The Swedish Nuclear Fuel Management Programme
2018-01-24
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Nuclear Sweden

- 10 (12) operating reactor units at 3 sites
- ~45% electricity
- 12,000 tonnes of spent fuel total program

- **SFR**; Final Repository for Short-lived Radioactive Waste
- **Clab**; Central Interim Storage Facility for Spent Nuclear Fuel
Funding of decommissioning and waste management in Sweden

Owners

VATTENFALL

FORSMARKS KRAFTGRUPP

e.on

okg

Financing

0.04 SEK per kWh of nuclear electricity

About 56 billion SEK in 2014
Our owners

- Vattenfall AB 36%
- OKG Aktiebolag 22%
- Forsmark Kraftgrupp AB 30%
- Sydkraft Nuclear Power AB 12%
New Swedish government

- The general elections in Sweden in September 2014 gave the Sweden Democratic Party 13% of the vote, up from 6.7%.
- Sweden Democrats immigration sceptical party
- No other party prepared to collaborate or talk to them
- Left wing minority government formed
- The new governments budget fell; opposition’s budget law
- Prime minister called for new extra election to be held in March 2015
- Just before new year extra election cancelled after agreement between all partied except Sweden Democrats
- In the agreement the right wing parties will not oppose present governments budgets in the next 4 years, and the same principle the 4 years after that – this was cancelled autumn 2015
- Government makes several decisions important for nuclear power, such as decides the tax to the nuclear waste fund
• Vattenfall announced a last year intention to close two reactors, Ringhals 1 and 2; increased taxation stated as one reason

• Oskarshamn 1 and 2; Eon has announced these be shut down as well

• Oskarshamn 2 will not be restarted; emptied by beginning of 2017

• Thereafter Oskarshamn 1 will follow

• Fee to nuclear waste management fund recalculated by authority (SSM) for period 2015-2018 for Oskarshamn’s power plants

• New energy agreement between ’regular’ parties summer 2016: special nuclear power tax to be gradually abolished

• This should save remaining 6 reactors in operation
Transport system

1. Final repository for short-lived radioactive waste (SFR)
2. Interim storage facility for spent nuclear fuel (Clab)
SFR
Final repository for short-lived radioactive waste

Integrated facility after extension

License application submitted in 2014

Approximately 130 000 m$^3$ of which 50 000 m$^3$ ILW
Licensing for KBS-3 – Current status
Siting of the repository for spent nuclear fuel

Knowledge accumulation

Study sites 1977-1985
General siting studies 1990s
Feasibility studies 1992-2001
Site investigations 2002-2007
Licensing ca. 2011-2020
Construction ca. 2020-2030

Siting process

Hultsfred
Malå
Nyköping
Oskarshamn
Storuman
Tierp
Älvkarleby
Östhammar

Oskarshamn (Laxemar)
Östhammar (Forsmark)

Decision on site 2009
License application submitted March 2011 for

- Spent Fuel Repository at Forsmark
- Encapsulation plant in Oskarshamn

Map showing locations of facilities.
SKB is applying

- To continue interim storage of spent nuclear fuel and reactor core components. The amount of spent nuclear fuel may reach a maximum of 8000 metric tons (calculated as uranium).

- To construct and operate a facility (Clink) to store spent nuclear fuel and core components and for encapsulation of spent nuclear fuel. Capacity of approximately 200 canisters per year.

- To construct and operate a facility for final disposal of spent nuclear fuel and nuclear waste (construction material in the fuel assemblies)
  - Final disposal of the spent fuel that is currently stored in Clab and
  - Future fuel that will arise from operating the ten reactors that currently have a permit to operate

- Final disposal according to the KBS-3 method with vertical placement of the canisters (KBS-3V)

- Water operations that are needed to build and operate the facilities

- Storage for rock aggregate
Licensing review according to Nuclear Act and Environment Code

SKB’s three applications

One according to Environmental Code

Two according to Nuclear Act

Review/Court hearings

Review

Approves or disapproves

Decides

Permit and conditions

Approves Safety Report
KBS-3 licensing review

- Environmental court announced in December 2015 that they will declare the license application complete
- Expected SSM will do the same – the formal review can begin
- May 2016: SSM wrote a largely positive report to the Environmental court.
- Around 400 comments and questions to be handled; not all of a very serious nature
- Hearings by the Environmental court took place autumn 2017, 4 weeks over 2 months
- Judgement delivered today January 23 2018
- Referendum in Östhammar municipality March 4, 2018, if yes from Environmental court.
- SSM gave recommendation to government earlier on Jan 23 – basically a ‘yes’.
- SKB hope the Swedish government can give construction permit in 2018
- Around 2030 planned operation of final repository

- Finland got government approval to start construction of their KBS-3 repository autumn 2015
- Finland now almost 10 years ahead of Sweden in time schedule. Mostly due to the fact that the Finnish time schedule is set in law
Judgement by Land and Environmental Court
January 23, 2018

Judgement by Land and Environmental Court, Nacka (My translation)

The facilities can be approved if

1. SKB submits documentation that shows that the final repository facility in the long term fulfills the requirements of the Environmental Act, despite uncertainties that remains about the protective capacity of the canister that is affected by
   a. Corrosion caused by reactions in oxygen-free
   b. Pit corrosion caused by reactions with sulphide, including the effect of the sauna effect on pit corrosion
   c. Stress corrosion caused by reactions with sulphide including the sauna effect on stress corrosion
   d. Hydrogen embrittlement
   e. Influence of radioactive radiation on pit corrosion, stress corrosion and hydrogen embrittlement.

2. It is made clear who is responsible according to the environmental act for the final repository facility in the long term
The reviewing of SR-Site

• The Swedish government has requested an independent NEA review, focused on SR-Site, to support SSM’s review

• The NEA review conclusions

  – “From an international perspective, SKB’s post-closure radiological safety analysis report, SR-Site, is sufficient and credible for the licensing decision at hand. SKB’s spent fuel disposal programme is a mature programme - at the same time innovative and implementing best practice - capable in principle to fulfil the industrial and safety-related requirements that will be relevant for the next licensing steps.”

  – ”Another challenge for the future will be to both enhance and broaden the basis for the scientific evidence supporting long-term safety. To that effect, additional research and more detailed calculations will be needed for the safety cases supporting the next licensing steps.”
Radiation safety authority – KBS-3 licensing review

• 277 requests for explanation or additional information up to March 2013
  – Additional requests received through November 2014
• Continuous dialogue SKB-SSM
• SKB answers provided gradually
  – Major deliveries
    • April, June and December 2013
    • February, July and September 2014
• SSM initial review completed and in-depth review started
• In-depth review of encapsulation plant on hold awaiting SKB response to SSM’s review report
• January/March 2015: SKB response on encapsulation plant including interim storage of 11000 tons. Comprehensive supplement on canister issues.

• Critical issues
  – Canister corrosion and mechanical stability
  – Slow water saturation of bentonite
  – Safety principles for encapsulation plant
  – Content needed in EIS (alternatives,…)

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## Environmental Court – KBS-3 licensing review

- **2012:** Court asked about requests for additional information/explanation
- **350 questions/requests** sent to court by stakeholders
- **April 2013:** SKB responses sent to court (600 pages)
- **Autumn 2013:** Reviewers reactions on SKB answers
- **September 2014:** SKB provides additional responses and statements
- **March 2015:** SKB provides updated information on encapsulation plant and interim storage capacity (11000 tons)
  
  This is an additional petition that will have to be submitted for review.
Main review comments on SKB applications

• Scope of Environmental Code Application and Environmental Impact Assessment
  – Level of detail with respect to nuclear safety issues
• Scope of documentation of other disposal methods
  – Deep boreholes
  – Spent fuel as a resource
• Site selection
  – Close to nuclear power plants
  – Inland site – regional groundwater flow
• Long term safety issues
  – Canister integrity
  – Detailed technical issues – mainly from SSM
• “Conventional” environmental consequences
  – Discharges to water
  – Consequences for endangered species and nature values
  – Consequences from traffic, noise from operations
  – Management of rock from excavation
SKB needs 5 Yes to start repository construction
Failed fuel handling in Sweden

- SKB is heading the effort to handle all failed fuel in Sweden
- Around 500 failed fuel rods at all the nuclear power plants
Failed fuel handling in Sweden

- All failed fuel is treated immediately to be in a form acceptable throughout the fuel chain, particularly final disposal
- Two methods used: Studsvik and Westinghouse Quiver methods
- The first step being carried out right now is to empty all Swedish nuclear power plants of failed fuel – 2015-2019
- Priority to the plants being shut down
- Next step to treat all failed fuel at intermediate storage facility Clab
- No untreated failed fuel will be finally disposed in geological repository
Failed fuel handling in Sweden cont.

Issues with failed fuel at NPPs:
• Dose to personnel and environment
• Increased waste management costs
• Challenges regulations
• Hinders decommissioning

Failure categories:
a. Broken
b. Top and/or bottom plug missing
c. Large cracks > 10 mm length
d. Small cracks ≤ 10 mm length
e. Debris fretting
f. Pin hole
g. Difficult cases
   - Broken rods stuck in skeleton
   - Pieces of fuel rods placed in
     purpose built storage canisters
All failed fuel rods are “wet”, and stored in
NPP fuel pools

All are treated in the same way; for the more ‘difficult’ cases the Studsvik method used
Failed fuel handling in Sweden cont.

- The methods must satisfy all requirements for final disposal, particularly:
  Dryness, in order to stop and avoid pre-oxidation of the fuel matrix and fulfill the criteria of maximum amount of water in the canister.
Failed fuel handling in Sweden cont.

• The Studsvik method established since long time, where the failed rods are brought to Studvik facility and cut up, dried and encapsulated in hot-cell. The capsule is then transported to Clab.
Failed fuel handling in Sweden cont.

- The Westinghouse Quiver method, where the failed rods are put in quivers, the rods punched hole in and then dried. All this is done on site, at the power plant, and then the full quivers are transported to Clab. The Westinghouse quiver has been modified in a number of respects to comply with SKBs final repository requirements.
Licensing of Quivers in Sweden

Key licensing principle:
The licensee of a nuclear facility is responsible for acquiring a valid approval from the Swedish nuclear regulatory body, SSM.

- Each license holder for a nuclear facility in which Quivers are to be used is responsible for assuring its license is valid for Quivers.

- Separate processes are initiated, at various stages, to obtain SSM approval for using Quivers in the various links of the Swedish chain.
Failed fuel handling in Sweden cont.

**Status**

**Studsvik**
(Barsebäck 1-2 emptied since more than 10 years)
Oskarshamn 2 has been emptied of failed fuel by five transports in 2016 (Studsvik method)
11 transporter från Oskarshman 1 to Studsvik are planned Jan – Aug 2018
3 transporter av svåra fall från R2, F2 och F3 till Studsvik planeras under 2018 och 2019

**Westinghouse**
Design of PWR Quivers ready, approved by SKB, manufacturing in progress
Design of BWR Quivers ready, manufacturing planned to Q1 2018
Encapsulation and drying planned for:
- Ringhals 2, 3 och 4 Feb – May 2018
- Forsmark 1, 2 och 3 Oct 2018 – Mar 2019
- Oskarshamn 3 Apr 2019
Transports of filled Quivers to Clab in the SKB transport casks are planned for Oct 2018 – Q4 2019

The remaining failed fuel rods are left at the power plant. When a quiver has been filled is the quiver closed and dried and transported to Clab.
### Licensing of Quivers in Sweden

#### Nuclear facility:
- **NPP**
- **Transport**
- **ISFS**
- **FSFS**

#### Licensee:
- **RAB**
- **FKA**
- **OKG**

#### Quiver application:
- Loading, encapsulation, and drying
- Temporary storage
- Transport in casks on special vessels
- Intermediate storage
- Encapsulation and final storage

#### Licensing status:
- **RAB**: In preparation
- **FKA**, **OKG**: Not started
- Soon to be prepared (special arrangement)
- In preparation
- Not started
SKB Quivers must be compatible with

**NPP requirements**
- Handling tools, criticality safety, safeguardability, RP, accidents etc.

**The transport system**
- Resistance to thermal loads, dimensions, structural strength etc.

**The intermediate storage system (Clab)**
- Handling tools, inspectability, ageing, accidents etc.

**The KBS-3 concept for final storage**
- Water content, no organic material, high corrosion resistance etc.
Utöver detta - kända svåra fall:
O2: 1 knippe
F2: 1 knippe
F3: 1 knippe
R2: 1 stavkassett
samt ett antal knippen på O1, O3 och F3 som ännu inte undersöks
The KBS-3 method

- Developed by Swedish SKB
- Adopted by Finnish Posiva
KBS-3

Cladding tube
Spent nuclear fuel
Cast iron insert
Bentonite clay
Surface portion of deep repository

Fuel pellet of uranium dioxide
BWR fuel assembly
Copper canister
Crystalline bedrock
Underground portion of deep repository
Canister in deposition hole

**Bentonite clay:**
Natural clay with very special swelling properties (nano-material)
Montmorillonite (around 80%) + secondary minerals

**Swedish bedrock:**
More than 900 million years old
Bentonite model

The work performed within the EBS Task Force clearly shows that the traditional approach is incorrect for modelling compacted bentonite.

Bentonite is not a conventional porous medium. It is rather a polyelectrolyte and therefore water cannot be treated as a separate phase.

Electrostatic potential differences
- implications for electrochemistry, e.g. copper corrosion

Ion equilibrium
- essential for correct description of diffusive transport

Hyperfiltration
- influences e.g. interpretation of THM-processes

Interlayer chemistry
- significant impact on ionic strength, activity coefficients, pH, etc.

Osmotic pressure
- central for e.g. buffer performance
Alternative methods

- Monitored storage
- Launch into space
- Reprocessing
- Transmutation
- KBS-3
- Very Deep Holes

Very Deep Holes Reprocessing Launch into space KBS-3
Clab – Central Interim Storage Facility for Spent Nuclear Fuel
Clab: Water is an effective radiation screen
Clab – Central Interim Storage Facility for Spent Nuclear Fuel

In the unloading pool the fuel assemblies are lifted out and placed in a storage canister.

Clab 2 increases the capacity from 5,000 to 8,000 tonnes.

Graphic art: Mats Jerndahl
Encapsulation plant
Clink – An integrated encapsulation and interim storage facility
SSM comments on Clink

- A more clear description of safety principles applied, i.e. description of barriers, safety functions and operating functions
- New principles for classification
- Update to current requirements
- New classification of events
  - Consider very improbable events (H5)
- Provide an F-PSAR on a conceptual level
The Nuclear Fuel Repository

- Final disposal of all spent fuel from the present Swedish nuclear energy programme
- Design capacity 6,000 canisters corresponding to 12,000 tonnes of spent fuel
- 15 years of planning, design, construction and commissioning
- 60 years of operation followed by decommissioning and closure

Planned surface facilities at Söderviken, Forsmark

The repository at 470 m depth, when fully built-out
The future final repository

- Depth: 400–700 m
- Rock requirements: 2–4 km²
- Around 4,500 canisters after 40 years reactor use
What degree of confidence do you have in the company Svensk Kärnbränslehantering AB, SKB?

- Very high confidence: Oskarshamn 86%, Östhammar 77%
- Quite high confidence: Oskarshamn 36%, Östhammar 54%
- Quite low confidence: Oskarshamn 11%, Östhammar 7%
- Very low confidence: Oskarshamn 2%, Östhammar 2%
- Don’t know/No answer: Oskarshamn 10%, Östhammar 6%

BASE: All (n = 800), year 2015
Final repository in own municipality?

Opinion 2005 and 2003

Source: TEMO