Nuclear fuel approval and ATF:s in the Swedish System

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SKB

Clear responsibility and sound financing

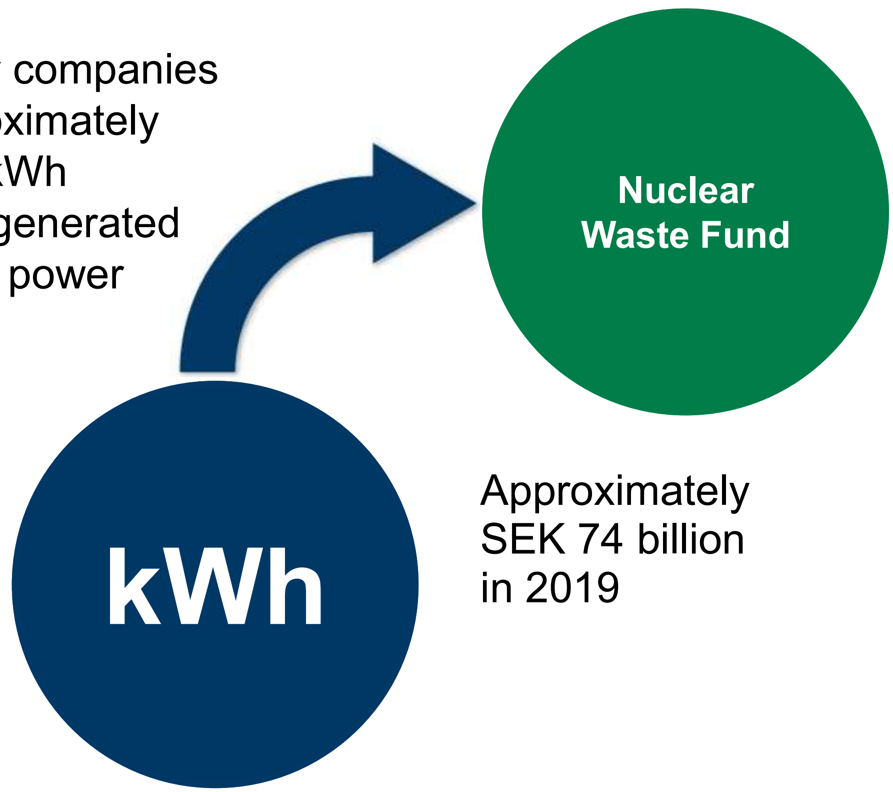
VATTENFALL

FORSMARKS KRAFTGRUPP

*Sydkraft Nuclear Power AB

okg - part of the energy business Uniper

The owner companies fund approximately 5 öre per kWh electricity generated by nuclear power

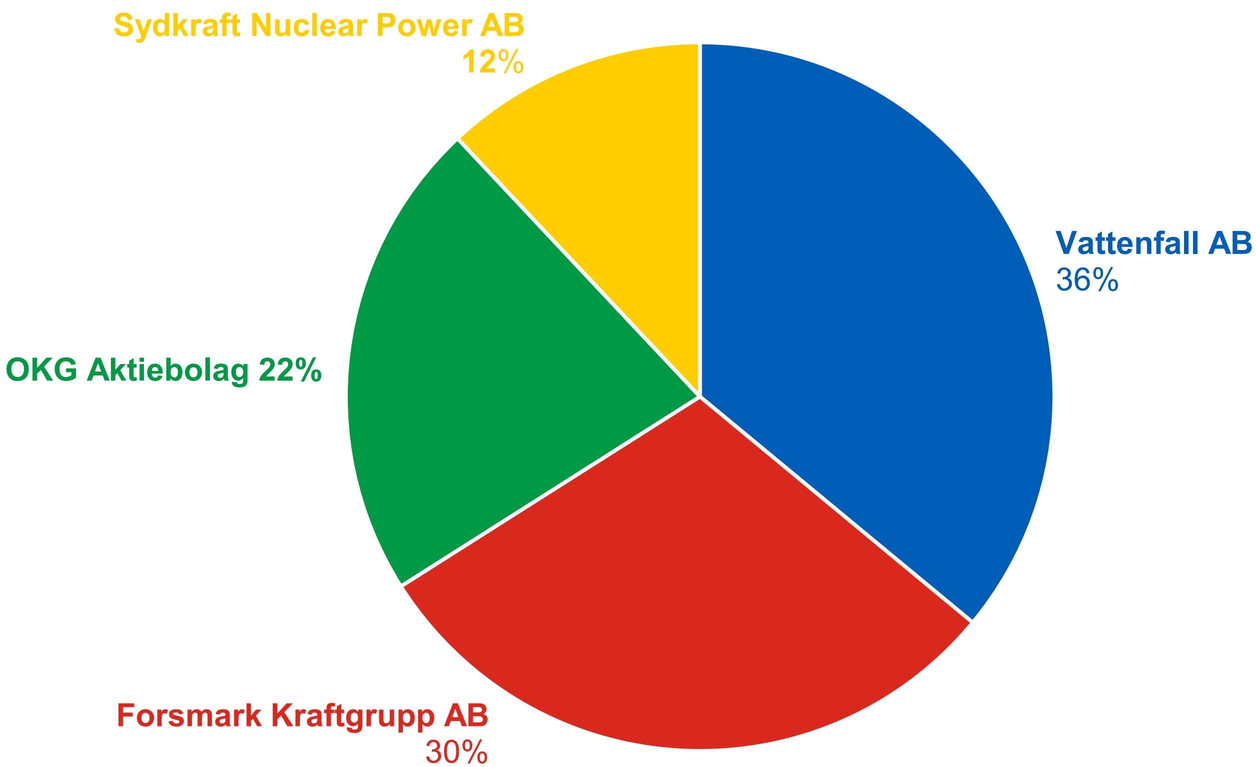


Approximately SEK 74 billion in 2019

*Sydkraft Nuclear Power AB is part of the Uniper group.

About SKB

Our owners



About SKB

Clear roles and legislation

The Government

Swedish Radiation Safety Authority

Nuclear Waste Council

Land and Environment Court

Municipalities

Financing Act

Nuclear Activities Act

Environmental Code

Radiation Protection Act

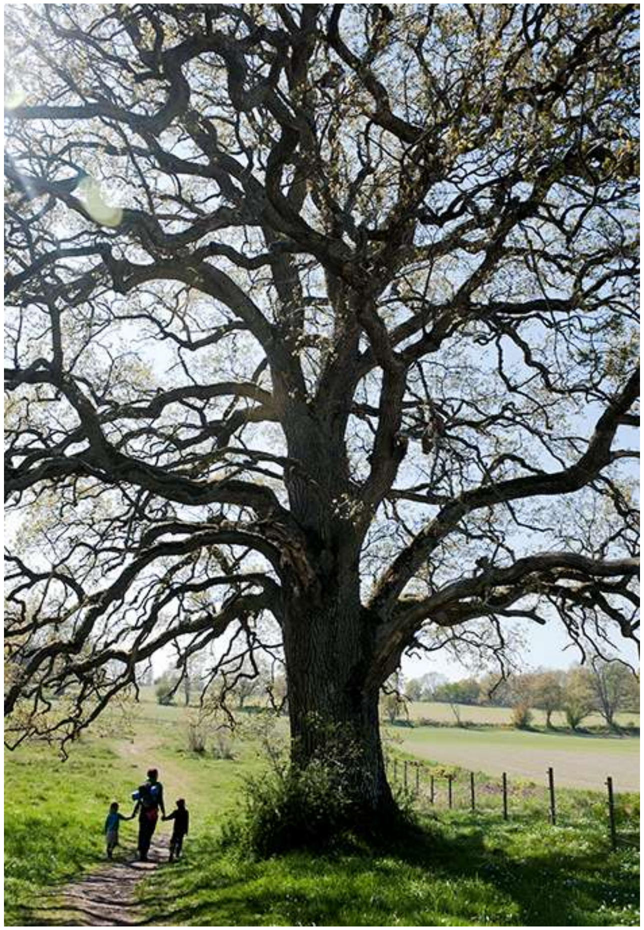
Planning and Building Act

Our mission

Regardless of the future of nuclear power, nuclear waste exists today from the Swedish nuclear power plants.

This waste must be taken care of to protect people and the environment.

This task is so extensive that we regard it as one of Sweden's most important environmental protection projects.

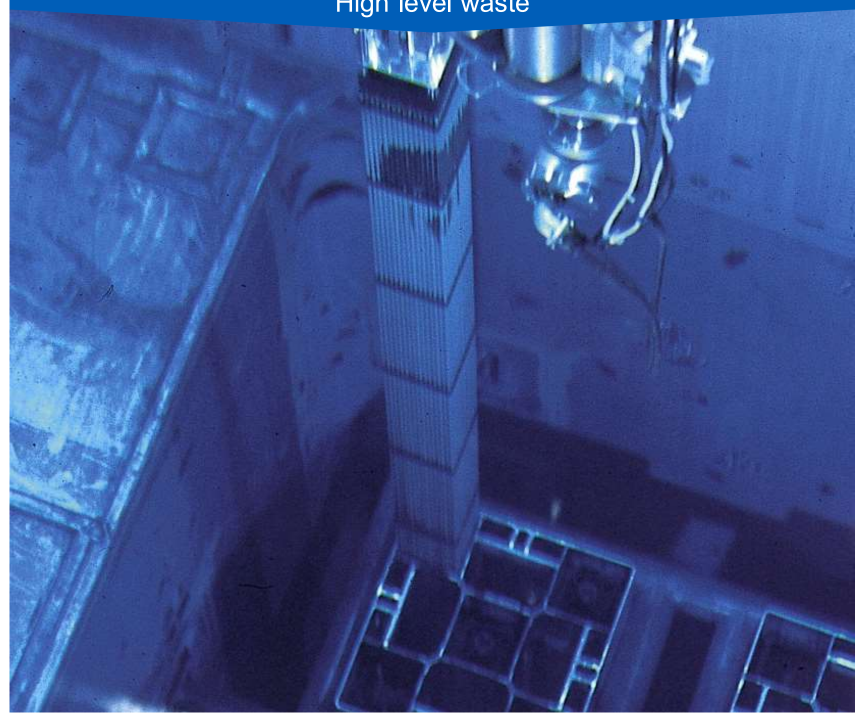


Our mission

Different types of waste – different solutions

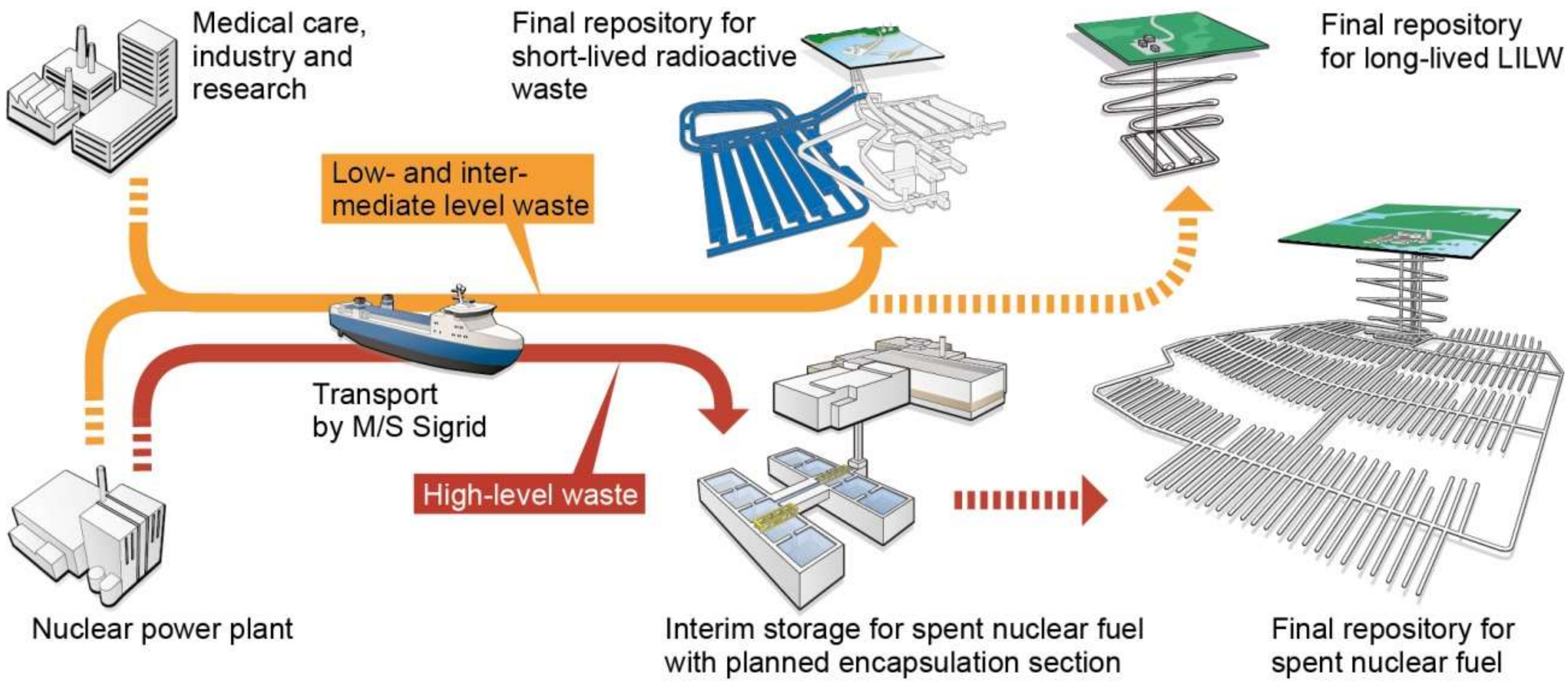
Operational and decommissioning waste
Low and intermediate level waste

Spent nuclear fuel
High level waste



Our operations

The Swedish system

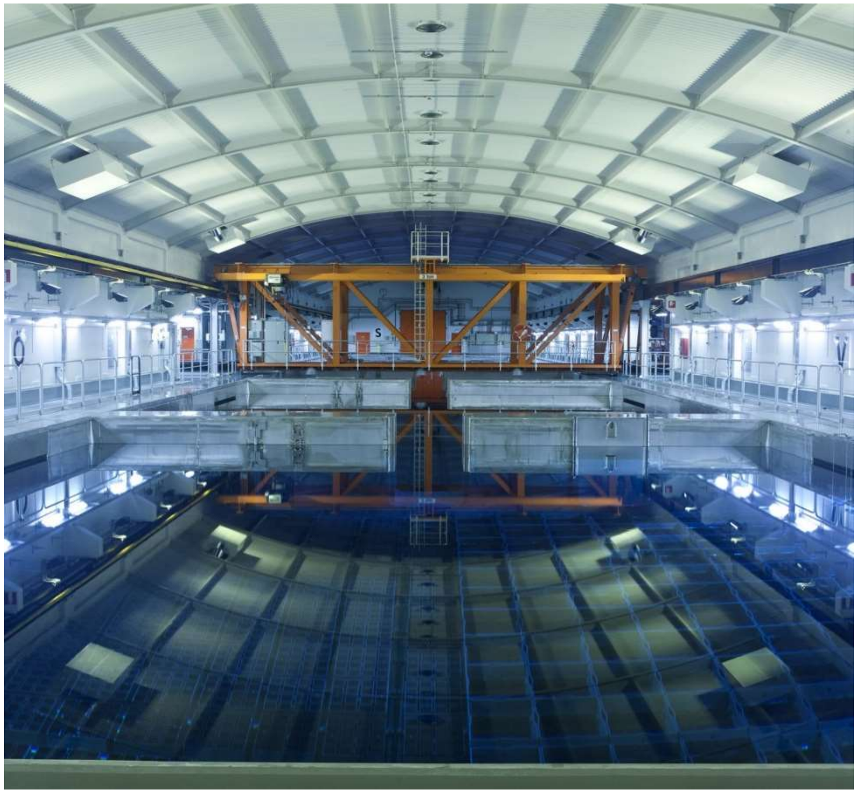


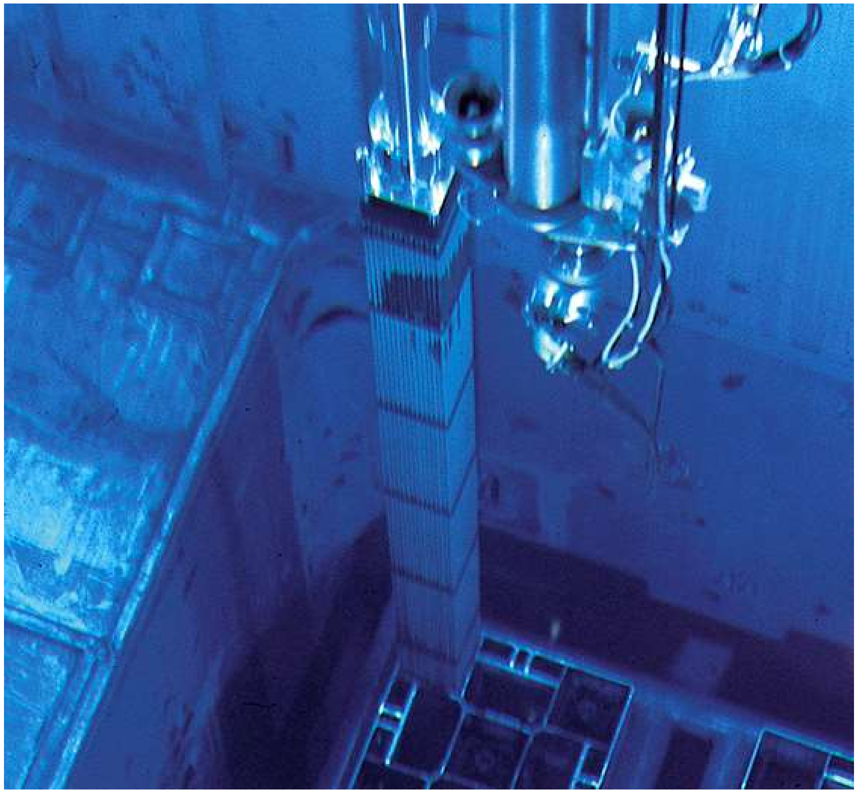
Our operations

Central Interim Storage Facility for Spent Nuclear Fuel, Clab

Our operations

Central Interim Storage Facility for Spent Nuclear Fuel, Clab





Our operations

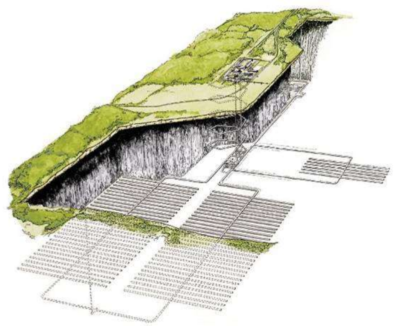
Final Repository for Short-lived Radioactive Waste, SFR

Our operations

m/s Sigrid

Future projects

Planned facilities

Canister factory and canisters	Encapsulation plant	Spent Fuel Repository
		
Investment and operation: **SEK 9 billion**	Investment and operation: **SEK 6 billion**	Investment and operation: **SEK 31 billion**

Future projects

The spent fuel repository

Future projects

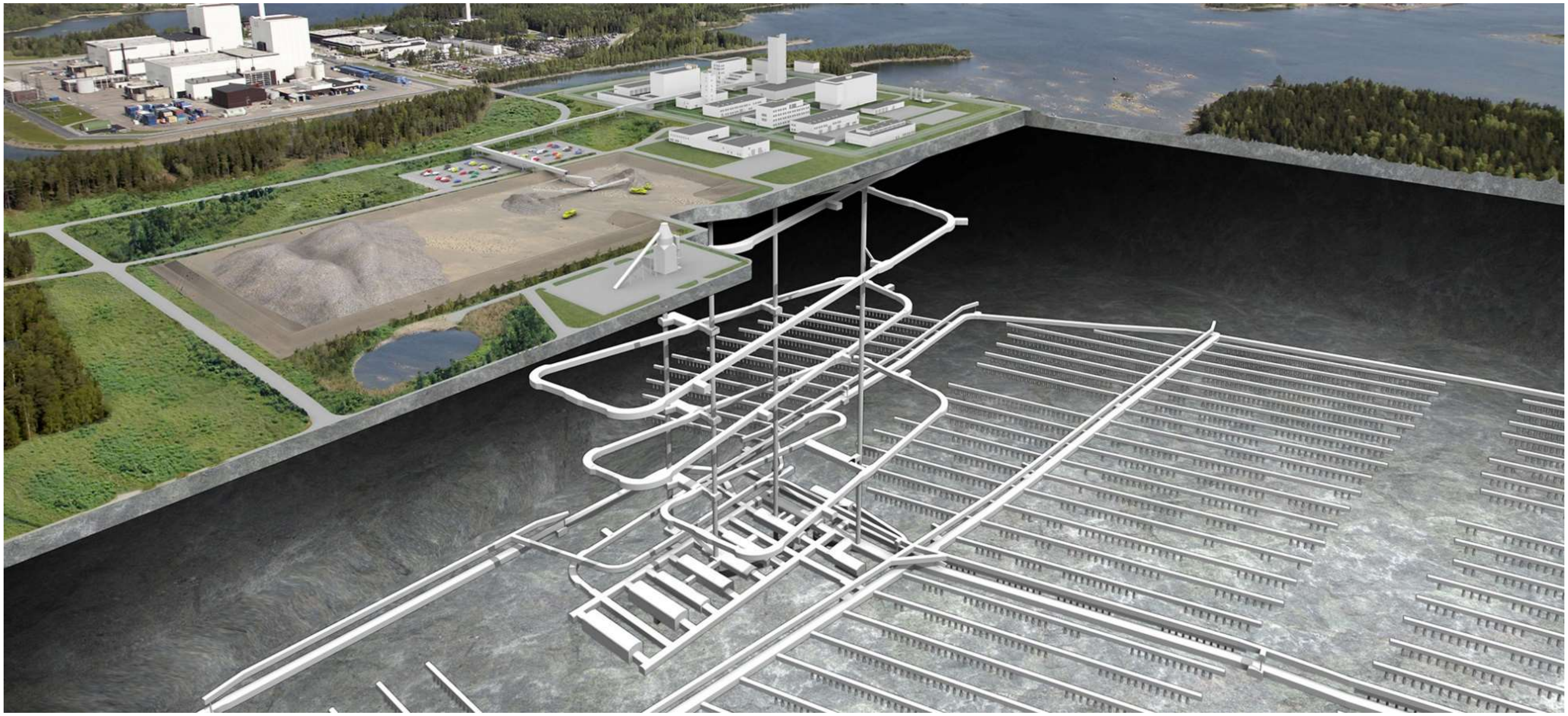
SKB has chosen Forsmark

- The rock in Forsmark provides good prerequisites for long-term safe disposal
- The buildings above ground can be built within the existing industrial area.

Future projects

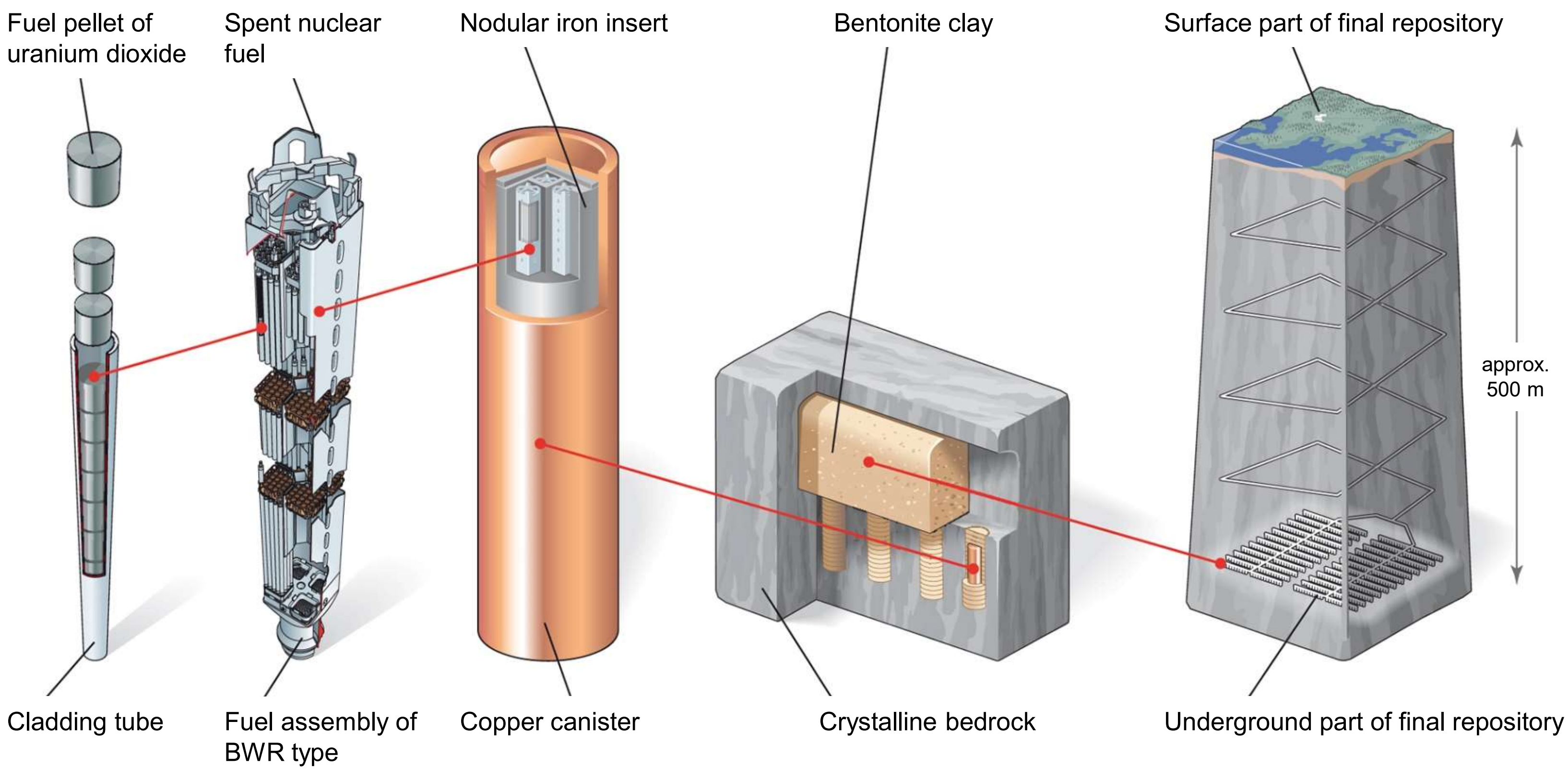
SKB

The Spent Fuel Repository at Forsmark

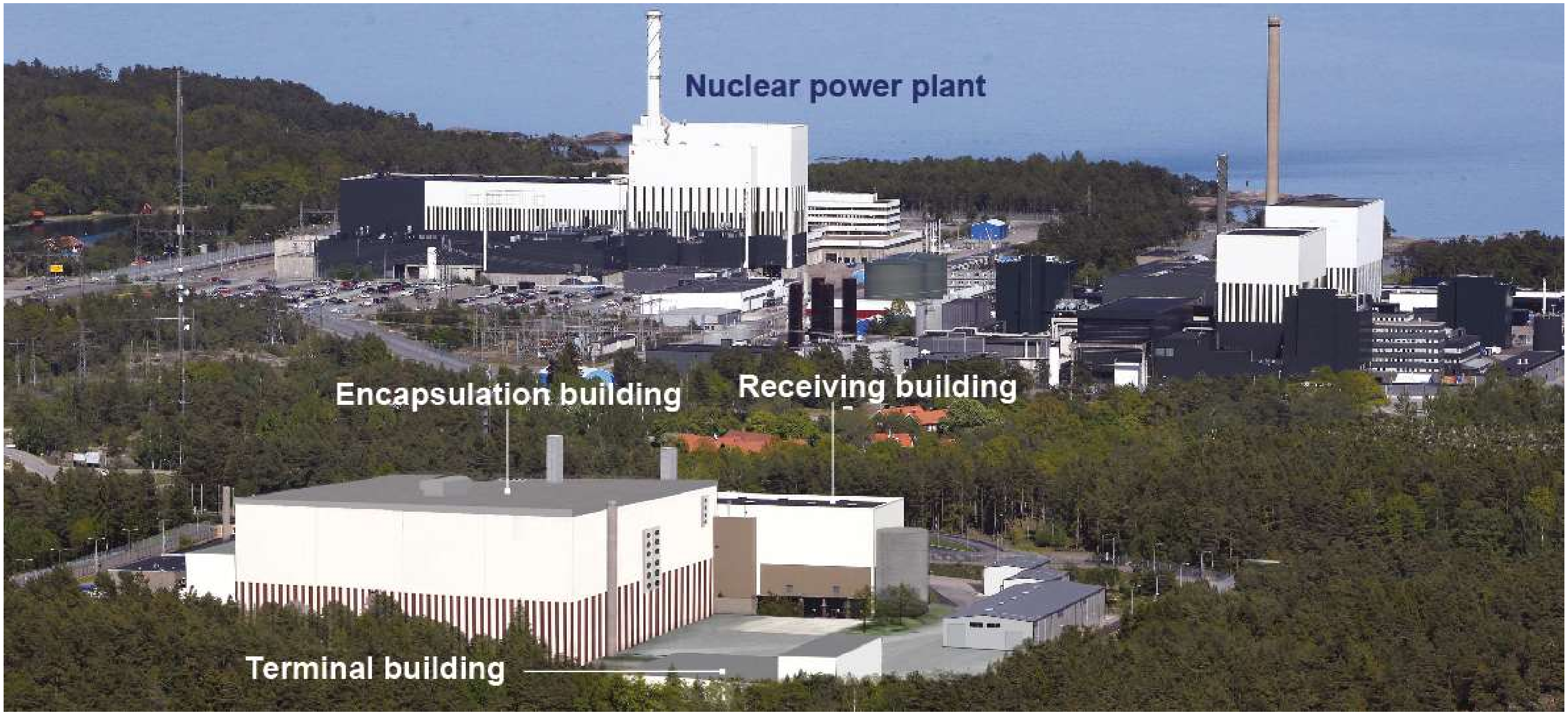


Future projects

SKB's method



Encapsulation plant



Future projects

SFL – long-life low- and intermediate level waste

- Type of waste:
  - Control rods and other components
  - Historical waste from Svafo
  - Waste from other actors
  - Total volume approximately 16,000 m^3
- Design and localisation of SFL has not been decided upon.

Back-end in Sweden

After leaving the reactor the fuel goes through the following steps in the Swedish back-end system:

At NPP

- Transport to fuel pools at NPP.
- In pools at the NPP, cooled for a few years

Transportation

- Dried for transportation in transport casks, maximum 24 h, normally around 12 h. Max temperature 400 deg C.
- Transport in dry transport casks, max temperature 400 deg C. Normally around 2 weeks, max Y months.

Back-end in Sweden cont.

Interim storage, Clab

- Transport cask off-loaded at Clab interim storage – from dry to wet
- Moved to service pools, then to storage pools – all wet; around 20-30 deg C.
- Storage pools, decades, 20-30 deg C.

Encapsulation, Clink

- Moved to dry hot cell in Clink.
- Dried at max X deg C. X not finally decided yet; will probably be between 125 and 250 deg C. depending on drying method
- Put into copper canister - dry.

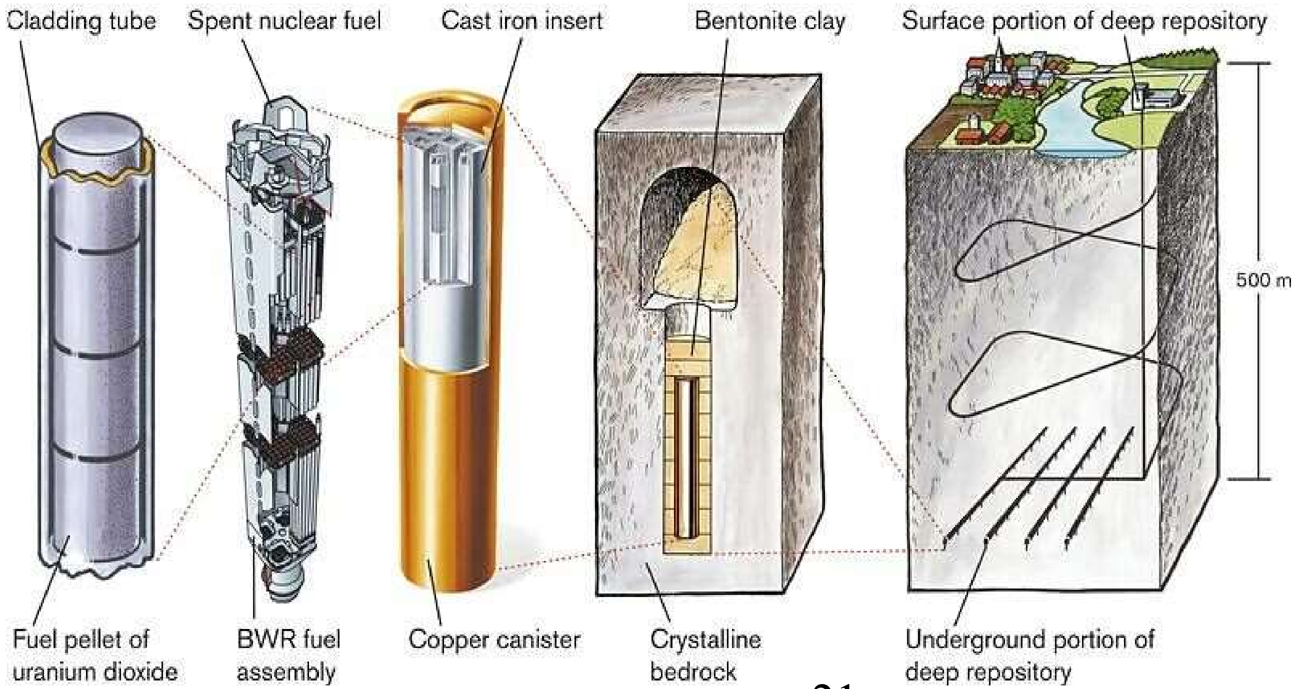
Back-end in Sweden cont.

Transportation to geological final repository

- Canister moved in transport cask to ship and then to geological repository.

Geological final repository

- Disposed of in the KBS-3 multibarrier system – ***eternity***.



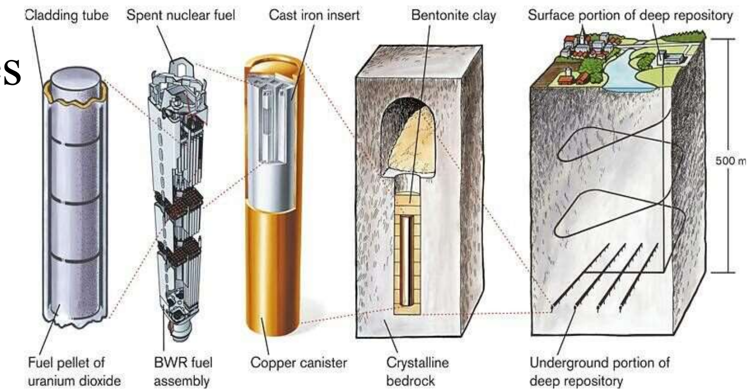
Parameters to characterize

- *Decay heat* – to fulfil temperature requirement on canister, bentonite, rock and fuel
- *Criticality* – multiplicity: to assure that criticality does not occur
- *Radiation doses* – both gamma and neutrons: For safety
- *Nuclide inventory: For safety analysis*
- *Safeguards verification*

Identify correct fuel, missing pins

Contents of fuel – amount of fissile material- Burn-up (BU), Initial enrichment (IE), Cooling time (CT), weight

- Fuel integrity and mechanical properties



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Optimization and economy

- >25 % of production cost of electricity is for the back-end in Sweden
- According to both the nuclear act and the environmental act, economy must be considered when designing nuclear systems
- Therefore, optimization is now a very important thing in the back-end in Sweden
- One, perhaps the most important, way is thermal optimization for the back-end, and particularly the final repository system
- Decay power determination, accuracy, materials, thermal modeling etc. are paramount in this process

Swedish nuclear fuel approval process

- All fuel to be used in a Swedish Nuclear Power Plant has to be approved in advance by SKB
- The reason is that the fuel must be possible to handle and appropriate in the back-end of the Swedish Nuclear fuel cycle
- The fuel is analyzed in the various parts of SKB that is relevant for the back-end:

Transportation

Intermediate wet storage (Clab)

Encapsulation

Final disposal

Swedish nuclear fuel approval process contnd.

- The power plant that wants to purchase fuel indicate its intention as early as possible
- Sometimes an indicative decision is requested, such as for new ATF types
- Meetings are set up to guide the process, beginning with an introductory meeting
- All parts have to sign off their approval
- In the end, a formal decision is made by the designated division head at a formal approval decision meeting
- Time average nine months for the process, but this could be done much faster, depending on when the decision is necessary for the fuel purchase process

Acceptance criteria

All fuel accepted must fulfill certain criteria, such as:

- Dimensions, weight etc. (so it fits the components of the system, such as casks and canisters)
- Criticality in the various parts of the system
- Radiation levels
- Initial enrichment
- Fuel mechanical integrity
- Uranium matrix consisting of UO2
- Fuel must be shown to have low dissolution rate in water
- Variations, such as with dopants, must be verified experimentally
- All information available for the fuel
- Such as all nuclide content of the fuel (including cladding and other components)
- If fuel does not fulfill these criteria, special analysis can be made, e.g. what can be done to remedy the situation, and the cost for this
- (Additional acceptance criteria when the fuel has been used in a reactor, such as burn-up, cooling time etc.)

Accident tolerant fuels (ATF)

All fuel accepted must fulfill certain criteria, such as:

- Beginning to be considered by the power plants
- Doped fuels already in the system and has been approved
- UO2 fuels generally considered to be acceptable, although has to be verified

General remark:

Surprising that after 70 years, or more, of nuclear power, it is not natural in the development of new fuels that there is a back-end, and that is must be better to optimize the cycle from the outset

Recommendation from the IAEA Working Group for the Nuclear fuel Cycle:

- While there has been a significant amount of research, development, and analysis regarding the performance of these fuels in reactors, very little work has been done to date to investigate these advanced fuels within the back-end of the nuclear fuel cycle. Only recently has work began to investigate the impacts of Cr-coated zircaloy clad accident tolerant fuels within the broader fuel cycle . Organizations responsible for the back-end in some countries (like Sweden) already have been requested to provide opinions for possible new accident tolerant fuel purchases by nuclear power plant operators, but have been unable to do so due to a lack of information about properties impacting long term safety of final disposal.

Recommendation from the IAEA Working Group for the Nuclear fuel Cycle contnd.:

- The IAEA, in its international leadership position, is well poised to begin addressing this issue for the benefit of member states. As such, the TWG-NFCO recommends that the IAEA undertake an activity in biennium 2022/2023 to consider the impacts of advanced nuclear fuels within the broader nuclear fuel cycle, including storage, transportation, reprocessing, and disposal. The TWG-NFCO believes that the IAEA could 1) identify different options for managing spent advanced nuclear fuels, 2) establish a process for identifying and evaluating these impacts , 3) identifying the data and information needed for these evaluations, and 3) demonstrate it in an evaluation of the potential fuel cycle impacts of advanced fuel forms that could be deployed in the next decade (including accident tolerant fuels that are expected to be deployed in the very near term). Future evaluations could include other fuel forms as they mature towards deployment.

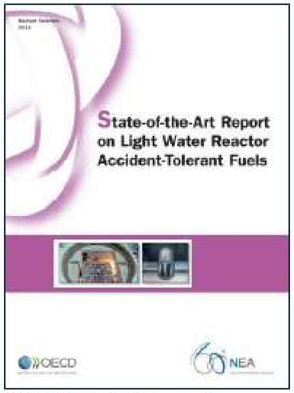
ATF fuels

Introduction

Managing ATF after Discharge

- Fukushima provided a focus for the industry to develop fuels with enhanced resilience to severe accident scenarios.
- Particular target to extend coping time during a Loss of Coolant Accident.
- Fuel and cladding concepts have been developed that range from *evolutionary* to *revolutionary* in their ambition.
- Deployment potential in existing LWR fleets, new build LWRs and some SMR designs.
- *Revolutionary* concepts might also be applicable to some Gen-IV reactor concepts.

Accident at Fukushima-Daiichi in 2011

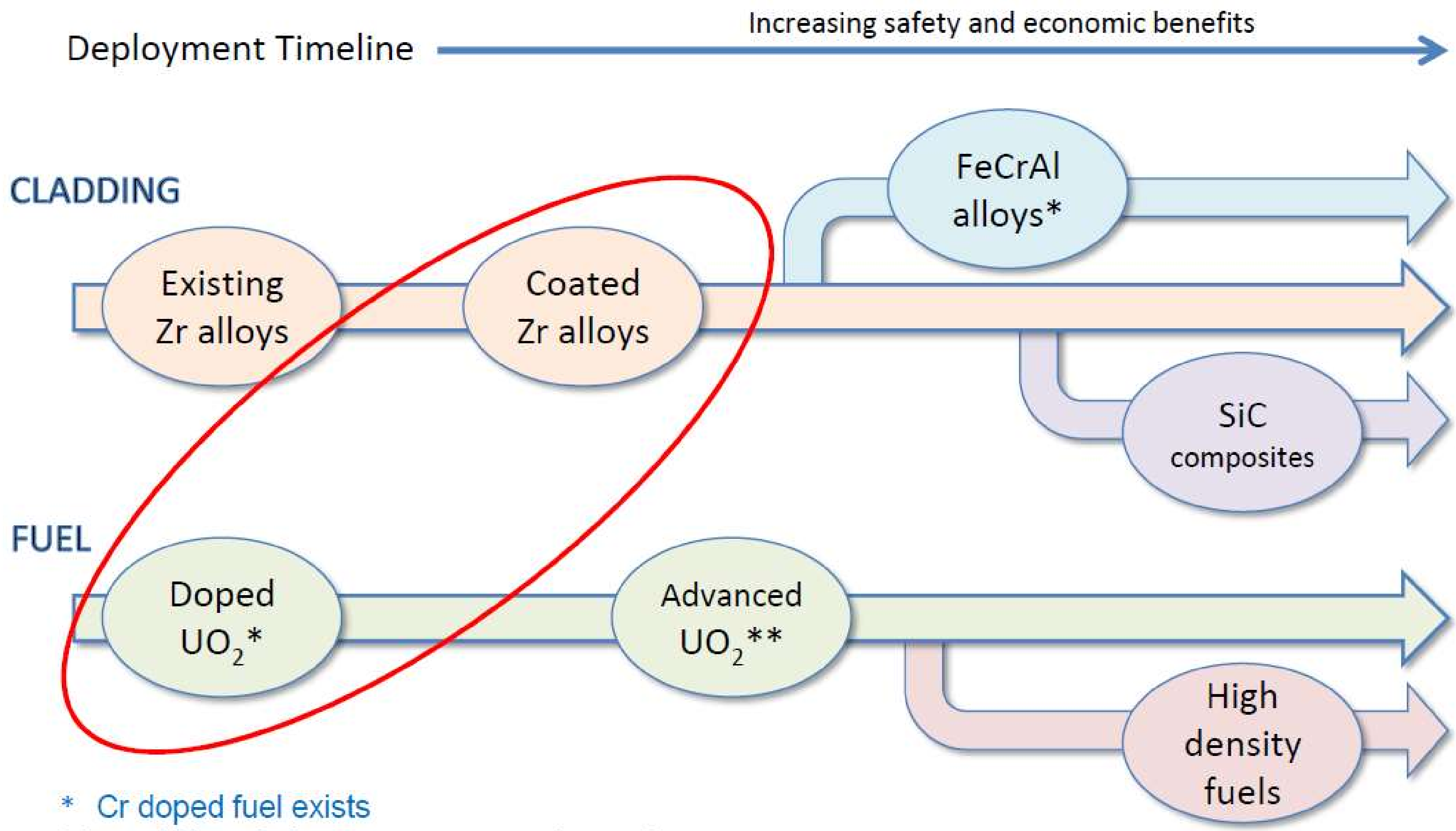


OECD-NEA Report published in October 2018

372 pages of detailed analysis of concepts but only ~ 5 pages devoted to spent fuel management!

SKB

Leading ATF Concepts



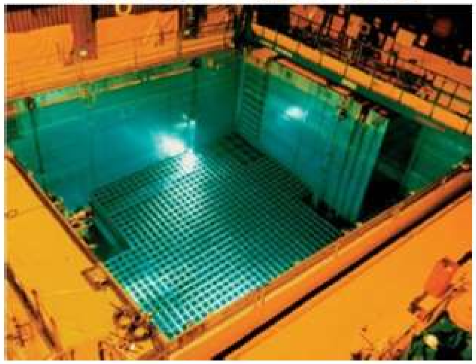
* Cr doped fuel exists
** Would benefit from increasing enrichment from 5 to 6%

Impact of ATF on SPENT Fuel Management

Main issues

- Fuel/cladding properties
- Corrosion behaviour
- Criticality
- Heat load

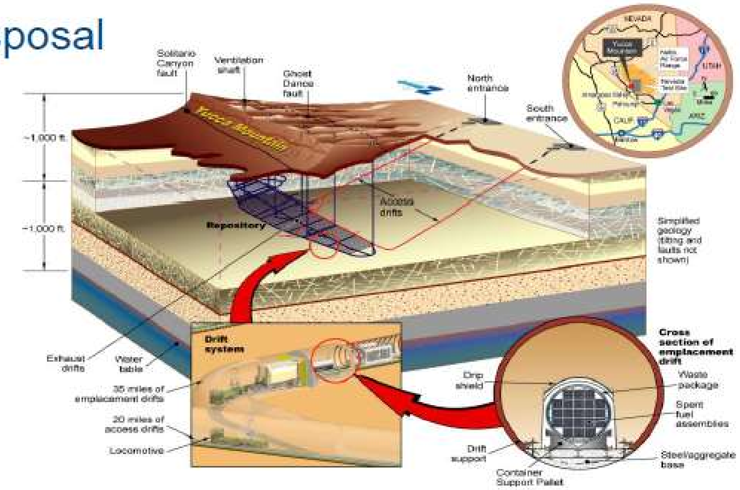
Reactor Fuel Pond



Storage

Transport

Disposal



Summary

Simplified overview of extent to which management of advanced fuels after irradiation are underpinned:

	Storage	Transport	Reprocessing	Disposal
Coated Cladding				
FeCrAl				
SiC				
Doped UO_2				
U_3Si_2				
UC				
UN				
Enrichment >5%				

Skriv en ekvation hä .

Level of certainty	acceptability confirmed	acceptability probable	anticipated issues	confirmed issues	anticipated problematic	confirmed problematic