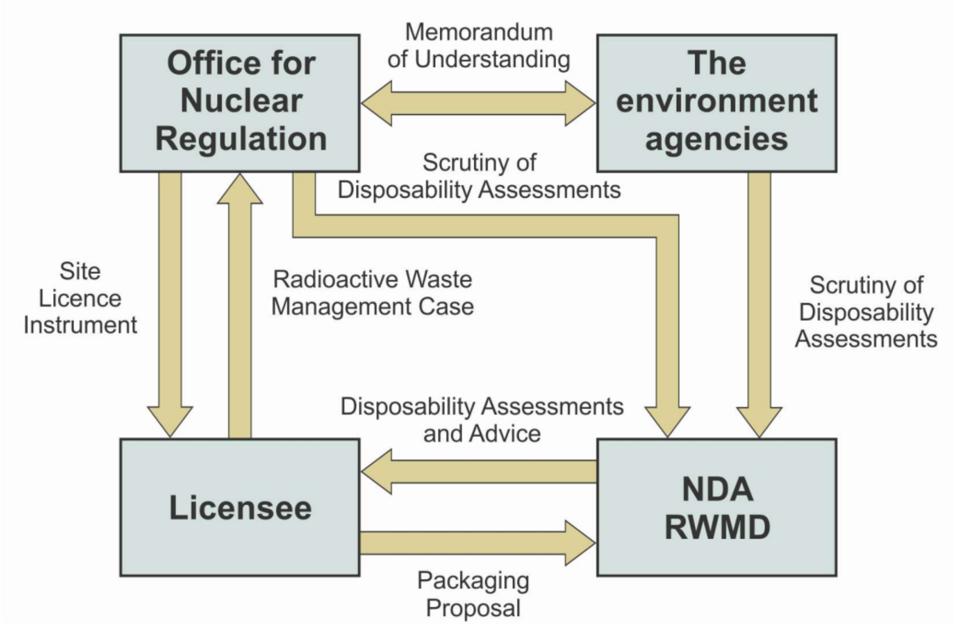
Joint guidance from the Office of Nuclear Regulation, the Environment Agency, the Scottish Environment Protection Agency and Natural Resources Wales to nuclear licensees

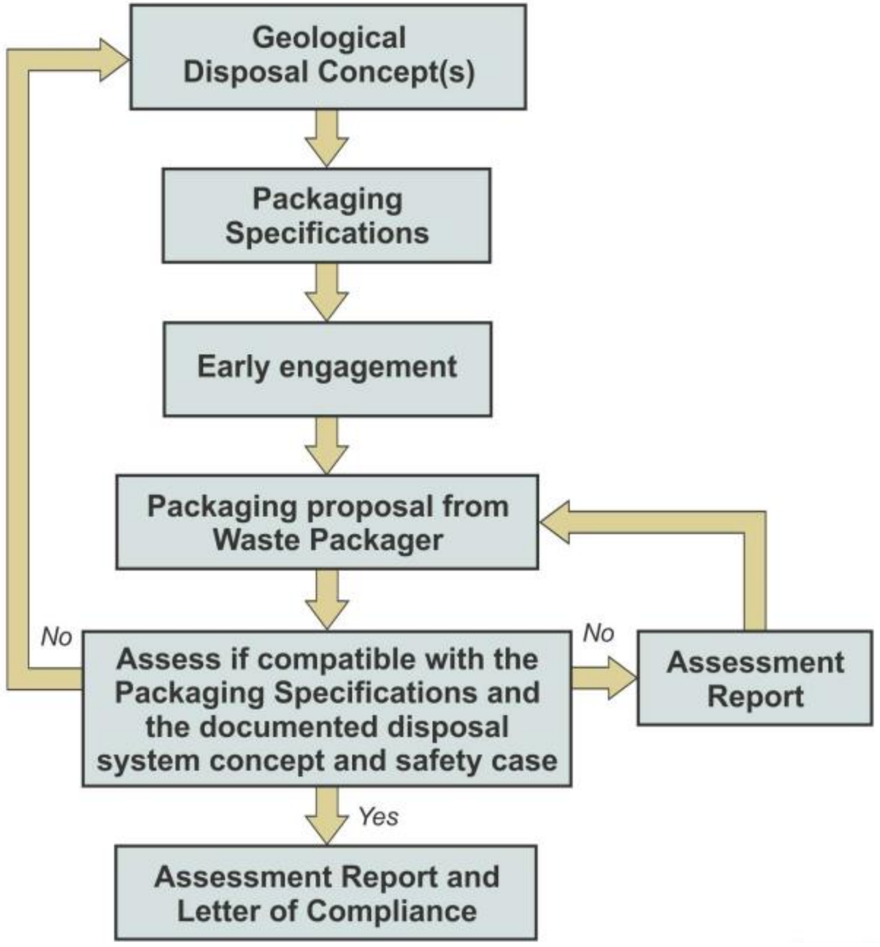
February 2015
Revision 2

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





NDA. An Overview of the RWM Disposability Assessment Process. WPS/650/03, 2014.

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.

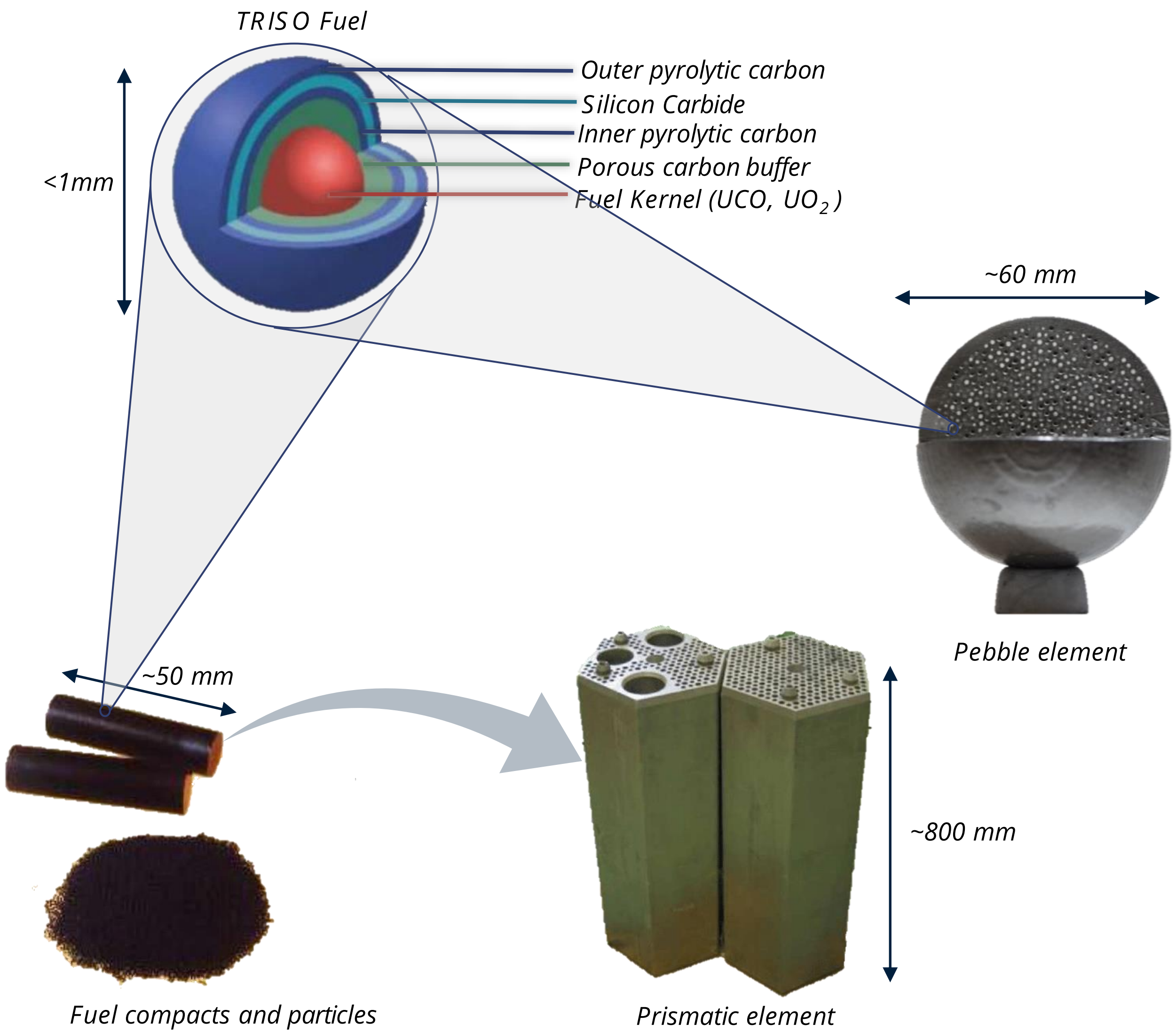
4. HTGR fuel management

Technological options and challenges

High Temperature Gas-cooled Reactor (HTGR)

Concept

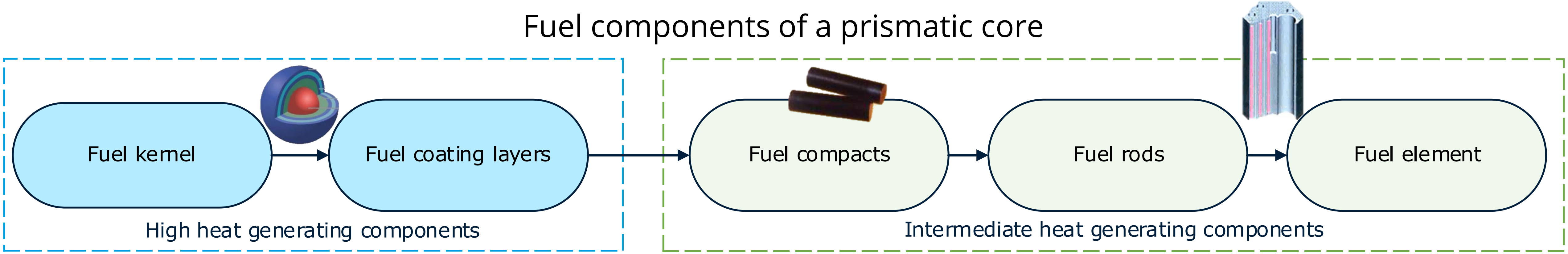
- High temperature output: 700 °C - 950 °C
  - Heat used in other industrial processes
- Coolant: Helium
- Fuel: Coated Particles
  - Uranium oxycarbide or Uranium dioxide
  - Overcoated with carbon and silicon carbide
  - Tristructural-Isotropic (TRISO) particles
- HTGR core design:
  - Prismatic
 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



Considerations for baseline case

What needs to be managed?

Fuel components of a prismatic core

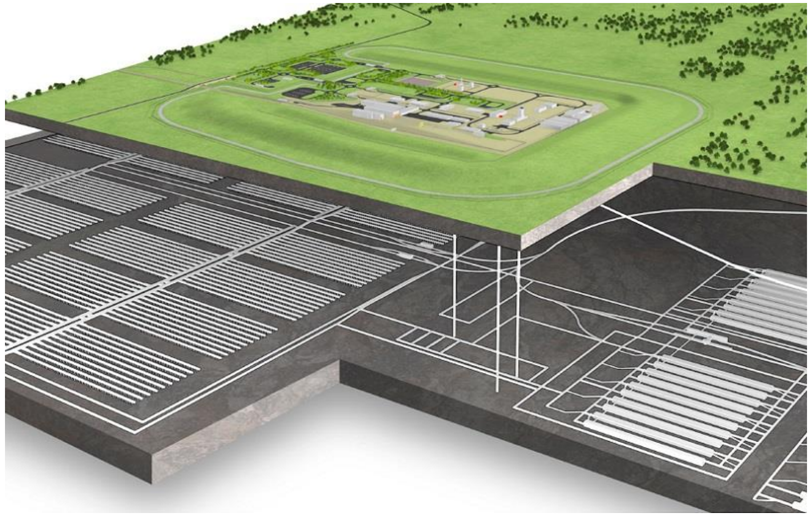


How is it going to be stored/disposed of?

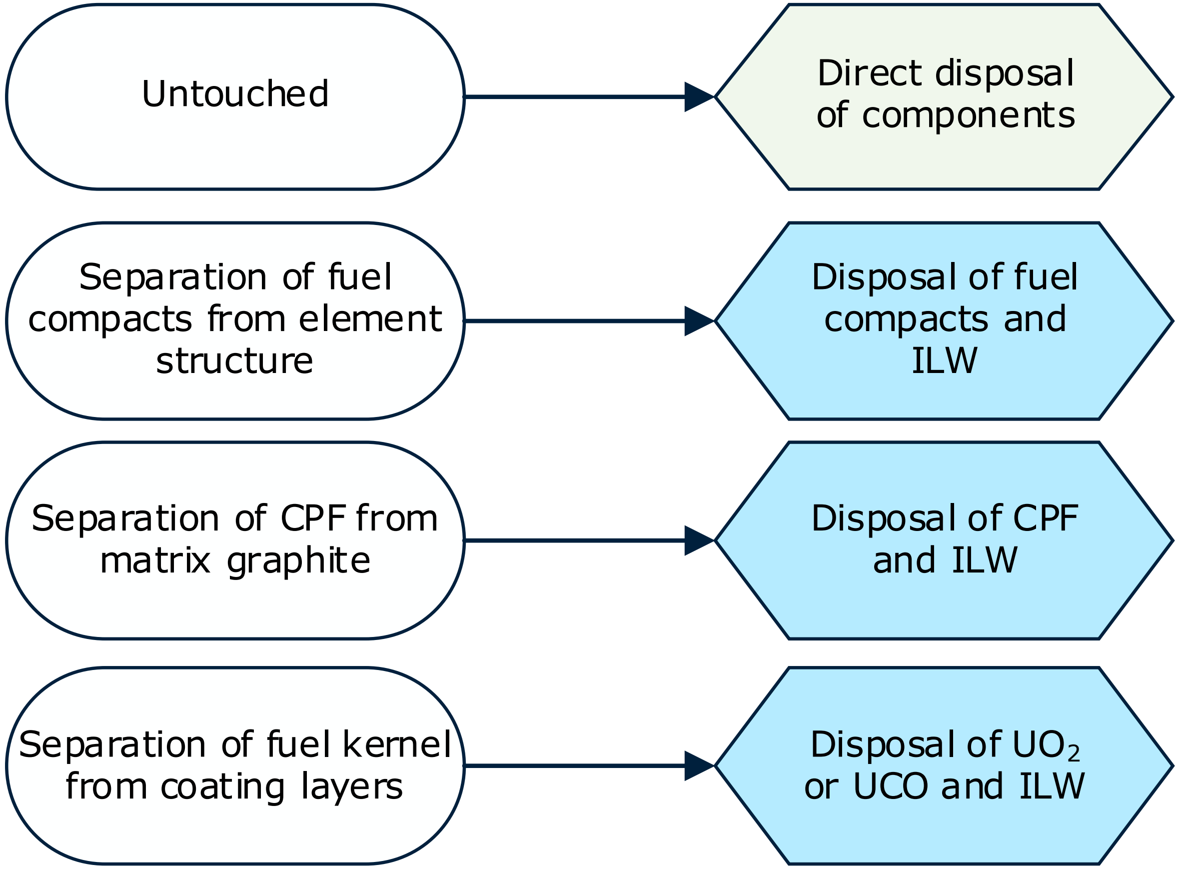
Fuel components in a dry sealed system as per LWR fuels.

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.



The UK's geological disposal concept



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

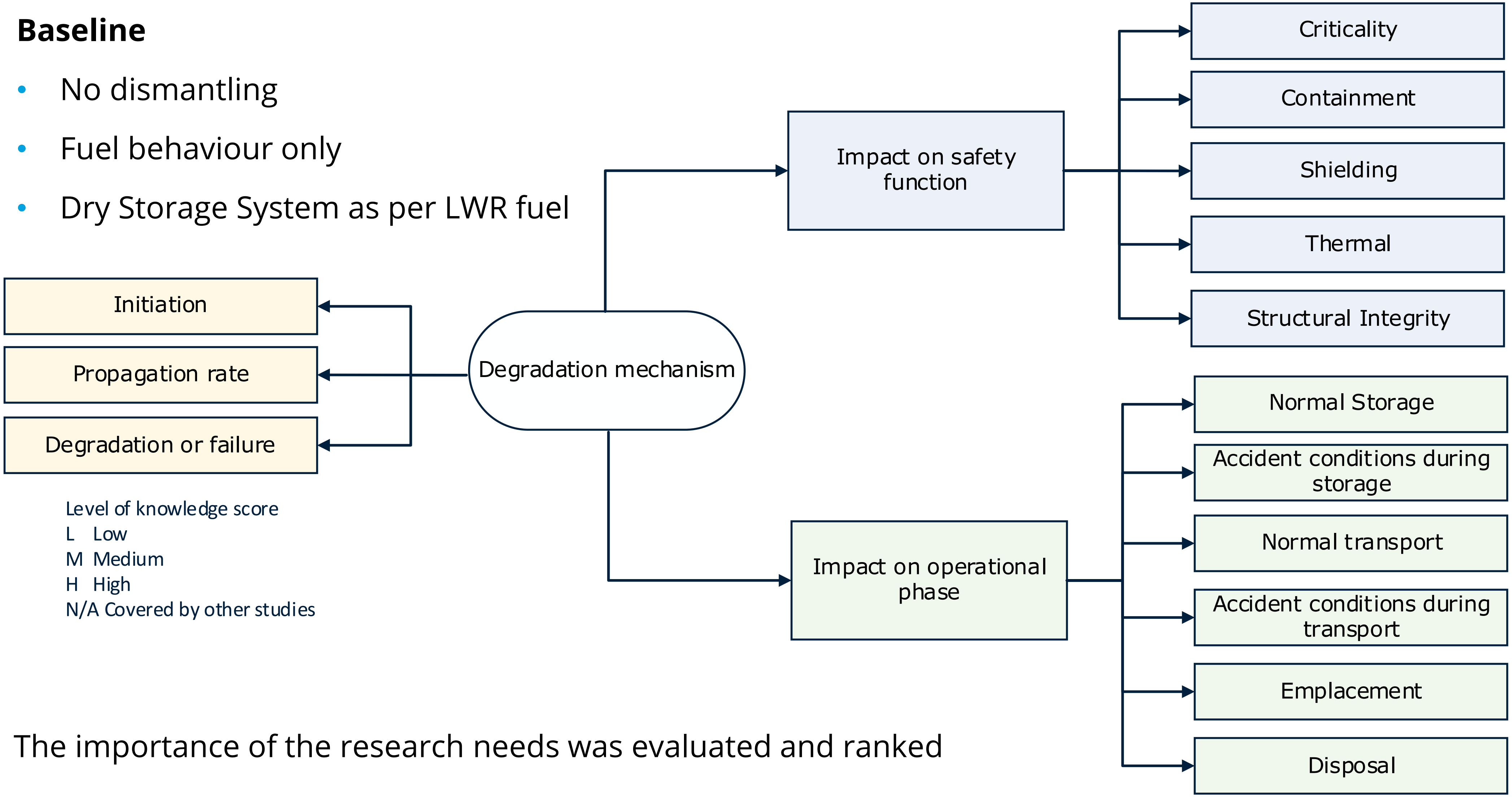
5. Gap analysis

Approach and findings

Methodology for evaluation of knowledge gaps

Baseline

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



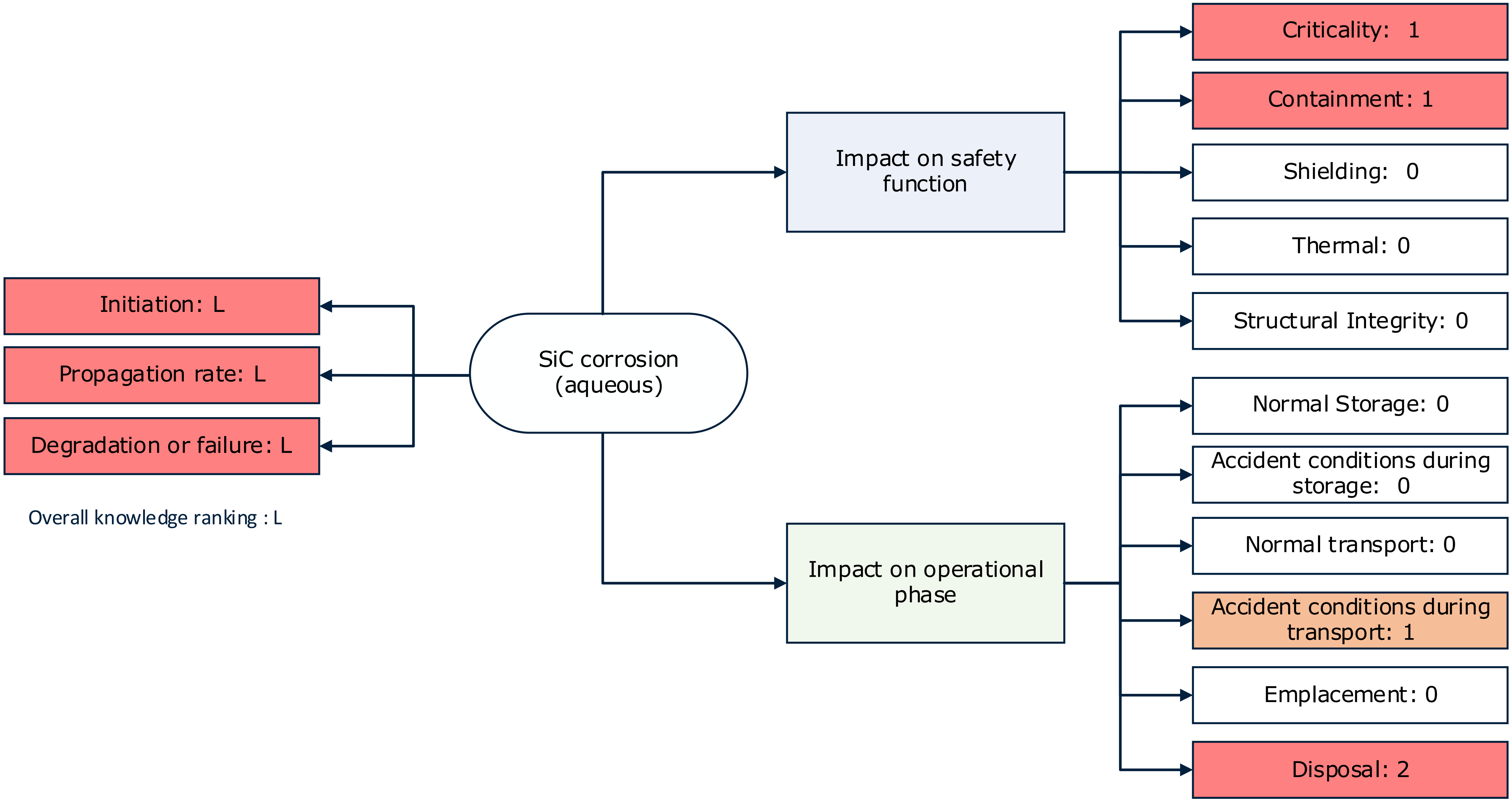
Level of knowledge score
L Low
M Medium
H High
N/A Covered by other studies

Scoring system
1 Affected
0 Not affected

Scoring system
3 Unknown
2 Significant Impact
1 Some impact
0 No/minimal impact

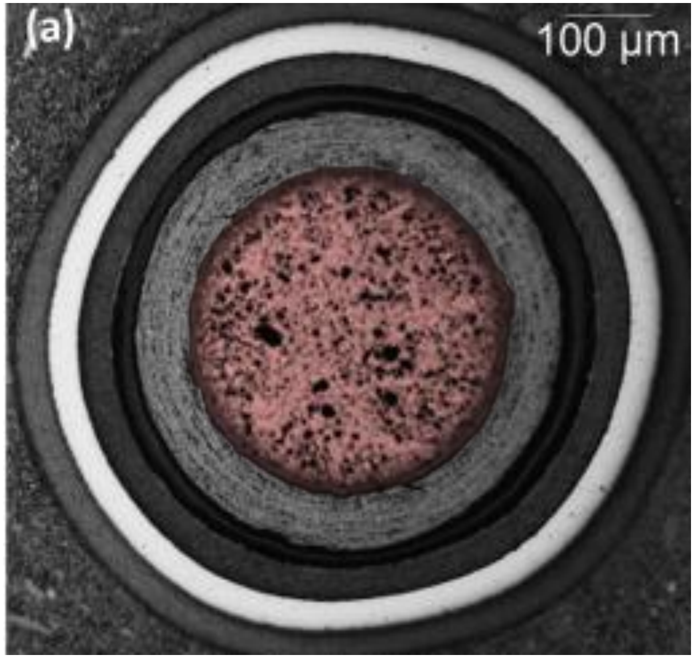
The importance of the research needs was evaluated and ranked

Example of evaluation process



Overall knowledge ranking : L

Gaps related to the fuel kernel

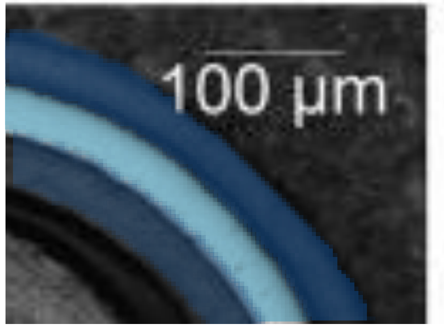


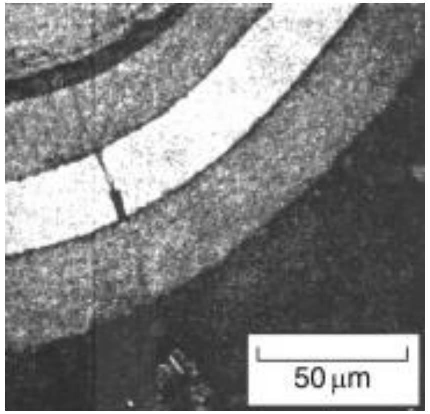
Paul A. Demkowicz, et al. TRISO-Coated Particle Fuel Fabrication and Performance,
Comprehensive Nuclear Materials (Second Edition), Elsevier, 2020, 256-333.

Low Priority:

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

Gaps related to the fuel containment layers





Paul A. Demkowicz, et al. TRISO-Coated Particle Fuel Fabrication and Performance, *Comprehensive Nuclear Materials (Second Edition),* Elsevier, 2020, 256-333.

High Priority:

- PyC corrosion (aqueous)
- SiC corrosion (aqueous)

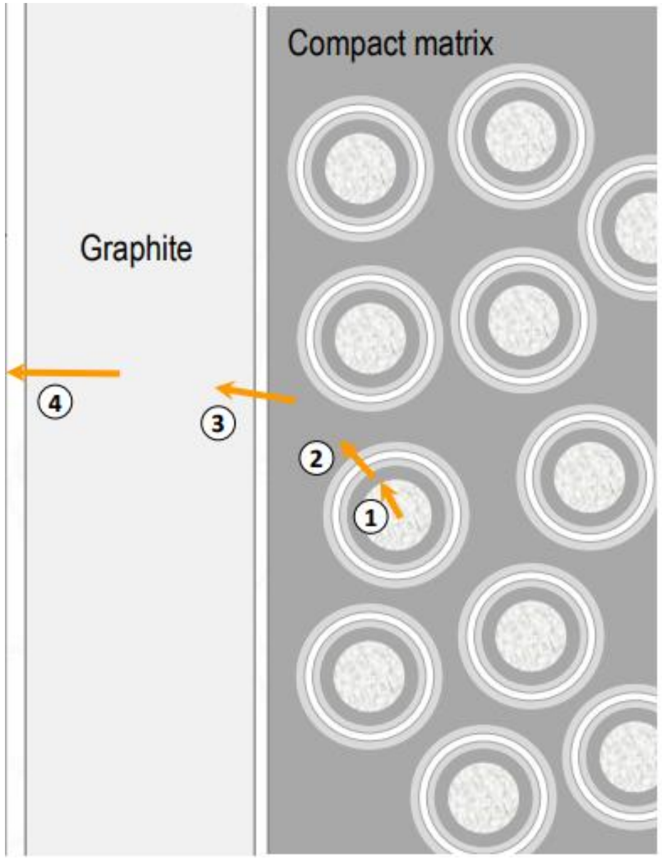
Medium Priority:

- 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



Paul A. Demkowicz, et al. TRISO Fuel: Design, Manufacturing and Performance, *Advanced Reactor Technologies*, Idaho National Laboratory, NRC HTGR Training, 2019.

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.

Acknowledgements

Department for Business, Energy & Industrial Strategy

This research was funded under the £46m Advanced Fuel Cycle Programme (AFCP) as part of the Department for Business, Energy and Industrial Strategy's (BEIS) £505m Energy Innovation Programme.

Thank you

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