Spent Fuel in Norway

IAEA TM on Spent Fuel Characterization for Management of Spent Fuel in the Back End of the Fuel Cycle
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Nuclear Reactors in Norway

The Institute for Energy Technology (IFE) operated the following research reactors in Norway:

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

• No commercial nuclear power in Norway
Halden Boiling Water Reactor (HBWR)

- Started operation in 1959
- Permanent shutdown announced 27 June 2018
- Used for fuel / materials testing
  - Determination of fuel/materials performance parameters.
  - Ca. 50% HRP, 50% bilateral
- Unique features
  - HRP – 20 countries (>100 organizations)
  - Loop systems
  - In-core instrumentation
- HRP continues without HBWR
  - Out of pile experiments, PIE, data preservation
JEEP II Reactor

• Located in Kjeller, Norway (near Oslo)
• 2 MW thermal
• D₂O Coolant (50-56 °C, 1 bar)
• Irradiation channels:
  • 7 wet + 2 dry
  • Several core positions
• Latest uses:
  • Neutron beams
  • Silicon doping
  • Irradiation of concrete (instrumented rigs)
  • Production of small quantities of medical isotopes (for research)
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Spent fuel in Norway

Only a relatively small amount (compared to nations with commercial nuclear power): 17 tons

However, there are many types of fuel:

- Metallic U, Aluminum cladding, natural enrichment
- $\text{UO}_2$, Aluminum cladding, ca 3% enrichment
- $\text{UO}_2$, Zircaloy cladding, up to 19.9% enrichment
- $\text{UO}_2$-Gd
- Doped $\text{UO}_2$
- MOX
- $\text{ThO}_2$
- $\text{PuThO}_2$
- Failed fuel
- Failed fuel, encapsulated in welded-shut containers

Fuel Storage:

- Many different spent fuel pools, pits, dry storage racks.
- Last core loading in Halden reactor is still in the core due to shortage of storage locations.
- JEEP I stavbrønn – pit in the ground, covered by a shed.
Corrosion has been found in some locations:

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Norwegian Nuclear Decommissioning

- Established in 2018
- Mandate: Decommission Norway’s nuclear facilities, and handle Norway’s nuclear waste (including the spent fuel)
- NND to take over ownership and operating licences of IFE’s nuclear facilities starting in 2021.
Plans for Spent Fuel Disposal

• Currently, Norway (NND) has not concluded on the final disposal route for Norways spent fuel

• Possible options:
  • Reprocessing (abroad)
  • Geological repository in Norway.
  • Interim (wet and/or dry) storage
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• Comply with the guidelines in IAEA’s SSG-40 “Predisposal Management of Radioactive Waste from Nuclear Power Plants and Research Reactors”.

• In this context, characterization refers to collating of information describing the condition of the spent fuel to such a degree, such as to completely facilitate all aspects of pre-disposal management.

• The behaviour and stability of the waste during the anticipated storage period is determined (1.9)

• Waste acceptance criteria for the storage, transport and postulated disposal routes are developed. (3.21. c)

• The information recoded is sufficient to demonstrate compliance with downstream waste acceptance criteria (3.21. g)

• The information needs to be managed so that it is available to support future disposal routes (which may occur decades after waste generation). (3.21. f)

• Characteristics should be recorded to allow management of the storage facility with respect to the waste’s activity, heat generation and potential for criticality (3.21. l)

• Establish requirement for training and qualification of staff and contractors (3.22.)

• Establish acceptance criteria and confirmation of conformance with the acceptance criteria.

• Records related to the waste should be stored in such a way as to minimize the consequence of accidental loss of information (e.g. from fire, flood). (4.18)

• The uncertainties in the information describing the waste characteristics should be determined. (5.7)

• The characterisation process should include the measurement of physical and chemical parameters. (6.19).
Process

1. Identify all relevant interests and their requirements for information. These include:
   - IFE
   - NND
   - DSA
   - Future relevant organizations, e.g.
     - Orano
     - Studsvik
     - GNS
     - Etc.

2. Identify available information on spent fuel and other fissile material

3. Evaluate the adaptation of available information to the requirements.

4. Identify measures (calculations, inspections) to address deficiencies in information. For example, review of documentation and subsequent calculations and/or measurements. Deficiencies in information may include:
   - Evaluation of cladding (aluminum, Zircaloy) condition as a result of e.g.
     i. Irradiation effects
     ii. Corrosion / erosion
   - Evaluation of fuel pellet condition

5. Verify that the requirements are met

6. Verify that the methods are satisfactory (for example, burnup calculations)

7. Verify results

8. Ensure that all relevant information is included in a database
Facilities for inspecting fuel

Hot cells (Kjeller)

Shielded compartments (Halden)
Non-destructive Examinations

- Visual inspection
- High-resolution macro photography
- Profilometry and dimensional measurements
- Eddy current
- Gamma Scanning
- Gamma tomography
- Neutron radiography (using the JEEP II reactor)
Destructive Examinations

- Rod puncturing and fission gas analysis (mass spectrometry: He, Kr, Xe)
- Metallographic preparation
- Light Optical Microscopy
- Scanning Electron Microscope (SEM) / Energy Dispersive Spectroscopy (EDS)
- Thermogravimetric analysis
- Hydrogen/oxygen measurements
- Mechanical testing (tensile, compressive strength, microhardness)
- Thin-slice LOM
- x-ray diffraction
- Density measurement of fuel pellets
Designed for:
• determining e.g. Radial power distribution
• quantitative analyses.

• HPGe detector (1)
• Fuel rotates
• Detector/collimator translate laterally
• Automated measurements
Gamma Emission Tomography
Imaging of fuel internal radioactive source distribution
Reconstructions from 9-rod Assembly

- $^{137}$Cs (662 keV)
  - $T_{1/2} = 30.08$ years
  - Fission product
  - Migration to pellet outer surface

- $^{154}$Eu (1274 keV)
  - $T_{1/2} = 8.60$ years
  - Fission product
  - No migration to pellet outer surface

- $^{125}$Sb (428 keV)
  - $T_{1/2} = 2.76$ years
  - Activation product in structural tie rods

- $^{85}$Kr (514 keV)
  - $T_{1/2} = 10.08$ years
  - Gaseous fission product (in fuel rod gas plena)
Reconstructions from 9-, and 13-rod Assemblies

- $^{154}\text{Eu}$ (874 keV)
  - $T_{1/2} = 8.60$ years
  - $\sim35$ counts in largest single peak!
  - Only high-burnup rods visible

- $^{134}\text{Cs}$ (796 keV)
  - $T_{1/2} = 2.07$ years
  - $\sim35$ counts in largest single peak!
  - $\sim10$ half-lives

- $^{144}\text{Ce}/\text{Pr}$ (2186 keV)
  - $T_{1/2} = 0.78$ years
  - Fission product

- Uranium X-rays (98 keV)
  - “Shadows” from structural tie rods visible.
%FGR Using Gamma Tomography (Relative Quantitative)
Dry Storage Testing

• Aim is to investigate effects of cladding temperatures and hoop stresses representative of dry storage conditions.

• Test setup:
  • 8 fuel rod positions
  • Electrical heaters to control temperature

• Measurements
  • Temperature (online)
  • Fuel rod internal pressure (online)
  • Fuel rod diameter (during interim inspections)

• Experiment startup in Q1 2020
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Knowledge / Information Management

- Currently determining needs for information and gathering existing information on all spent fuel
- Experimental fuel data preserved in Halden Reactor Project Legacy Database (part of HRP)
- Driver fuel information will also stored in a (separate) database.
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