Plans for management of research reactor spent fuel in Norway

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- Technical Meeting on Operating experience and Lessons Learned on Managing Non-Standard Legacy Power and Research Reactor Spent Fuels
- 18 – 21 February, 2025

Spent fuel management in Norway: key players

Ministry of Trade, Industry and Fisheries

- Funding for decommissioning and RW management

Norsk nukleær dekommisjonering (NND)

- RWMO, established 2018
- Will take over nuclear facilities and staff from IFE

DSA Norwegian Radiation and Nuclear Safety Authority

- Regulator

IFE

- Licensee
- Responsible for storage of spent fuel until transfer to NND

Institute for Energy Technology (IFE)

- Independent foundation
- Established by the Norwegian government in 1948 as Institute for Atomic Energy
- Changed name to IFE in 1980s

- 2 locations in SE Norway

- 100 M€ annual revenues

- 600 employees
- 38 nationalities

Norwegian Nuclear Decommissioning (NND)

- State Agency under Ministry of Trade
- Located in Halden
- Established by the Norwegian government in 2018. Not considered appropriate to manage RW through an independent foundation such as IFE

- At that time 2 research reactors in operation, not planned for NND to take over operating RRs
- RRs closed in 2018 and 2019. Plan changed to transfer nuclear facilities and staff (ca 200) from IFE to NND as soon as possible
- Transfer delayed due to judicial and regulatory issues, current estimate is 2025 (Halden) and 2028 (? Kjeller)

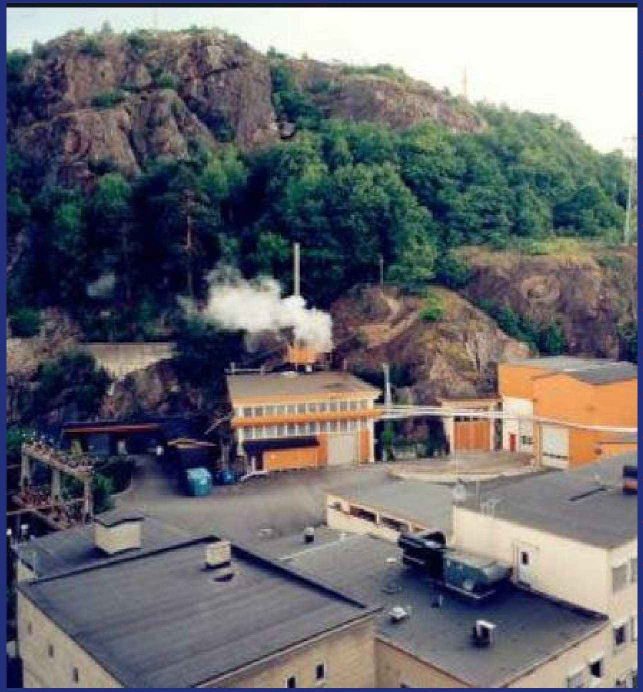
- Currently ca 40 employees

Research reactors in Norway

IFE operated four research reactors in Norway:

• JEEP I	1951 – 1967	Kjeller
• NORA	1961 – 1967	Kjeller
• JEEP II	1966 – 2019	Kjeller
• Halden Reactor	1959 – 2018	Halden

- No commercial nuclear power in Norway



Halden reactor (Halden)

JEEP II reactor (Kjeller)

Spent fuel in Norway

Only a relatively small amount (16,5 tonnes), but many types:

- Metallic uranium, aluminium clad, natural enrichment
- UO_2, aluminium clad, 3,5% enrichment
- UO_2, Zircaloy clad, up to 19,9% enrichment
  - Similar to power reactor fuel (but generally higher enrichment)
- Experimental fuel from Halden reactor, <5 to 93% enrichment
  - UO_2
  - UO_2 – Gd
  - Doped UO_2
  - MOX
  - ThO_2
  - $PuThO_2$
  - HEU-Th
  - Inert matrix fuel
  - Extruded fuel
  - Spherepac
  - Coated fuel
  - …
  - Various claddings: Zircaloy, Zry developments, steel, Al …
- Stored as assemblies and individual rods
- Failed fuel, some encapsulated in welded-shut containers
- Sectioned fuel for PIE
  - Often embodied in epoxy
- Burnup range 0,1 to >100 MWd/kg HM

JEEP I and JEEP II fuel elements

Storage experience

- Old facilities – all constructed 1950s and 1960s
- Different designs – no two facilities are the same
  - Designed and constructed to the then current standards and requirements
  - Wet and dry
- Varying condition
- Some modifications / improvements made, and others proposed
- Aging management programmes in place for some facilities, but are under revision
- Other AMPs under development
- Fuel with known failures placed in storage – but unknown extent of further failures or degradation

Development of a national strategy for SNF management

- meanwhile continuing storage

Up to 2011: Government appoints committees of experts & stakeholders

2015-2016: Choice of Concept study and review

Government decision to follow up recommendations

* NND established in 2018

NND/IFE continue work on strategy for spent fuels management

2020-2021 Choice of Concept study & review

* Reprocessing
* Dry oxidation / recladding
* Direct disposal

Review by regulator

2023 -2025

New study: Clarification phase

* Align government and regulatory requirements

Multi-criteria decision making

- Method similar to IAEA BRIDE-BASCET methodology, as practised in UK

- Options assessment panel recruited. Expertise in:
  - Workshop facilitator (non-voting)
  - Workshop secretary (non-voting)
  - Technical feasibility
  - Safety
  - Security
  - Environment
  - Regulatory and international requirements
  - Disposal
  - Transport
  - Costs

Roles and participant identification
The required roles and responsibilities will be defined and team members identified for each role.

Identify RRSNF Groups
Identify the different groups of fuel that each set of options should be generated for.

Identify options
Wide range of options will be considered. Options should be available, reliable and reasonably robust within the required timeframe for a solution.

Determining uncertainty and risks
Significant data gaps will be identified, recorded and, wherever possible, resolved through further information gathering. The assessment will clarify how uncertainties have been addressed.

Initial option screening
Short-listing of options to eliminate options that are not viable. Initial screening will use coarse screening criteria agreed by the options assessment panel.

NND review
NND will review the remaining options after the screening to ensure they are satisfied with the options to be carried forward to the options assessment workshop.

Update available options
Options and option descriptions will be updated where required following NND review; this may involve the addition of options or update/clarification of option descriptions.

Define assessment criteria
The NDA (NDA) Value Framework (VF) will be used as a basis for selecting relevant criteria; additional criteria will be added where necessary, for example, from the IAEA non-economic factors.
The Tier 1 NDA VF factors are:
- Health and Safety;
- Security;
- Environment;
- Risk and hazard reduction;
- Socio-economic impacts;
- Lifetime cost;
- Enabling the mission.

The assessment criteria for this study will be selected from the Tier 2 criteria that provide a greater focus on specific aspects of the broad Tier 1 categories.

Options assessment workshop
Weight assignment for criteria: Different criteria weighting methods can be used; a consensus will be sought from the Options Assessment Panel (OAP).
The OAP will use its collective expertise and experience to provide qualitative arguments on the advantages and disadvantages of each option against the agreed criteria.
Scores will be assigned to each option based on the balance of advantages and disadvantages.
Alternatively, a Red/Amber/Green (RAG) ranking could be used to identify poor/average/good options respectively for each criterion if a numerical scoring scheme is not used.

Sensitivity Analysis
Sensitivity analysis is carried out to test the robustness of the results in the presence of uncertainty.

Option Integration
Integrate the preferred options to determine the overall strategic option.

Options assessment report
The options assessment report presents the entire assessment process in a single report, describing the study scope, the generation and screening of options, the assessment of the viable options, including sensitivities, and generation of an options hierarchy.

Screening criteria (Yes / No)

- Does the option meet the project objectives?
- Is the option technically feasible?
- Can the option meet national policy and strategy, and all legal and regulatory requirements?
- Can implementation of the option meet the required timescales?
- Is the option clearly sub-optimal?

Assessment criteria

- Health & safety
  - Workers / public radiological & non-radiological risk
  - Nuisance
- Security
  - Waste
  - Information
- Environment
  - Discharges: radiological & non-radiological
  - Materials & sustainability
  - Non-human biota
- Risk / hazard reduction
  - Disposability
  - Radiological & non-radiological risk reduction
- Socio-economic
  - Infrastructure
  - Economic impact
- Lifetime cost
  - Costs
- Enabling the mission
  - Conceptual enablers
  - Physical enablers

Fuel groups

Group	Fuel	Cladding	Mass, kg	Enrichment, %
1	Metallic uranium	Aluminium	10 000	0,7
2	UO2	Aluminium	1 500	3,5
3	UO2	Stainless steel	< 200	1,5
4	UO2	Zircaloy	3 750	< 20
5a	UO2 with additives	Zircaloy	< 200	< 20
5b	MOX	Zircaloy	< 200	< 20
5c	Thorium fuels	Zircaloy	< 200	HEU
5d	UO2	Various	< 200	< 20
5e	«Exotic»	Various	< 200	< 20
5f	PIE residues	Various		< 20

All identified options

- Do nothing
- Storage & postponed decision
- Mechanical conditioning & direct disposal
- PUREX reprocessing
- Dry oxidation (metallic U)
- Decladding & repacking
- Melt processing
- Pyroprocessing / electrochemical dissolution
- Re-use in reactor
- Transmutation in reactor
- Encapsulation
- Return to provider

Options - after screening

Option	Sub-option
1. Storage & postponed decision	-
2. Mechanical conditioning with direct disposal	2: Supply chain
	2N: National
3. Processing	3a: PUREX supply chain
	3aN: PUREX national
	3b: Dry oxidation: Supply chain
	3bN: Dry oxidation: national
	3c: Decladding supply chain
	3cN: Decladding national

Option	Sub-option
3. Processing (national)	3d: Melt processing
4. Encapsulation (national)	4a: Bitumen
	4b: Polymer
	4c: Cement

Fuel groups vs options suitability

Fuel Groups	Fuel Groups	1. Storage and delayed decision	2. Mechanical conditioning for direct disposal	3. Processing followed by disposal				4. Encapsulation (without processing)		
		1a, 1b	2: Direct Disposal	3a PUREX	3b Dry Oxidation	3c Decladding	3d Melt Consolidation	4a Bitumen Encapsulation	4b Polymer Encapsulation	4c Cementitious Encapsulation
1	**1**	Viable	Viable with uncertainty	Viable	Viable	Non-Viable	Viable	Viable with uncertainty	Viable with uncertainty	Non-Viable
2	**2**	Viable	Viable with uncertainty	Viable	Non-Viable	Viable	Viable	Non-Viable	Non-Viable	Non-Viable
3	**3**	Viable	Viable	Viable	Non-Viable	Non-Viable	Viable with uncertainty	Non-Viable	Non-Viable	Non-Viable
4	**4**	Viable	Viable	Viable	Non-Viable	Non-Viable	Viable	Non-Viable	Non-Viable	Non-Viable
5	5a	Viable	Viable	Viable	Non-Viable	Non-Viable	Viable	Non-Viable	Non-Viable	Non-Viable
	5b	Viable	Viable	Viable with uncertainty	Non-Viable	Non-Viable	Non-Viable	Non-Viable	Non-Viable	Non-Viable
	5c (1,2,3)	Viable	Viable	Non-Viable	Non-Viable	Non-Viable	Viable	Non-Viable	Non-Viable	Non-Viable
	5c (4)	Viable	Non-Viable	Non-Viable	Non-Viable	Non-Viable	Viable	Non-Viable	Non-Viable	Non-Viable
	5d	Viable	Viable	Viable	Non-Viable	Non-Viable	Viable	Non-Viable	Non-Viable	Non-Viable
	5e	Viable	Viable	Viable with uncertainty	Non-Viable	Non-Viable	Viable	Non-Viable	Non-Viable	Non-Viable
	5f	Viable	Viable	Viable with uncertainty	Non-Viable	Non-Viable	Viable	Viable with uncertainty	Viable with uncertainty	Viable with uncertainty

Possible waste forms from SNF processing – requirement for compatibility with storage and disposal

- Fuel rods and/or assemblies after mechanical treatment placed in eg stainless steel containers
- UO_2 pellets in stainless steel tubes – from oxidation of metallic uranium or decladding
- Vitrified waste from PUREX reprocessing
- Melt processing ingots
- Waste drums with bitumen/polymer/cement encaspulation of metallic uranium fuel and/or PIE residues

Status and future work

- Production of detailed option descriptions for Assessment Panel
- Options assessment workshop
- Development of integrated options
- Reporting