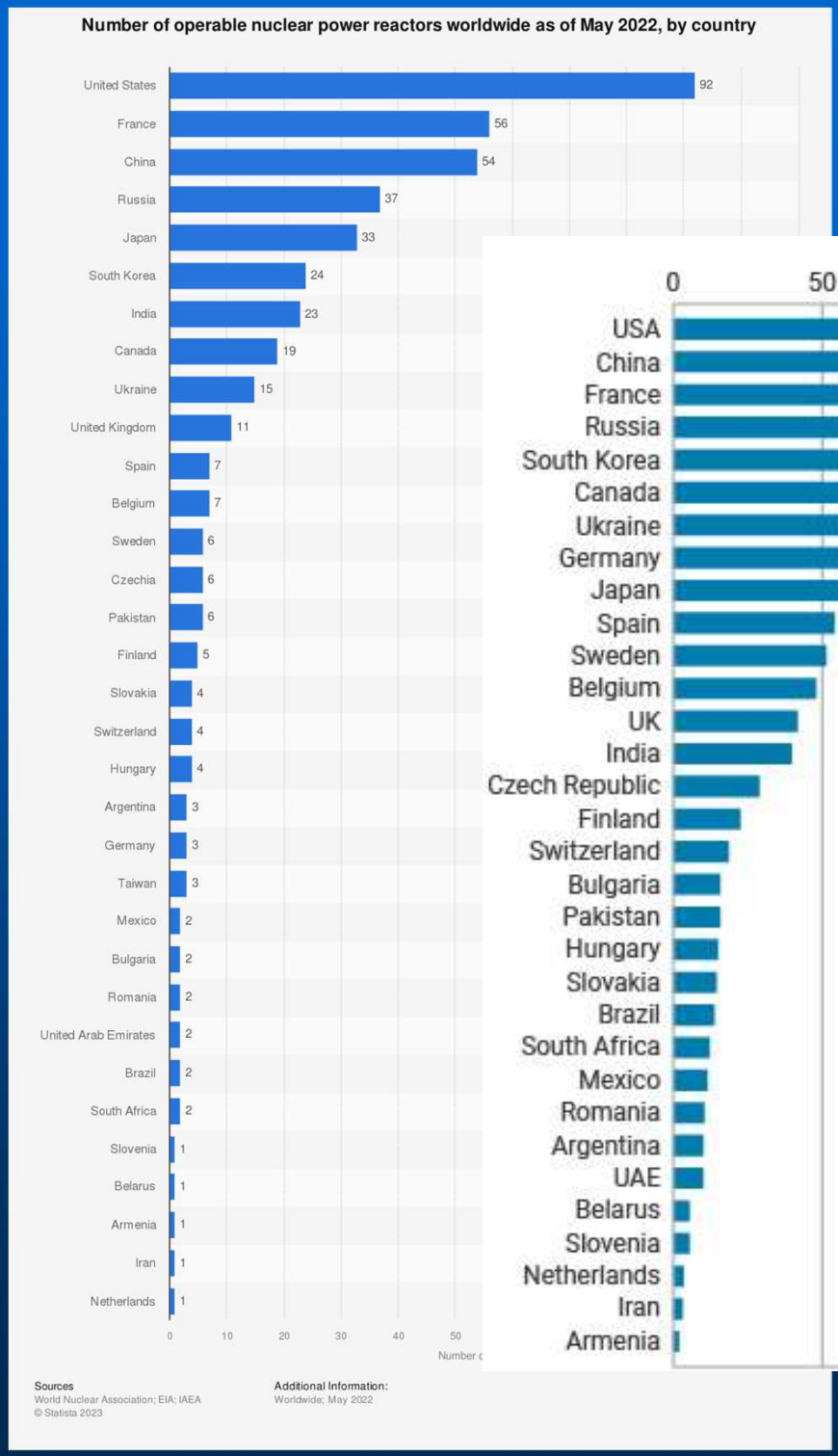
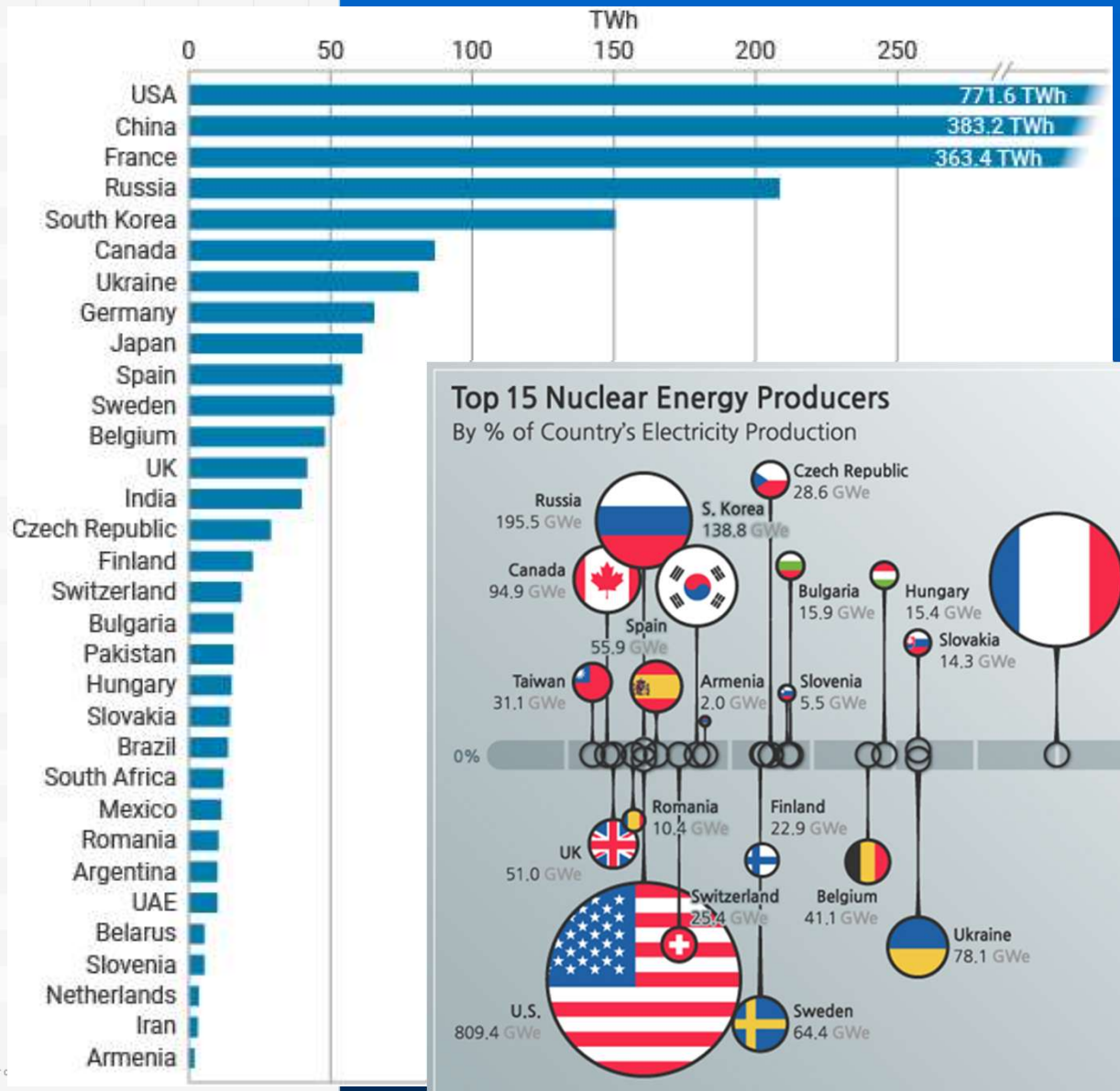
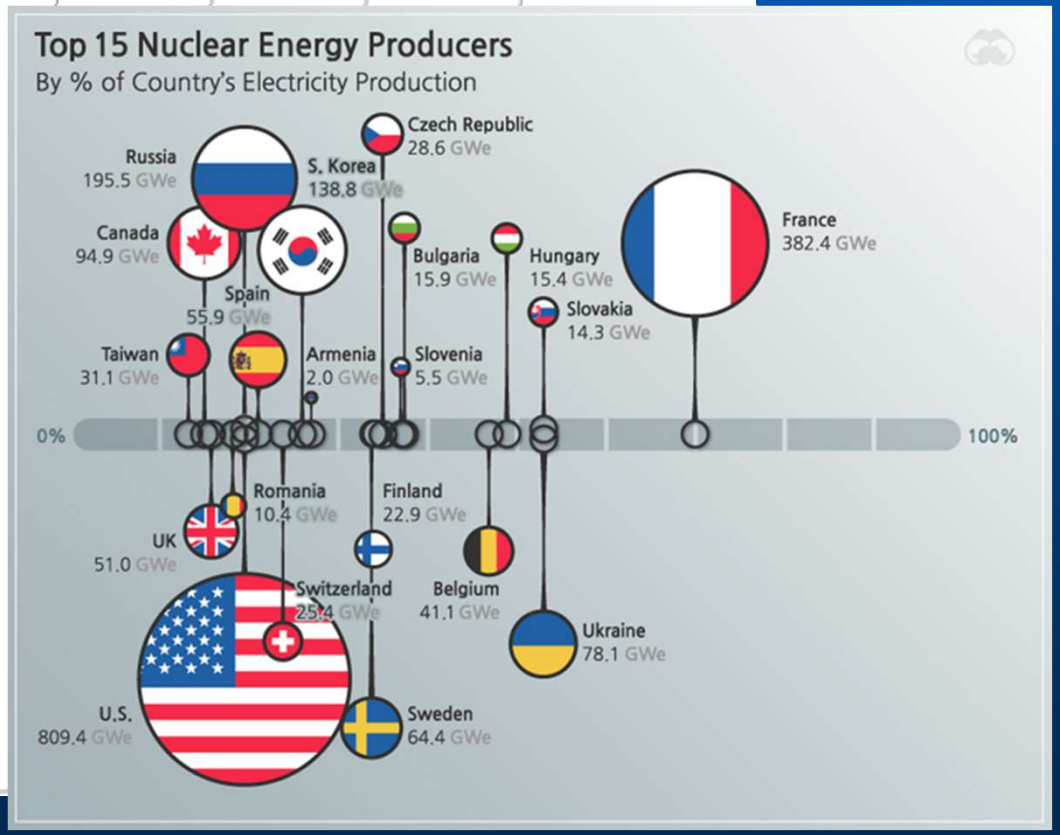
Radioactive Waste Management: an International Perspective

“Do you know, my dear boy, that to reach the interior of the earth we have only five thousand miles to travel?”

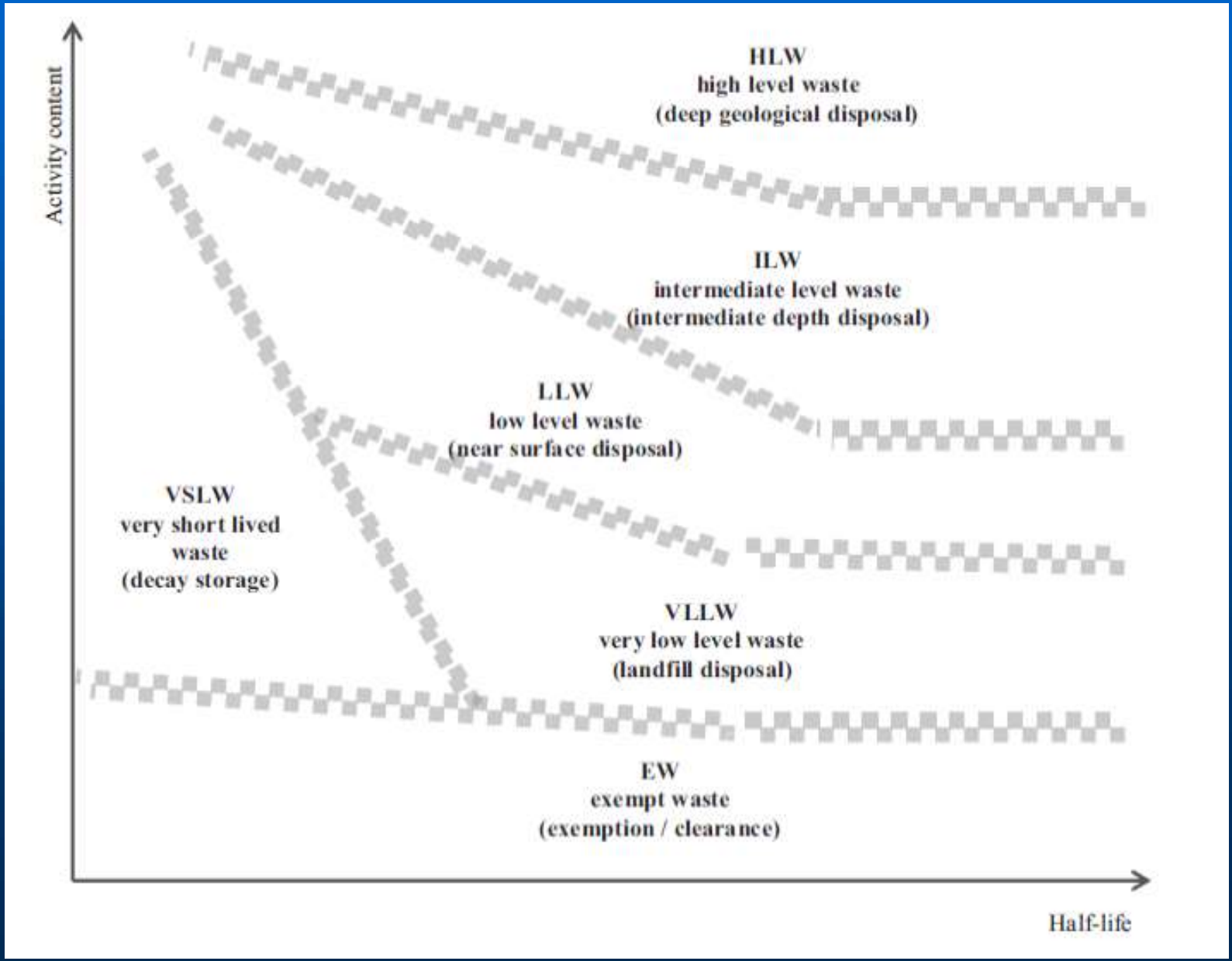
—Prof. Von Hardwigg in “Journey to the Center of the Earth” by Jules Verne.

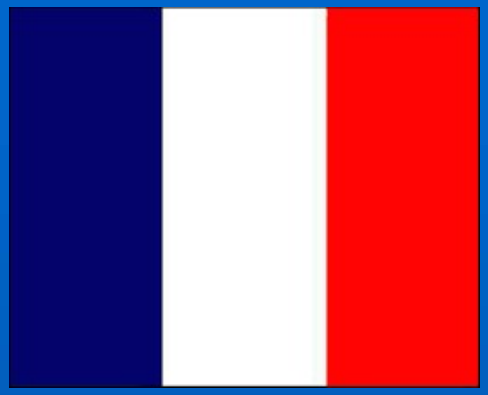

Number of operable nuclear power reactors worldwide as of May 2022, by country
United States 92
France 56
China 54
Russia 37
Japan 33
South Korea 24
India 23
Canada 19
Ukraine 15
United Kingdom 11
Spain 7
Belgium 7
Sweden 6
Czechia 6
Pakistan 6
Finland 5
Slovakia 4
Switzerland 4
Hungary 4
Argentina 3
Germany 3
Taiwan 3
Mexico 2
Bulgaria 2
Romania 2
United Arab Emirates 2
Brazil 2
South Africa 2
Slovenia 1
Belarus 1
Armenia 1
Iran 1
Netherlands 1
0 10 20 30 40 50
Sources
World Nuclear Association; EIA; IAEA
© Statista 2023
Additional Information:
Worldwide; May 2022


TWh
0 50 100 150 200 250
USA 771.6 TWh
China 383.2 TWh
France 363.4 TWh
Russia
South Korea
Canada
Ukraine
Germany
Japan
Spain
Sweden
Belgium
UK
India
Czech Republic
Finland
Switzerland
Bulgaria
Pakistan
Hungary
Slovakia
Brazil
South Africa
Mexico
Romania
Argentina
UAE
Belarus
Slovenia
Netherlands
Iran
Armenia


Top 15 Nuclear Energy Producers
By % of Country's Electricity Production
Russia 195.5 GWe
Czech Republic 28.6 GWe
S. Korea 138.8 GWe
France 382.4 GWe
Canada 94.9 GWe
Bulgaria 15.9 GWe
Hungary 15.4 GWe
Spain 55.9 GWe
Slovakia 14.3 GWe
Taiwan 31.1 GWe
Armenia 2.0 GWe
Slovenia 5.5 GWe
0%
100%
Romania 10.4 GWe
Finland 22.9 GWe
UK 51.0 GWe
Switzerland 25.4 GWe
Belgium 41.1 GWe
Ukraine 78.1 GWe
U.S. 809.4 GWe
Sweden 64.4 GWe

IAEA Waste Classification





French Republic

56 pressurized-water reactors housed in 18 power plants.
1 under construction (on grid by 2024).
14 being decommissioned.
Generates 70% of its electricity. 17% from MOX fuel.
World's largest net exporter of electricity.

French Republic

Does not have uranium. Uranium imported from Canada, Australia, Kazakhstan and Russia.

Closed fuel cycle: enrichment, chemical reprocessing using Purex, conversion, fuel fabrication, and waste treatment.

Strong public support.

"Why the French Like Nuclear Energy"

http://www.pbs.org/wgbh/pages/frontline/shows/reaction/readings/french.html

"No oil, no gas, no coal, no choice."

"French people like large projects."

"Scientists and engineers have a much higher status in France than in America."

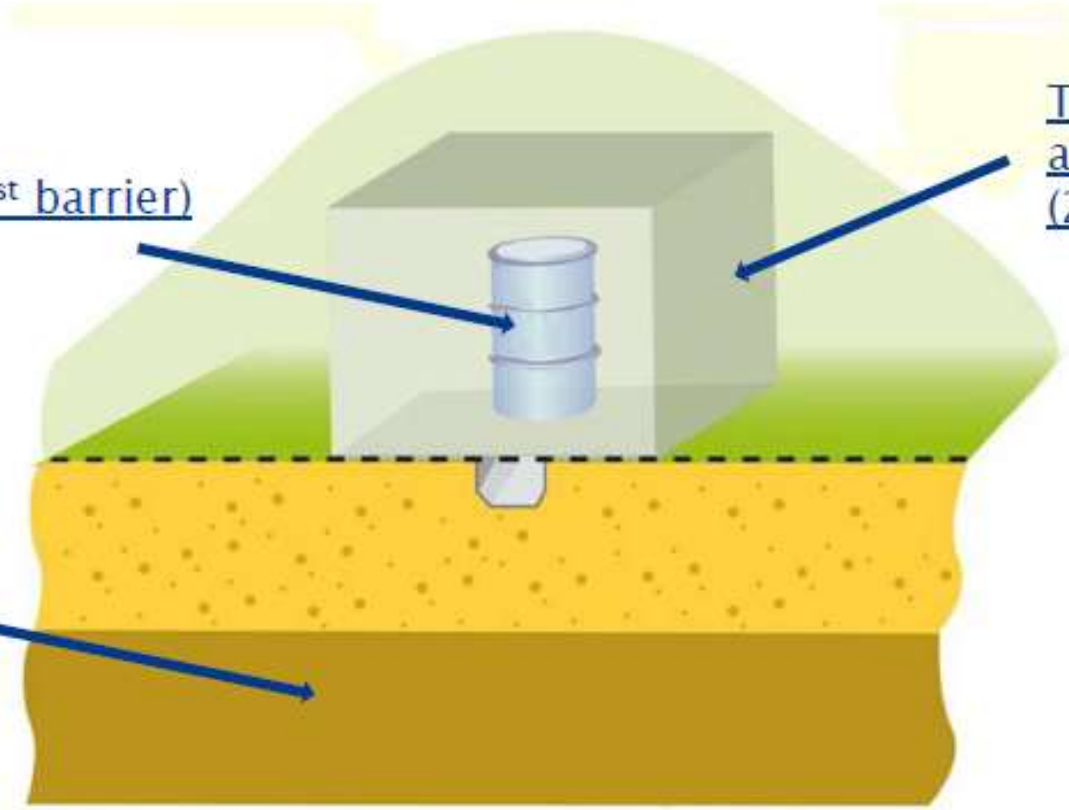
" . . . the French authorities have worked hard to get people to think about the benefits of nuclear energy . . . "

Waste Classification in France

Waste category	Waste characteristics
Very Short-Lived	Medical and research sources. Half-life less than 100 days.
Very Low-Level (VLL)	Decommissioning wastes and operational wastes. Radionuclides with a half-life that is ≤ 31 years. Specific activity less than 100 Bq/g.
Low-Level and Intermediate-Level, Short-Lived (LIL-SL)	Decommissioning wastes and operational wastes.
Low-Level, Long-Lived (LL-LL)	Graphite and radium-containing wastes. Specific activity 10 to 10^5 Bq/g. Radionuclides having a half-life longer than 31 years.
Intermediate Level, Long-Lived (ILW-LL)	Reprocessing wastes. Specific activity 10^6 to 10^9 Bq/g. Radionuclides having a half-life longer than 31 years.
High-Level Waste (HLW)	Vitrified wastes from reprocessing. Specific activity greater than 10^9 Bq/g.

The surface disposal concept

Three barriers to isolate radioactive waste from the environment (in compliance with the RFS1.2 framework)



Waste management in France

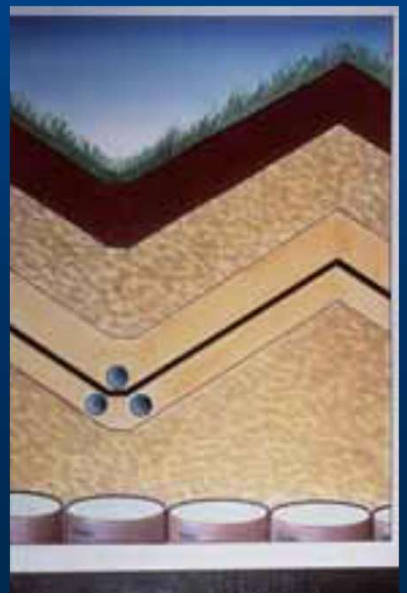
The National Waste Management Agency (Andra) is responsible for all waste management.

Low- and Intermediate-Level Short-Lived waste: Near-surface facility called Centre de la Manche, CSM or simply the Manche repository.

Waste packages were placed in concrete cells in the 12 ha-site.

Closure of Manch

Closed in 1994 after the final cover was added. Cover design: (from bottom to top) compacted coarse-grained shale and sandstone, a fine-sand drainage layer, a 5.5-mm thick bituminous-based geomembrane, a second fine-grained sand drainage layer, a second layer of coarse-grained shale and sandstone, and as the uppermost cover, 0.3 m of soil.



The CSM repository (Manche district)

527,000 m³ of LIL waste disposed of from 1969 to 1994, over 10 ha. Post-closure monitoring phase begun in 2003.

The Soulaines repository

The replacement for the Manche facility for Low- and Intermediate-Level Short-Lived waste is called the Soulaines-Dhuys (soo-lan doo-ees) Repository, CSA, or simply the Soulaines repository. The 200-L waste drums are stacked in concrete vaults at the near-surface repository. The vaults are intended to isolate the drums from groundwater for 300 years.

Centre de Soulaines disposal facility

- *Opened in 1992 to receive waste through 2022*
- *Enough capacity through at least 2050, thanks to volume and quantity reductions achieved since then*

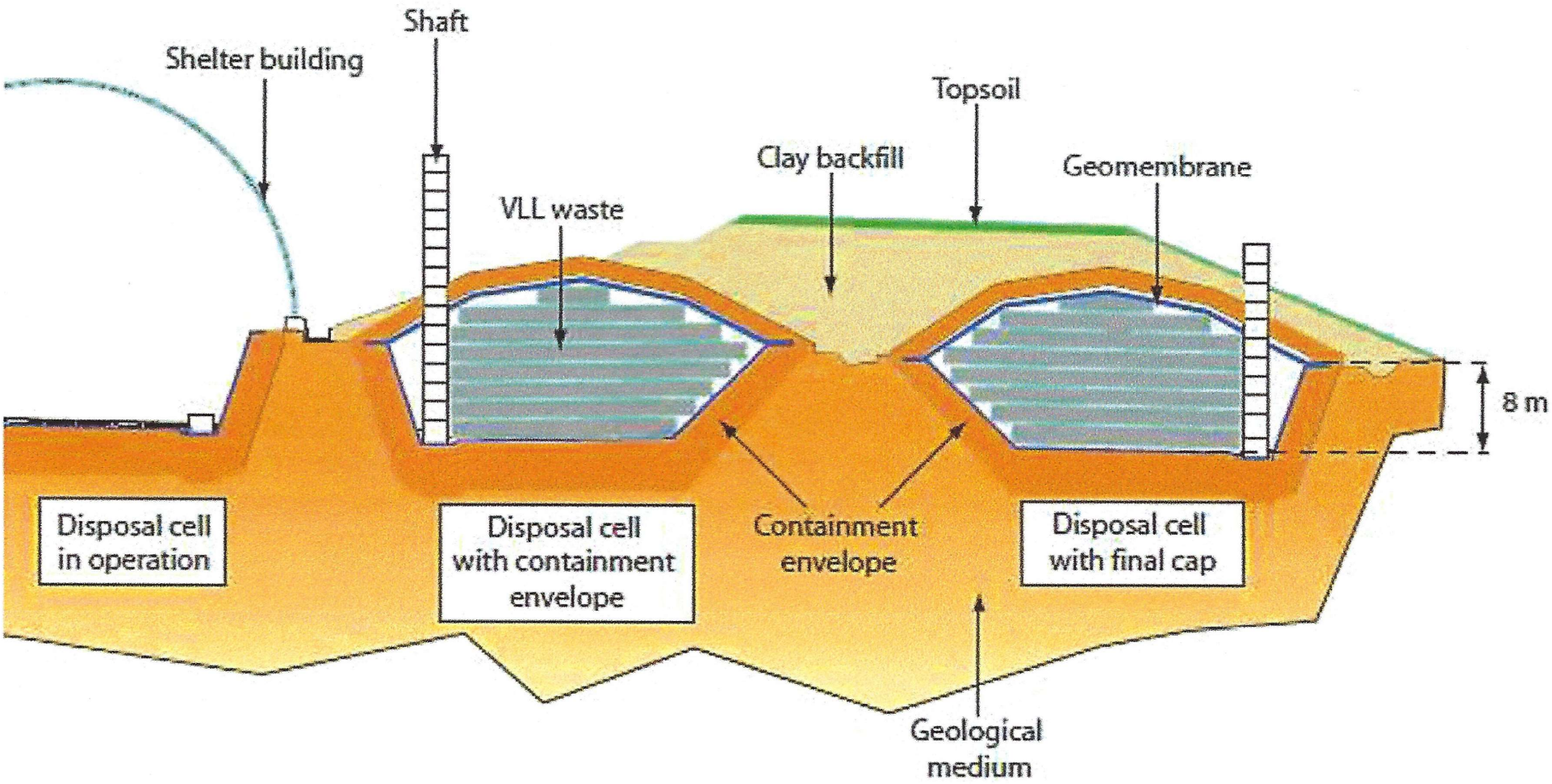
The Morvillier repository

Very Low-Level wastes.

CIRES or the Morvillier (more vil-yāh) repository.

Waste drums are placed in soil trenches at the near-surface 45-ha facility.

A moveable shelter is used to keep precipitation out of the trench.

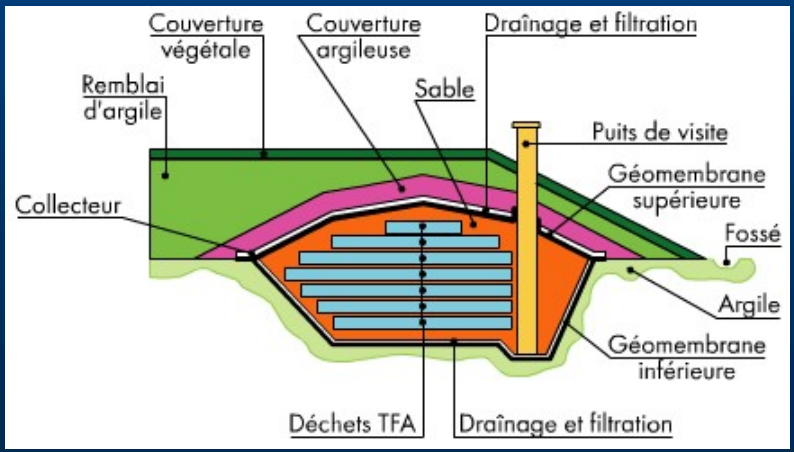

Shaft
Shelter building
Topsoil
Clay backfill
Geomembrane
VLL waste
8 m
Disposal cell in operation
Disposal cell with containment envelope
Containment envelope
Disposal cell with final cap
Geological medium

The Morvillier repository

Containers are placed in 26-m wide, 174-m long, and 8.5-m deep disposal cells. When the trench is full, void spaces filled with sand.

2-mm thick, high-density polyethylene geomembrane placed on wastes.

Covered with 1 to 5 meters of compacted clay.



The disposal cell, the roof and the final cover

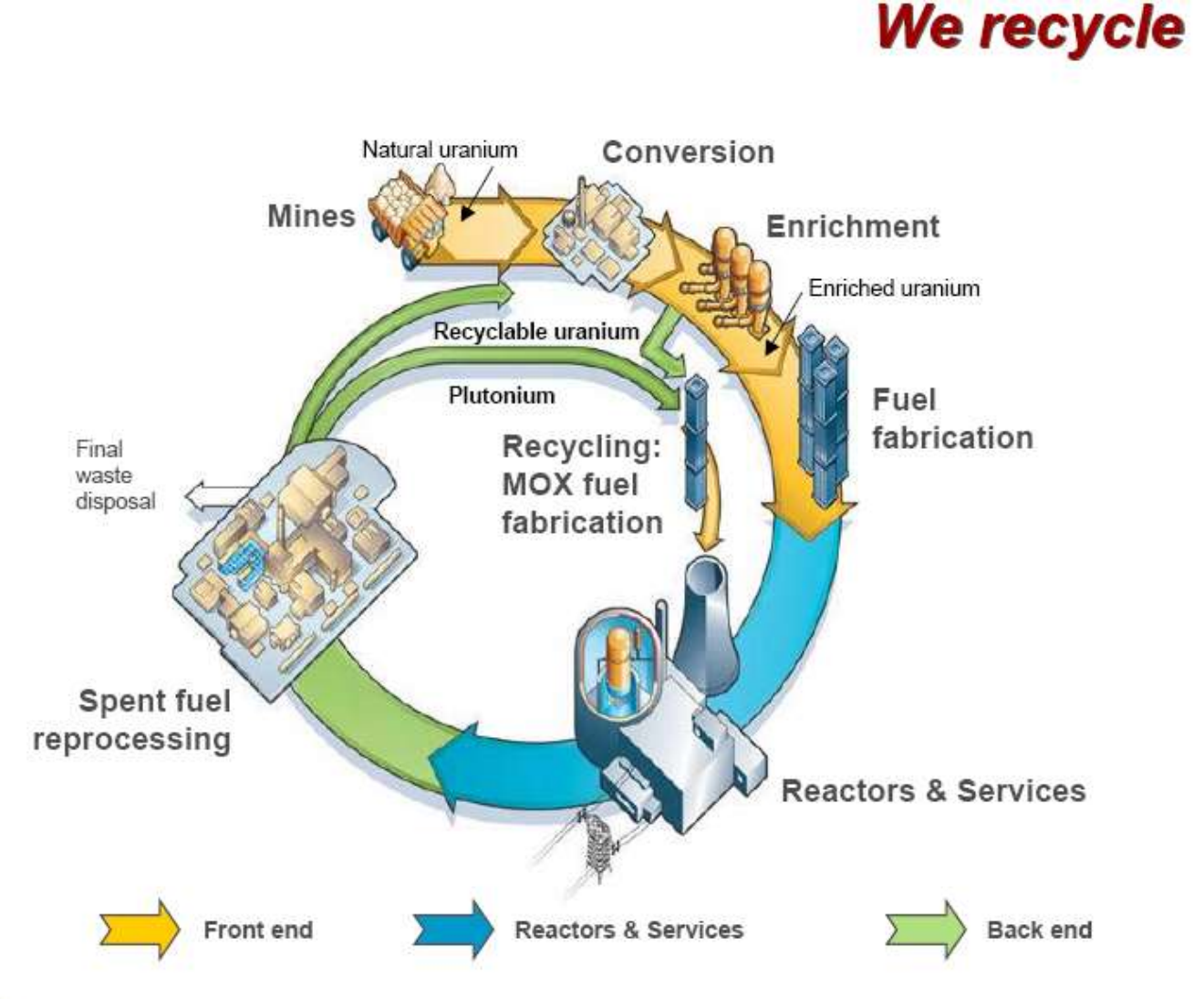
Monitoring the environment

- **Radiological monitoring**
  - Nearly 16,000 analyses of surface waters (rivers, streams) and groundwater, air, sediments, food chain, vegetation, milk
  - Reference point: ecological and radiation state in 87/88 and 90/91

- **Non-radiological monitoring**
  - Chemical and physico-chemical analyses of water, ecology, noise and vibrations, etc.

- **Monitoring of the ecology of the various surrounding environement**

UNF is reprocessed after wet and dry storage



Vitrified waste is temporarily stored in this building awaiting final disposal

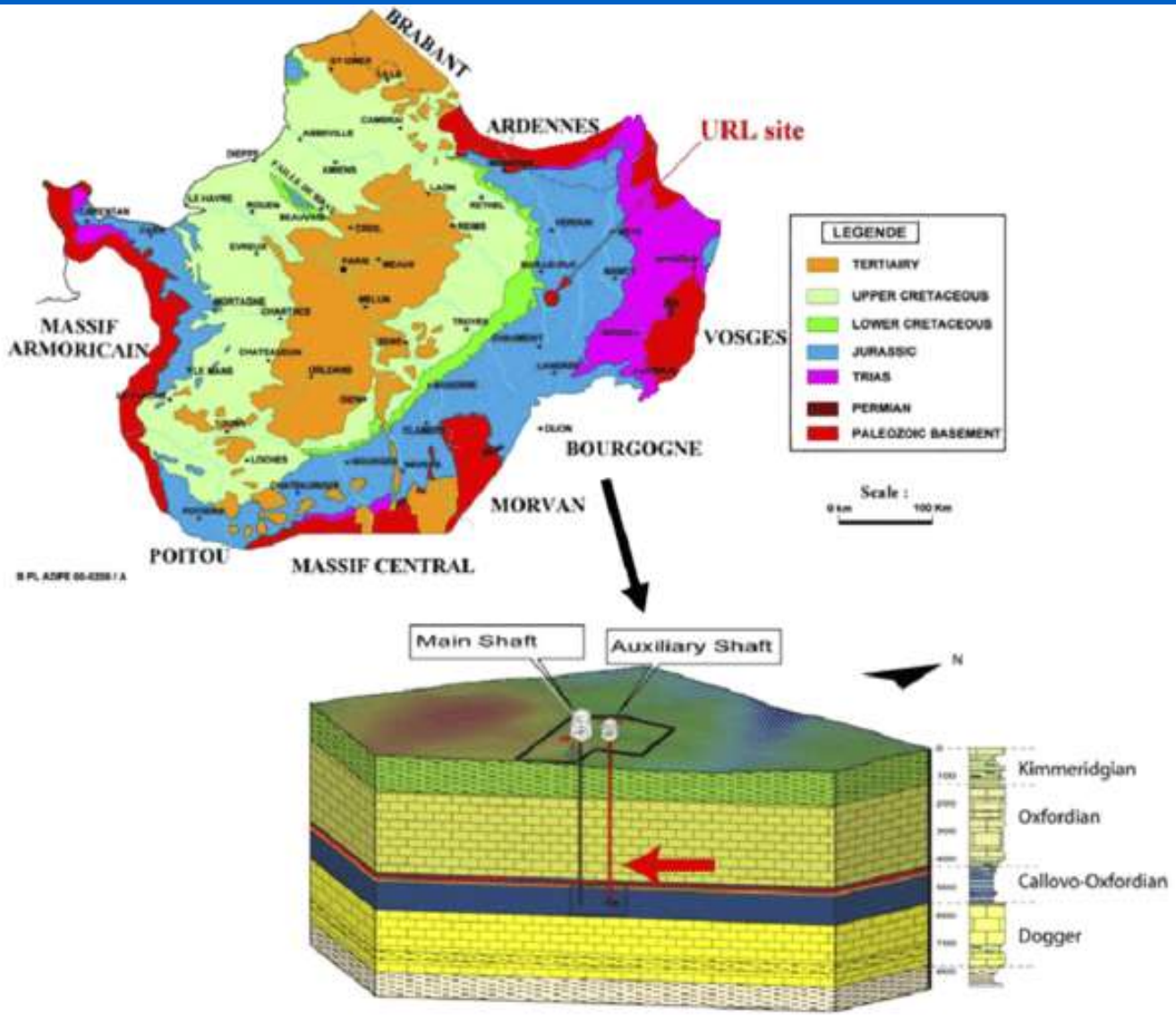
EV South East

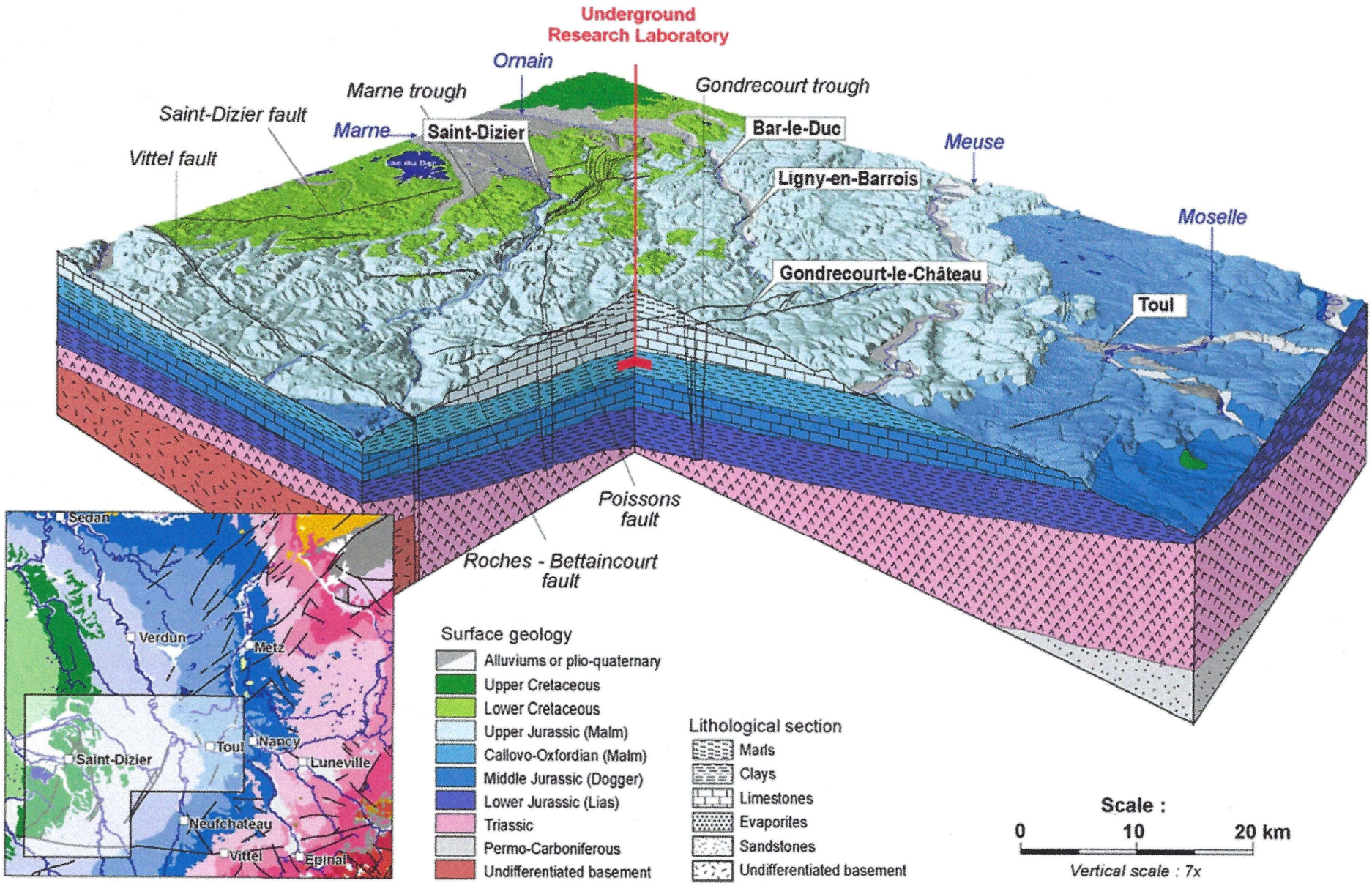
The vitrified waste containers corresponding to 40 years of French electronuclear production lined up side by side would only occupy a single football field

HLW may be placed in geological repository in the near future

In 1999, the French government authorized Andra, to build a underground research laboratory at a depth of 500 m in a 150-million-year-old clay formation in Eastern France, Near Bure (boor).

Storage of HLW in a clay layer




Underground
Research Laboratory
Ornain
Marne trough
Gondrecourt trough
Saint-Dizier fault
Marne
Saint-Dizier
Bar-le-Duc
Meuse
Vittel fault
Ligny-en-Barrois
Moselle
Gondrecourt-le-Château
Toul
Poissons
fault
Roches - Bettaincourt
fault
Sedan
Verdun
Metz
Nancy
Toul
Saint-Dizier
Luneville
Neufchateau
Vittel
Epinal
Surface geology
Alluviums or plio-quaternary
Upper Cretaceous
Lower Cretaceous
Upper Jurassic (Malm)
Callovo-Oxfordian (Malm)
Middle Jurassic (Dogger)
Lower Jurassic (Lias)
Triassic
Permo-Carboniferous
Undifferentiated basement
Lithological section
Marls
Clays
Limestones
Evaporites
Sandstones
Undifferentiated basement
Scale :
0
10
20 km
Vertical scale : 7x

MEUSE / HAUTE - MARNE
Underground Research Laboratory
AUXILIARY SHAFT
MAIN SHAFT
-254 m
EXPERIMENTAL DRIFT
-445 m
MAIN LEVEL
-490 m
-490 m
EXPERIMENTAL DRIFTS
Accelerometric station
Excavated drift (30/03/2012)
Future drift
D PL ACSE10-0263 / B
ANDRA

Underground at Bure

Stations at 490 m

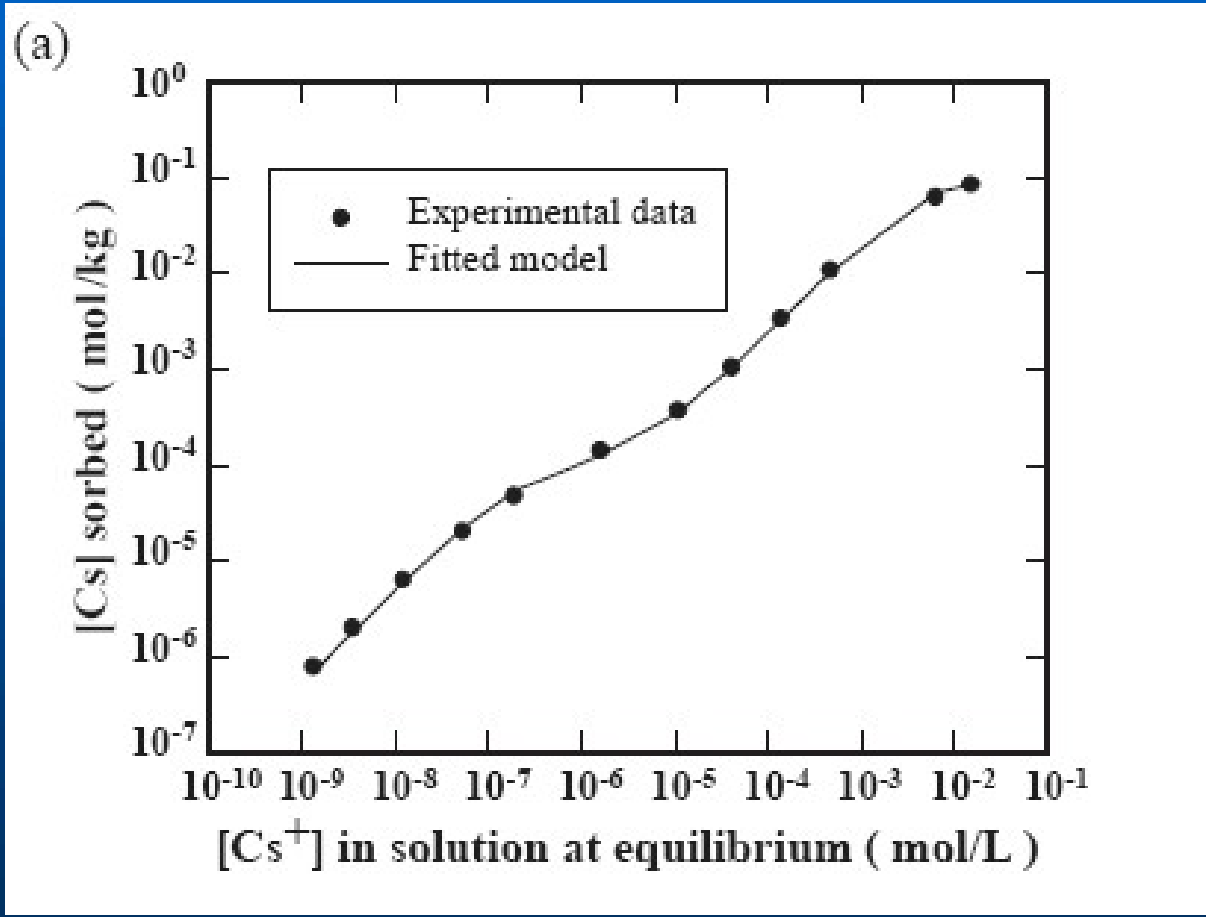
Callovo-oxfordian argilite

130 m thick
160 million years old

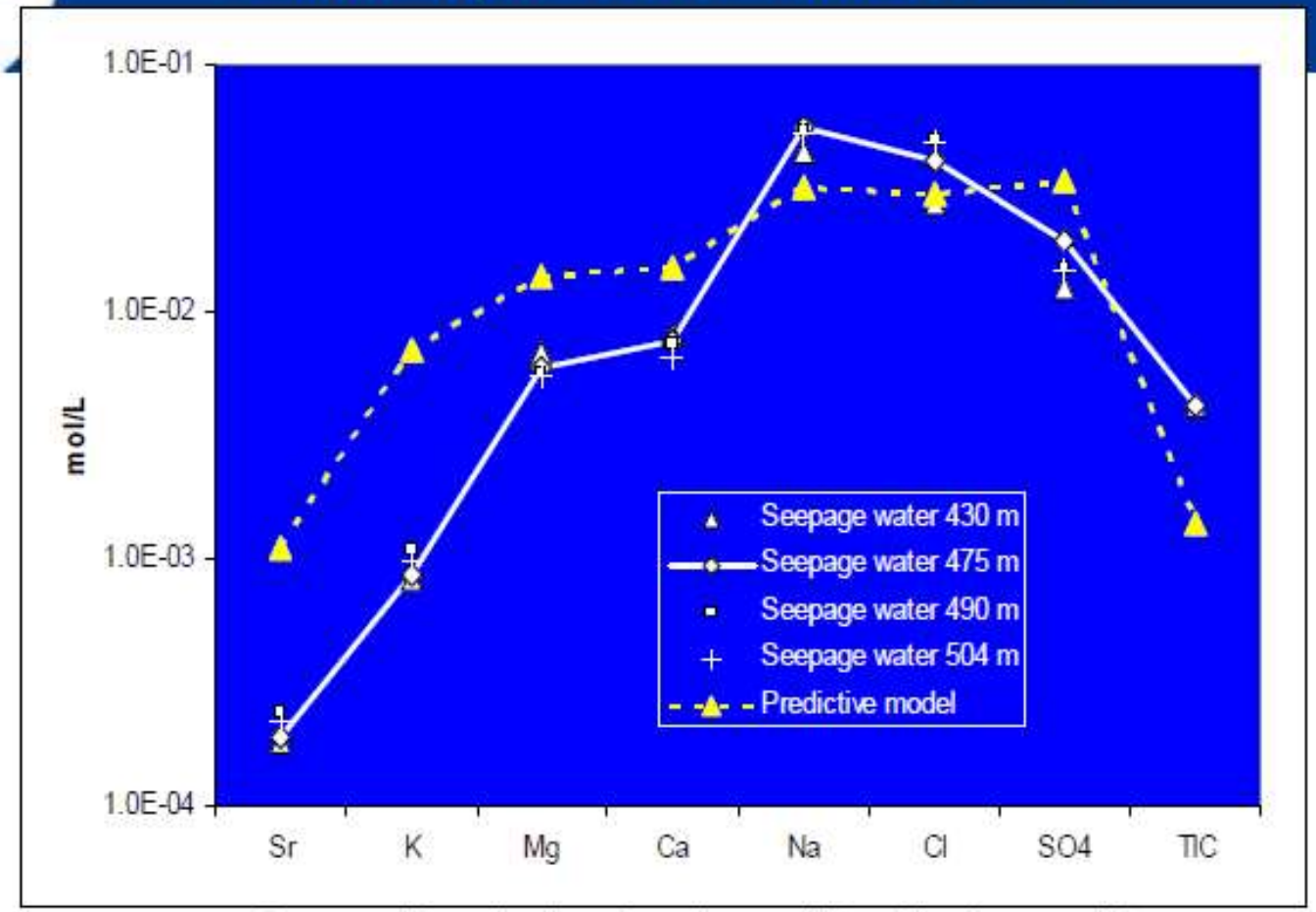
very low permeability

Research is on-going at the Bure Facility

Experiments in heat transfer, radionuclide migration, behavior of gases, and sealing of shafts and galleries.



Chemical pore water characterization



- Compositions in the domain predicted by the model
- *In situ* water sampling helps improving the model

General Schedule Deep Geological Disposal – steps ahead (2013-2025)

- **2013:** public debate on the project for the reversible deep geological disposal facility

- **2015:** filing of the licence application for the reversible deep geological disposal facility

- **2016:** voting of a law laying down the conditions of reversibility applicable to this disposal facility

2035: commissioning of the reversible deep geological disposal facility

The future geological repository

Andra plans to build the repository 5 km from the Bure URL.

It is called is named the Centre Industriel de Stockage Géologique (Cigéo) or Industrial Center for Geological Disposal (see-jay-oh).

Reversible disposal of vitrified wastes and long-lived intermediate wastes.

Cigéo

Vitrified wastes will be placed in steel overpacks then placed in holes in the clay.

Additional engineered barriers are regarded as unnecessary.

Andra plans to have Cigéo operational by about 2030 for 10,000 m^3 of vHLW.

https://www.youtube.com/watch?v=UiSrVLKZ-TA (1:37)

People's Republic of China

55 power reactors (1 Candu, 2 water-water energetic, 3 advanced Chinese, and various French and Chinese pressurized water reactors) located in 15 power plants that generate 5% of the country's electricity.

People's Republic of China

22 reactors under construction. 46 are planned and about 156 are proposed. China can convert and enrich uranium and fabricate fuel. It has 5% of the world's uranium and operates seven mine districts.

Why nuclear in China?

At present, 63% electricity from coal resulting in serious air pollution and coal transport issues are driving interest in nuclear power.

China now *the* major source of CO_2 emissions.

Uranium in China

China has low-grade uranium ore. About 5% of the world's resources.

Resources of 100,000 tons (90,720 tonnes) of uranium. Produces about 840 tons/year (760 tonnes/a).

China, however, relies heavily on international sources of uranium. Imported from Kazakhstan, Russia, Namibia, and Australia.

Another source of uranium in China?

Advanced trials on leaching U from coal ash in China. Background:

U.S. Geological Survey (USGS) database: the mean concentration of U in U.S. coals is 0.69 ± 5.28 pCi/g based on 6,923 samples.

Another source of uranium in China?

USGS database: average ash content of coal combusted in the U.S. is 10.06 ± 6.33%, based on 6,665 coal samples.

Assuming that uranium is not volatile and is concentrated in the ash, 0.69 pCi/g x 10 = 6.9 pCi/g of ash.

Another source of uranium in China?

There are coals in the southern part of China that contain anomalously large concentrations of uranium in the provinces of Guizhou, Guangxi, and Yunnan. Uranium thought to be from magma intrusions and related hydrothermal activity were widespread during the Mesozoic and Cenozoic Eras (Roy, 2014).

Roy, W. R. 2014. Assessment of Radioactive Elements in Coal Combustion Products. Electric Power Research Institute, report number 3002003779, EPRI, Palo Alto, CA.

When coal meets nuclear energy

In the Yunnan Province, Sparton Resources Inc. announced that the fly ash pile at the Xiaolongtang Power Plant contains between 160 and 180 mg/kg of uranium (53 and 59 pCi/g).

When coal meets nuclear energy

Sparton extracted an ash sample with sulfuric acid and produced yellowcake, which is an intermediate product in the production of nuclear fuel.

http://www.world-nuclear-news.org/explorationNuclearFuel/Sparton_produces_first_yellowcake_from_Chinese_coal_ash-161007.shtml

Waste management

Radioactive waste management in China can be described as tenuous and evolving.

Waste classification: Low-Level,

Intermediate-Level, and High-level. No details located in English.

LL and IL wastes are disposed at one of two near-surface excavations consisting of concrete vaults in disposal cells: the Northwest Disposal Site and the Beilong Center.

Low- and Intermediate-Level wastes in China

The Beilong Center is in the Guangdong Province near the Daya Bay Nuclear Plant.

Few details and no photographs located. Operated by the Everclean Environmental Engineering Corporation.

Spent fuel is currently being moved from source power plants to wet storage in the Lanzhou Nuclear Fuel Complex.

Future plans

The Chinese plan to reprocess used nuclear fuel using the Purex process at the Lanzhou Nuclear Fuel Complex, and fabricate MOX fuel after about 2030. No photos located.

Future plans

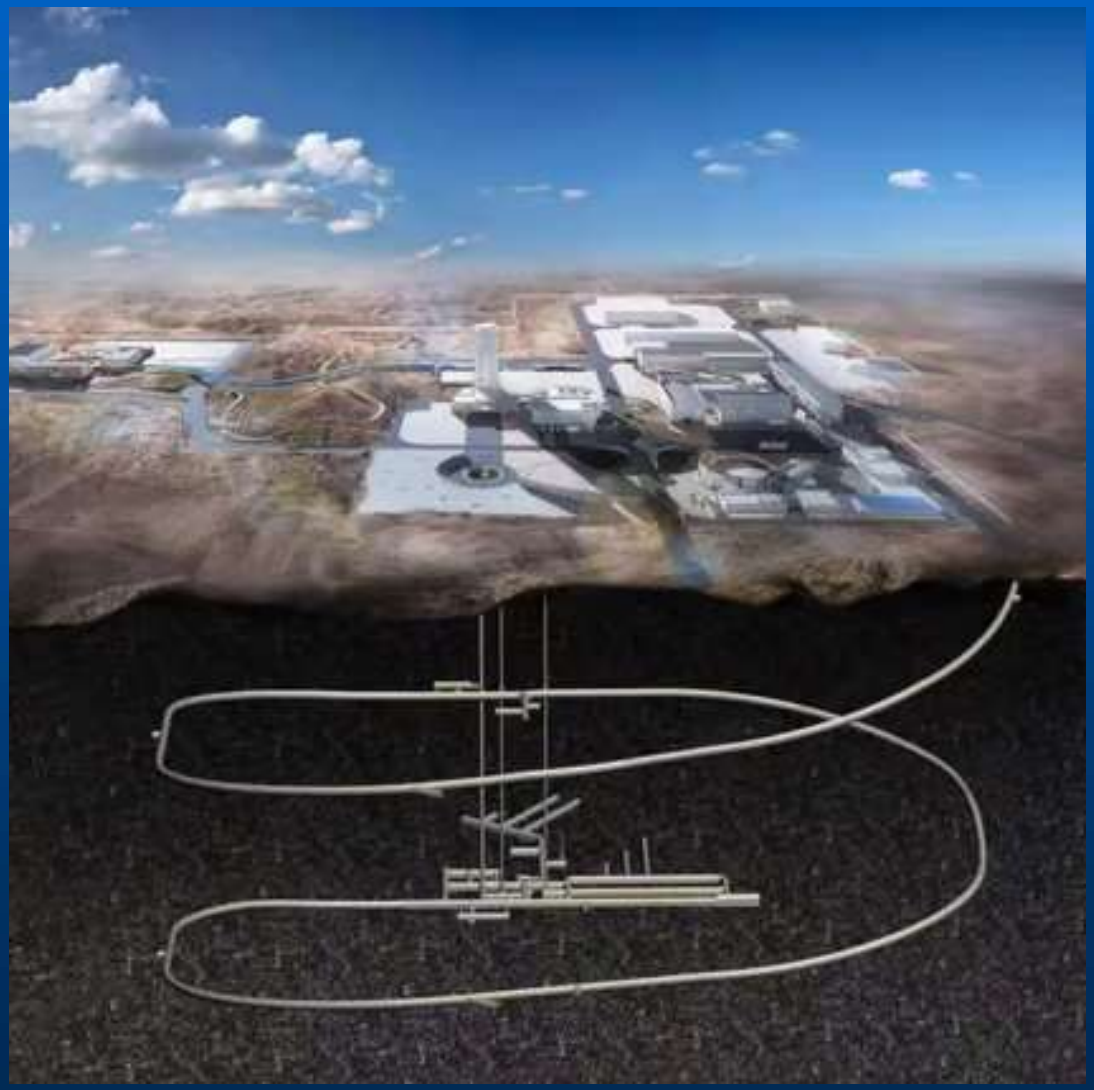
The Lanzhou Complex was China's main site for highly enriched uranium production for nuclear weapons. In 1997, it shut down for more advanced enrichment technologies (such as gas centrifuges) from Russia. No photos located,

Future plans

The Chinese government plans to build a geological repository for vitrified HLW. Site selection on-going, but it will be in a Pre-Cambrian-age granite in northern China.

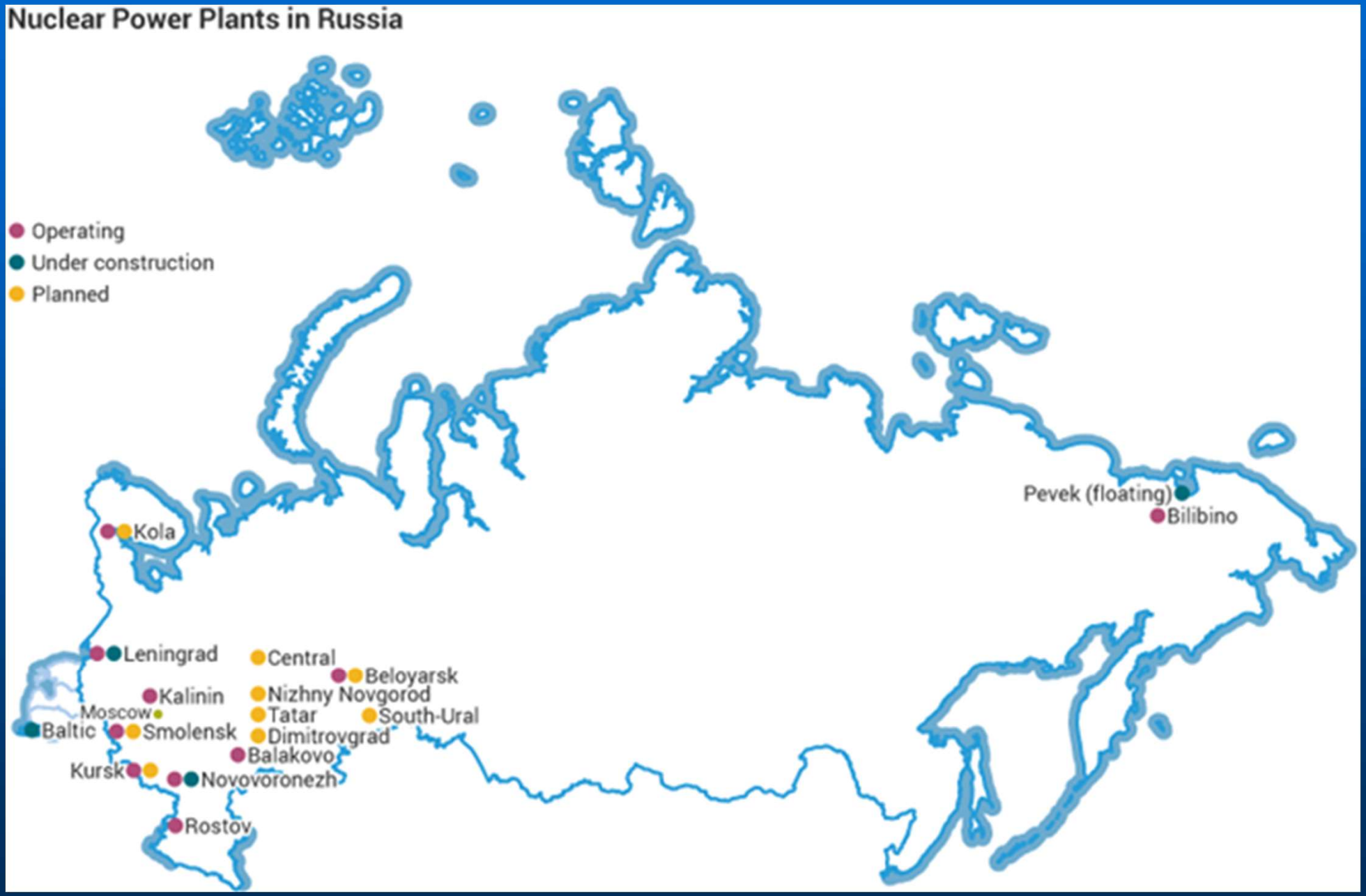
An underground research laboratory is under construction and the repository may be operational by about 2050.

Beishan Underground Research Laboratory



Russian Federation

37 power reactors (20 water-water energetic, 10 high-power channel, 3 light-water, and 2 sodium-cooled breeder reactors) located in 10 power plants. 19% of the country's electricity was from nuclear energy in 2019 (no update available).


Nuclear Power Plants in Russia
Operating
Under construction
Planned
Kola
Leningrad
Kalinin
Moscow
Baltic
Smolensk
Kursk
Central
Beloyarsk
Nizhny Novgorod
Tatar
South-Ural
Dimitrovgrad
Balakovo
Novovoronezh
Rostov
Pevek (floating)
Bilibino

Russian Federation

Rosatom plans 40 to 50% electricity from nuclear power by 2050.

Three plants under construction.
27 planned.
21 proposed.
10 being decommissioned.

Russia

Russia can enrich uranium, fabricate reactor fuel, chemically reprocess used nuclear fuel using the Purex process, and vitrify the raffinate wastes.

Russia has about 9% of the world's resources of uranium. It has numerous underground mines, and in-situ leaching facilities. Russia is a major exporter of uranium.

Russian radioactive waste classification

Resembles the IAEA system:

Waste category	Alpha + transuranic sources	Beta sources
	Bq/g	
Very Low-Level Waste (VLLW)	< 100	< 1,000
Low-Level Waste (LLW)	100 to 1,000	1,000 to 10,000
Intermediate-Level Waste (ILW)	1,000 to 10^6	10,000 to 10^7
High-Level Waste (HLW)	> 10^6	> 10^7

Waste management

The National Operator for Radioactive Waste Management (NORWM) is responsible for radioactive wastes and used nuclear fuel.

NORWM plans to establish some type of regional sites for LLW and IWL.

Liquid wastes (low-level and high-level) are disposed by deep-well injection.

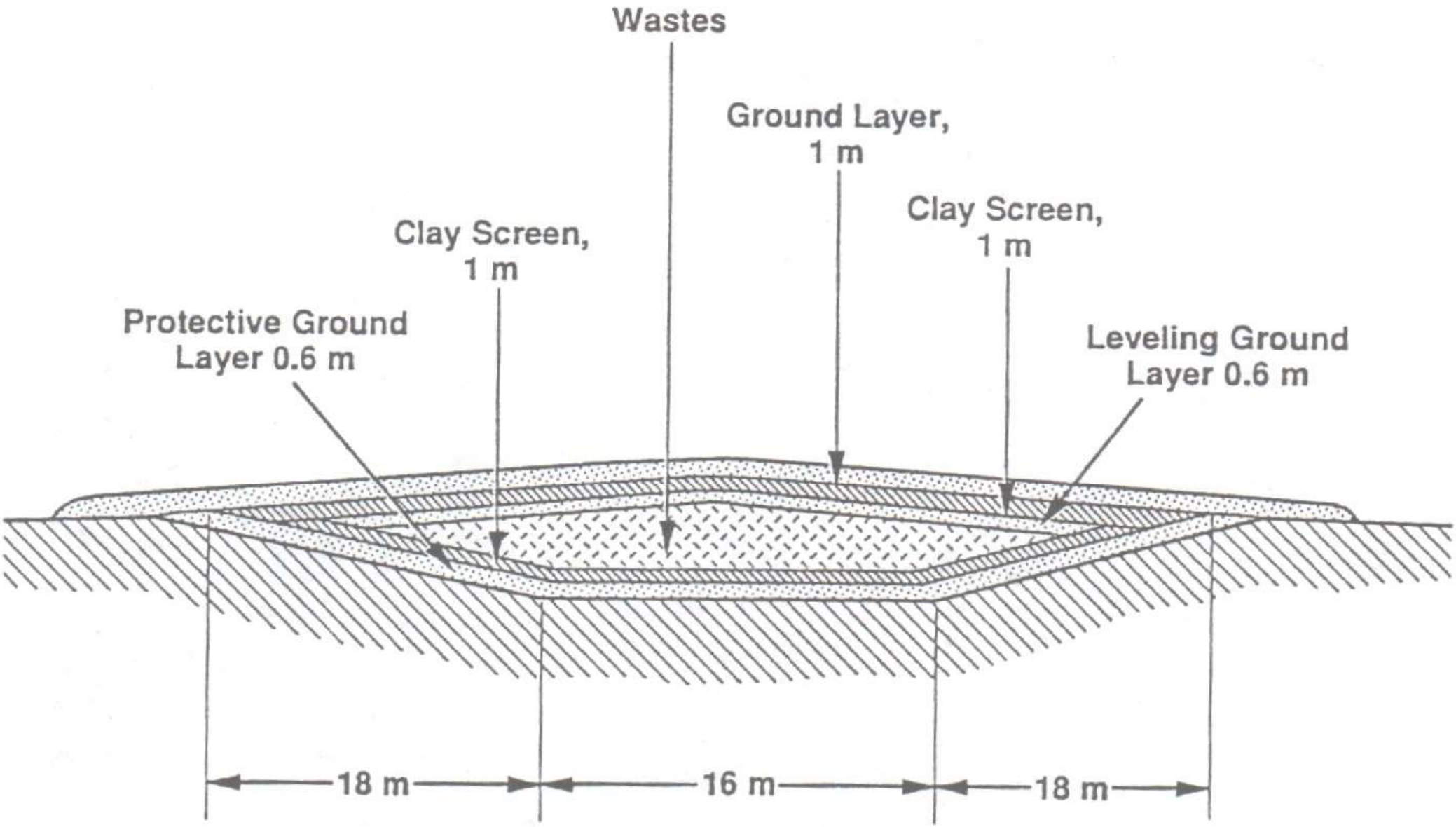


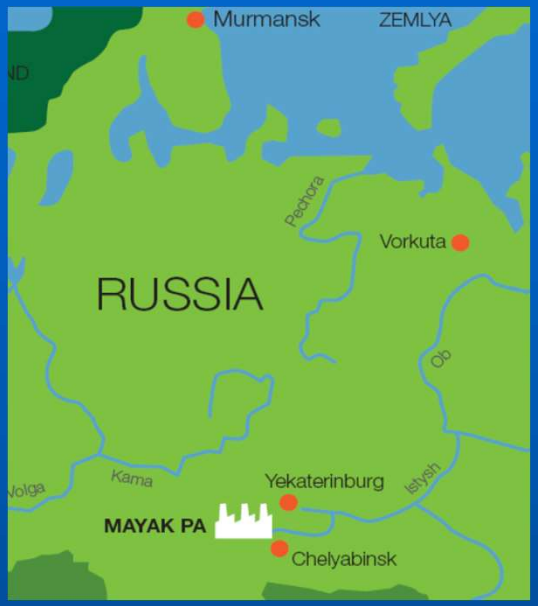
Figure 16.2. Diagram of Low- and Intermediate-Level Waste Disposal Facility Near Chornobyl

Spent nuclear fuel in Russia

Russian policy is to reprocess UNF and to use Pu in MOX fuel. Recently however, only 16% of the used fuel was reprocessed. At present, however, UNF from pressurized-water reactors is in wet storage and in dry storage casks.

UNF from VVER (water-water energetic reactors) and naval reactors is chemically reprocessed at Mayak using Purex.

Mayak



Raffinate wastes are vitrified at Mayak and stored on-site. Historically, there was little distinction between LLRW, SNF, and HLW from the Cold War and utilities, and were co-disposed in rivers and ponds and were undocumented.

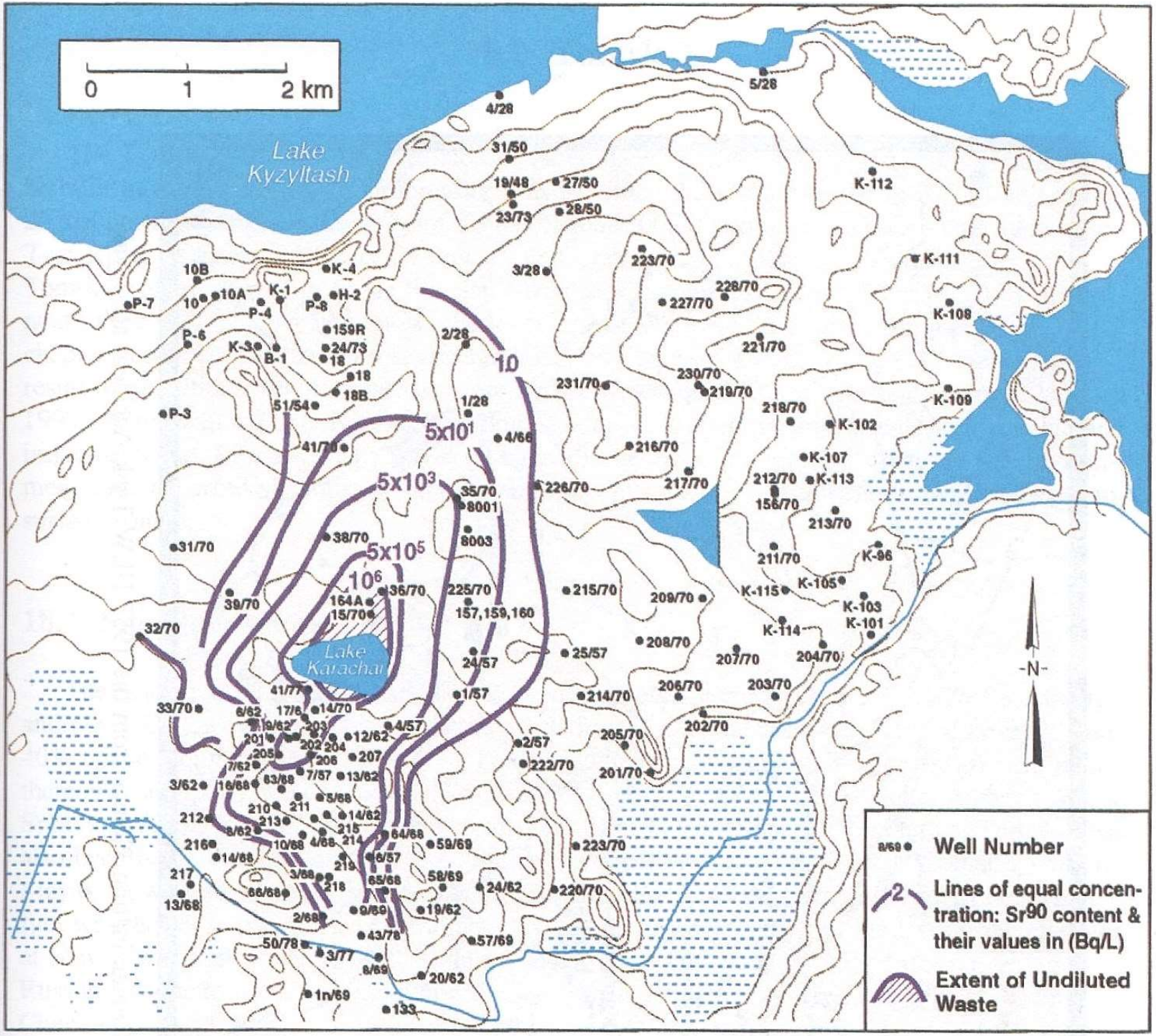


Figure 17.27. Migration of ^{90}Sr from Lake Karachai in 1990

At Mayak

There are 206 underground storage tanks, and 25 above-ground tanks, containing a total of about 224 million Ci (8.3 million TBq).

Russia plans to establish a deep geological repository for the ILW and vitrified wastes. The Kola Peninsula has been chosen for detailed field studies.

Russian plans

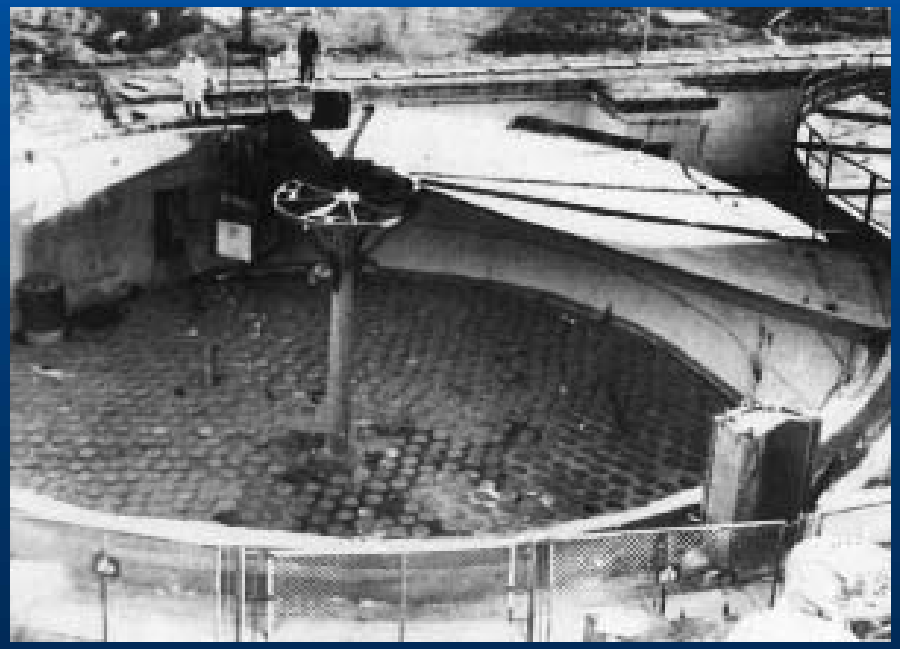
NORWM proposed to construct an underground research laboratory (URL) in Pre-Cambrian granite.

The geological repository may be constructed by about 2035.

No details are available for the ULR or the repository.

Legacy SNF

21,000 SNF units from submarines are stored in concrete tanks at Andreeva Bay on the Kola Peninsula.



Some SNF exposed!

Widespread contamination around Moscow

Trucks transporting radioactive wastes along the roads of Moscow often spilled wastes prior to about 1990.

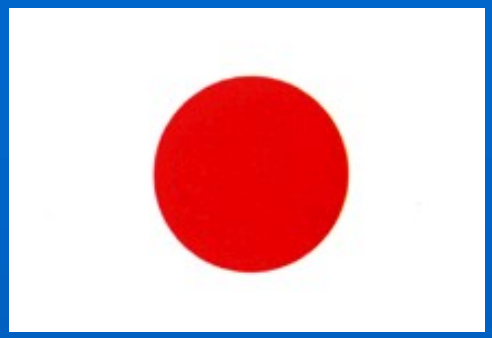
A rod of ^{60}Co was found in a children's play area with an activity of 4 rem/hour.

Widespread contamination around Moscow

A 612 mrem/hour source was found in a sandbox at a day-care center.

A housing project was built on a former radioactive dump. Activities up to 1.8 rem/hour.

From:
Behind the Nuclear Curtain: Radioactive Waste Management in the Former Soviet Union by D. J. Bradley. 2017. Battelle Press, Columbus, Ohio, 20 chapters, 12 appendices, 716 p.



Japan

Currently 33 pressurized-water reactors in 15 power plants.

16 may be restarted after the reactors pass new safety standards.

27 may be shutdown.

Japan has the ability to enrich uranium, fabricate fuel, reprocess used fuel using the Purex process, make MOX fuel, and to vitrify reprocessing wastes.

Japan does not have uranium. Must import from Australia, Canada, and Kazakhstan.

Fukushima's impact

In 2002 the Japanese government announced that it would rely heavily on nuclear energy to achieve greenhouse gas emission reduction goals set by the Kyoto Protocol.

However, following the Fukushima accident, in 2011 the government decided that "Japan's dependency on nuclear energy will be reduced as much as possible in the medium-range and long-range future." Specific plans are in a state of flux.

Radioactive waste classification

Japan does not use the IAEA system.

There are two broad categories:

High-Level Waste (reprocessing wastes)

Low-Level Wastes

Used nuclear fuel is not regarded as a waste.

Low-Level Wastes

Four categories based on origin.

1. Power Plant Wastes (referred to as operational wastes in other countries).

2. Long-Lived, Low-Heat Generating Wastes (also informally referred to as Transuranic Wastes and as Mixed Oxide Fuel Fabrication Wastes).

Low-Level Wastes

3. Uranium Wastes (derived from uranium enrichment and fuel fabrication).

4. Facility Wastes (derived from research and medical facilities).

The Ministry of Economy, Trade, and Industry is responsible for waste management policy.
Japan Nuclear Fuel Ltd manages LLW.

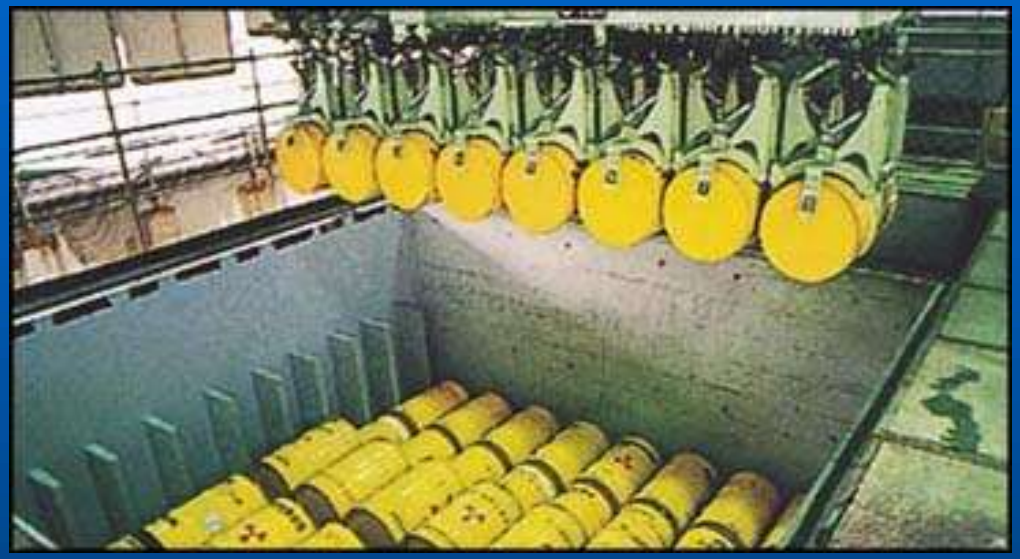
LLW management

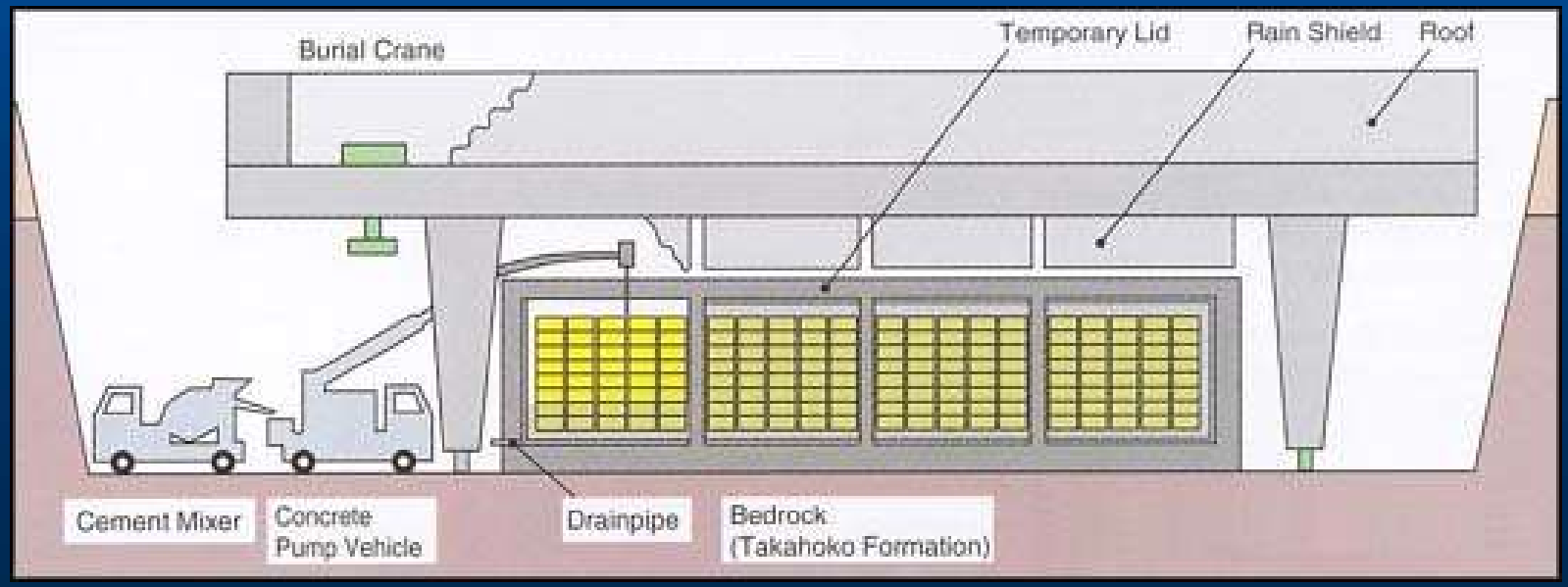
Japan Nuclear Fuel operates the Rokkasho Low Level Disposal Centre.

Near-surface trenches excavated into bedrock. In operation since 1992.

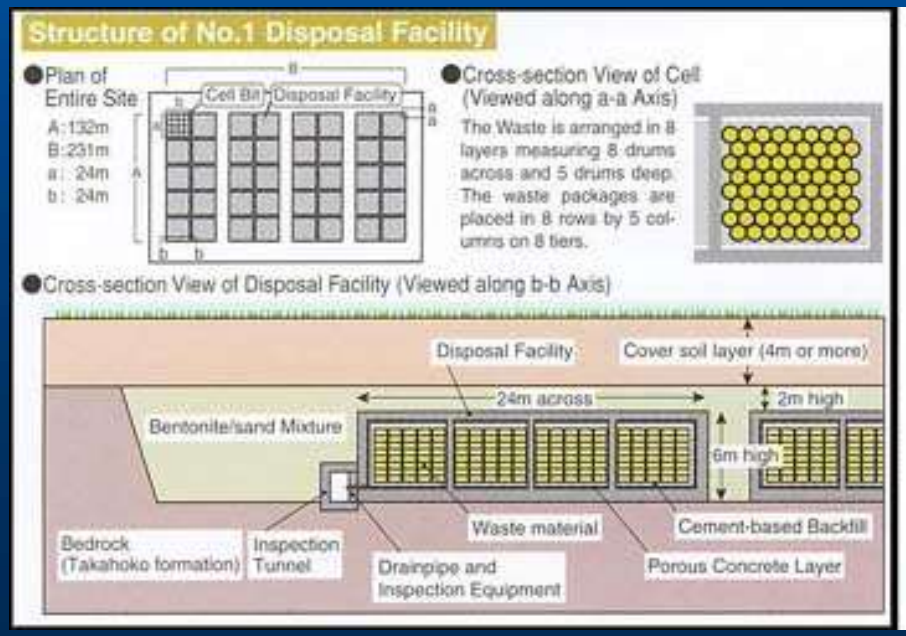
200-L drums from all power plants are sealed with concrete then stacked in concrete vaults at Rokkasho.

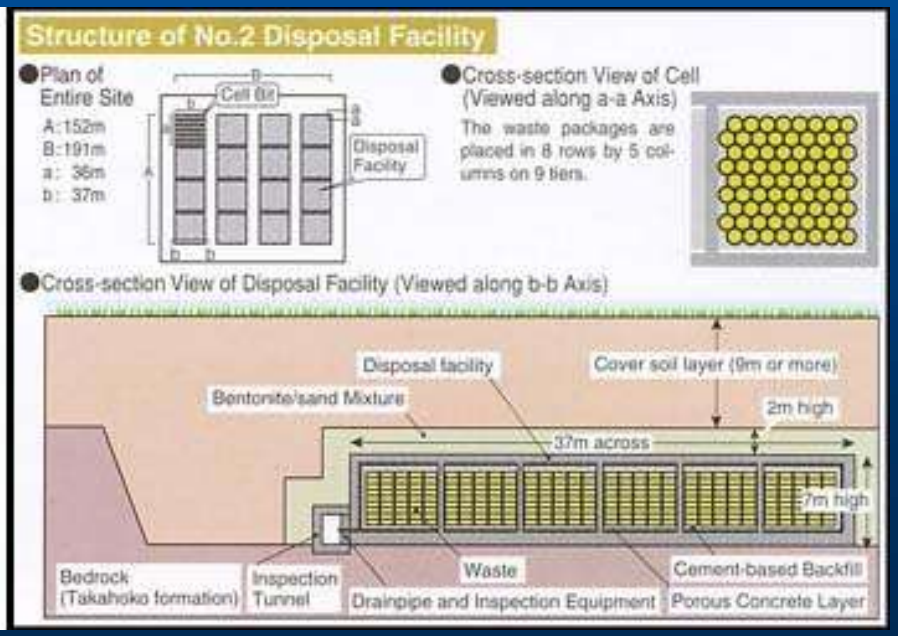
Stacking of LLRW drums





Covered with concrete then buried with soil





Used nuclear fuel management in Japan

It is the policy of the Japanese government to chemically reprocess used nuclear fuel.

Japan has few natural resources, and it is economical to use MOX Fuel. Used fuel is stored by wet and dry cask storage.

TEPCO, Fukushima-Dai-Ichi
under Restoration
1995-, 9BWR (74tU)

JAPCO, Tokai-Dai-Ni NPS
under Operation
2002-, 15BWR (160tU)

Interim storage

An interim used fuel storage facility was constructed in Mutsu. The Recyclable Fuel Storage Centre is expected to begin operating in 2023 with an initial capacity of 3,000 tonnes of used fuel. A groundbreaking ceremony for the facility was held on 31 August 2010.

Ready, steady, go! RFS president Kubo Makoto signals the start of construction at Mutsu

Interim storage of SNF in Mutsu City in a dry-cask, away-from-reactor facility by the Recyclable-Fuel Storage Company

Table 2.3. Mutsu interim storage

Technology	Dry storage
Capacity	5,000 tHM
Status	Planned
Construction cost	¥100 billion (including dry casks)
Year of Operation	2023

Figure 2.4. Mutsu interim storage facility (Image)

Japan chose reprocessing over geological repositories for UNF

Because of Japan's nuclear regulatory requirements, utilities *must* submit evidence that their UNF will be reprocessed before they load fresh fuel.

In the past, Japan made long-term contracts with reprocessing companies in France and the UK.

Reprocessing shipping via the Panama Canal

2,940 tons (2,670 tonnes) of UNF shipped to France for reprocessing from 1969 to 1990.

4,100 tons (3,720 tonnes) of SNF shipped to the UK.

From 1995 to 2007, 700 tons (635 tonnes) of vitrified HLW shipped from France to Japan for disposal. vHLW from the UK were shipped from 2008 to 2016.

The Rokkasho Complex

Timeline:

In 1993, construction began of plants for reprocessing used nuclear fuel, MOX fuel fabrication, high-level waste vitrification, and a low-level waste site.

2006: Greenpeace launched a campaign against Rokkasho called "Wings of Peace—No More Hiroshima Nagasaki!"

The Rokkasho Complex

2008 to 2013: Testing of the reprocessing and vitrification plants. Problems with the furnaces required that they be redesigned and retested. This also delayed progress at the reprocessing plant.

Japan Nuclear Fuel Limited recently announced that the complex would be fully operational soon.

Rokkasho Complex

The need for a geological repository

In 2000, the Japanese Diet passed the Law on Final Disposal of Specified Radioactive Waste for (only) vitrified waste from reprocessing and TRU wastes.

The Nuclear Waste Management Organization (NUMO).

Site selection, operation of a monitored retrievable storage for 50 years.

Underground Research Labs

The Japan Atomic Energy Agency has established two underground research laboratories (URL)

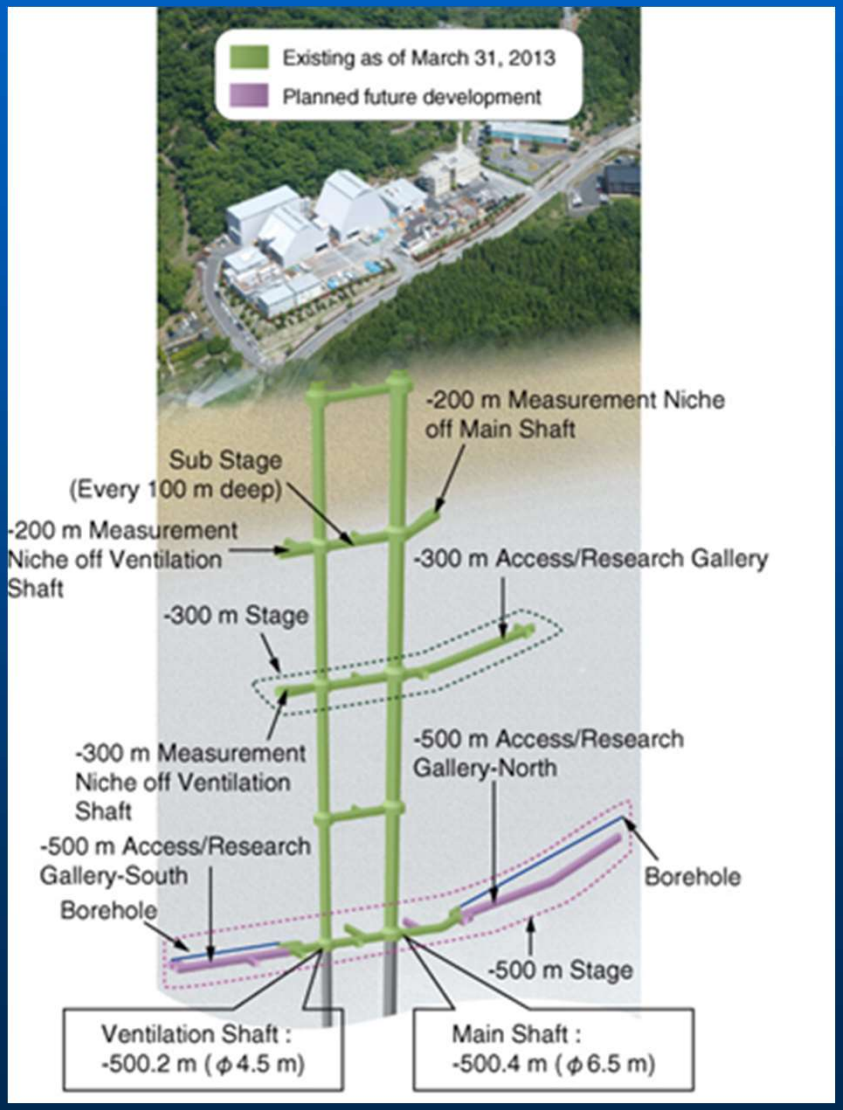
The Mizunami URL

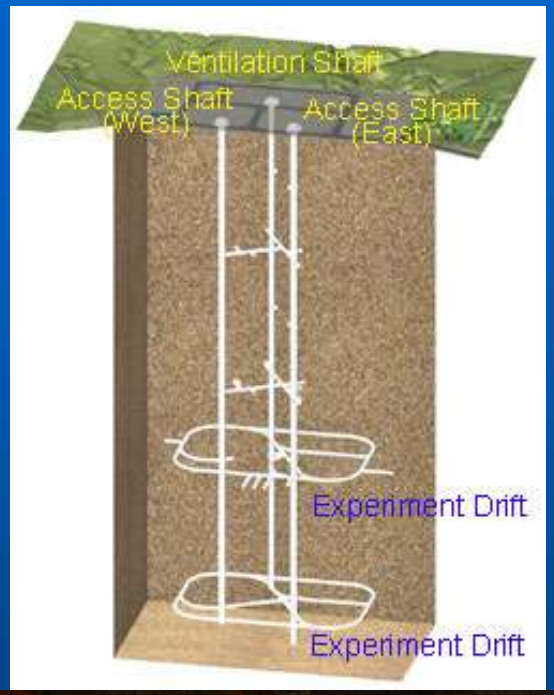
Currently 500 m deep in Cretaceous-age granite

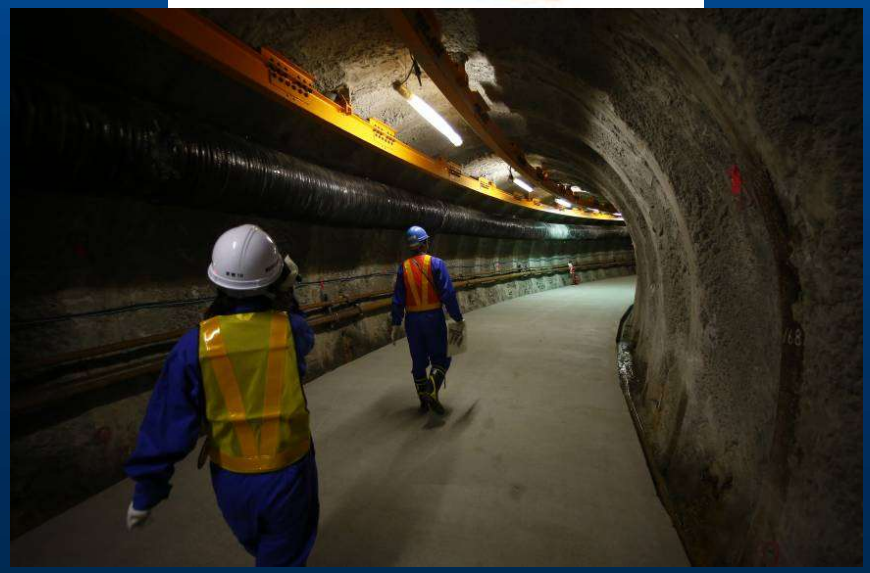
The Horonobe URL

Currently 350 m deep in Neogene-age mudstone.

Mizunami (left) Horonobe (right)







Underground Research Labs

Purpose of URLs: collect field data and gain experience necessary for the construction of the geological repository.

Research includes hydrogeological, geochemical, geophysical, rock mechanical investigations, and geological mapping.

A geological repository

Expected cost: JPY 3,000 billion to be paid by funds accumulated at 0.2 yen/kWh from the electric utilities paid to NUMO.

20 vitrified-High-Level Waste canisters in steel casks surrounded by bentonite.

A geological repository

The CAvern REtrievable (CARE) concept:

the repository is implemented in two distinct stages; in the first, ventilated underground caverns are operated like a surface storage facility, with waste being fully accessible.

CARE

When a decision is made to close the repository (after about 300 years), the caverns (excavations) are then backfilled and sealed.

An advantage of this option is thermal loading is decreased by the radioactive decay of during the storage or institutional control period. Also, CARE emphasizes the ease of inspection and waste retrieval over long-time.

A geological repository

The CARE concept could be applied to used fuel, but the canisters would require additional shielding.

Retrievability would be a greater priority because of the potential for reprocessing when compared to vHLW.

A geological repository

A supplemental waste bill in 2007 required the government to help “the public understand . . . [and] get [public approval] without delay.”

Seeking communities to volunteer to host the repository, but none have.

In 2014, "The government will play an active role in choosing a permanent place. We will abandon the current system of waiting for volunteers to raise their hands."

A geological repository

NUMO expects that the site-selection process will be completed by 2030.

Republic of Korea

25 reactors (9 pressurized-water, 3 pressurized heavy-water, 11 optimum power [Korean], advanced power [Korean]), in six power plants provide 27% of the country's electricity (2020). Three reactors under construction.

Republic of Korea

ROK can fabricate reactor fuel, but does not enrich or reprocess spent fuel.

ROK has no uranium resources. Must import from Kazakhstan, Canada, Australia, and Niger.

Future directions

The future of nuclear power in ROK was uncertain because then former government wanted to phase it out by about 2057. President Yoon Suk-yeol rejected this policy in 2022! A new policy calls for an increase in nuclear capacity. This would be achieved through the construction of six new reactors by 2033.

Waste classification

Radioactive waste classification is simple:

High-Level Waste (spent fuel)

Low- and Intermediate-Level Waste (LILW) which includes everything that is not HLW. The IAEA system is being considered.

LILW in South Korea

The Korean Radioactive Waste Agency (KORAD) is responsible for managing all radioactive wastes.

KORAD
KOREA RADIOACTIVE WASTE AGENCY

LILW are placed in a near-surface, geological repository called the Wolsong Low and Intermediate Level Radioactive Waste Disposal Centre.

The siting process

In 2000, the Nuclear Technology Institute called for local communities to volunteer to host a disposal facility. Seven volunteered!

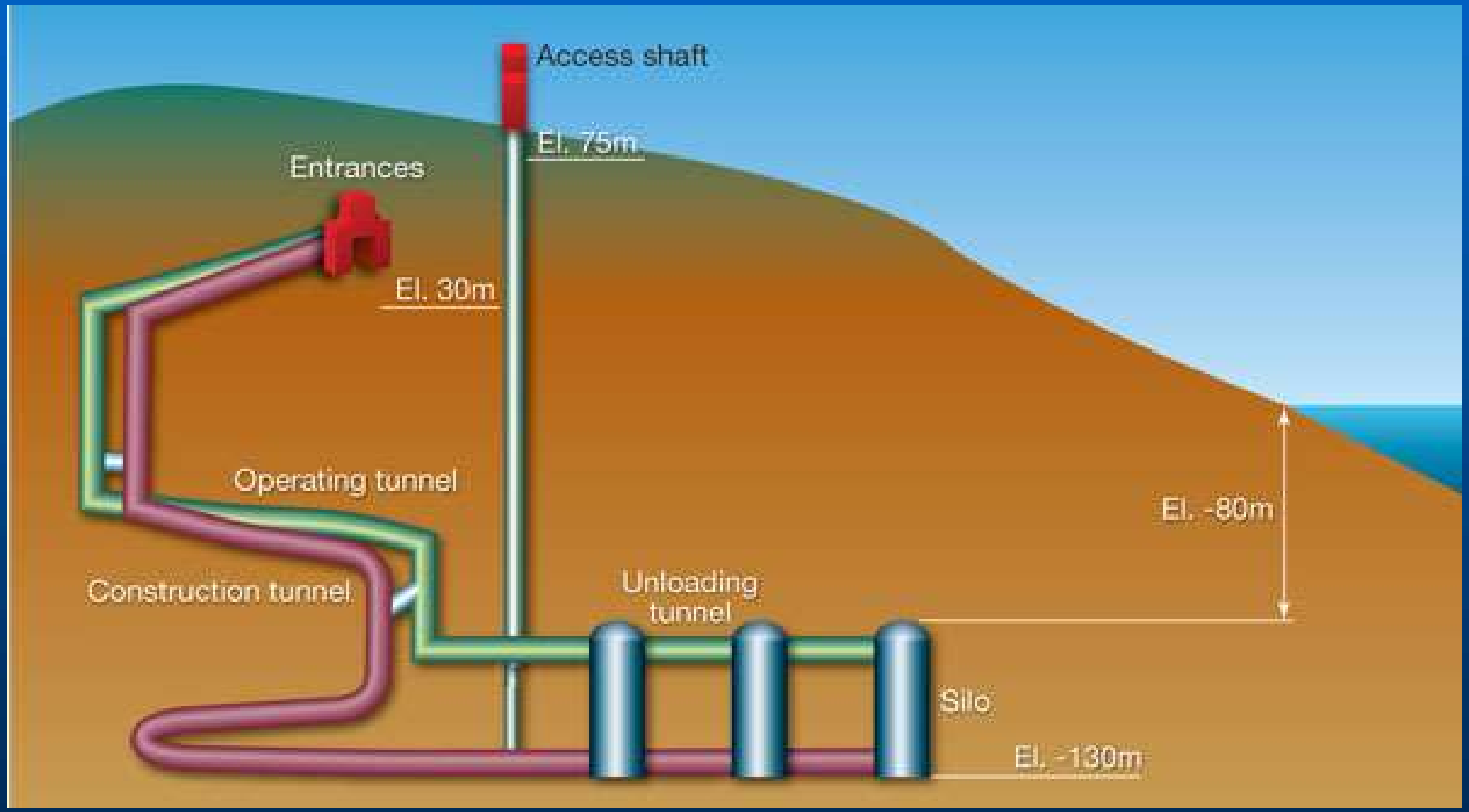
2001: "all local governments vetoed the proposal"

The siting process

2003: The Minister of Commerce, Industry and Energy selected four sites for preliminary site assessments. The area selected will receive 300 billion won ($290 million) to "compensate for the psychological burden on residents"

In 2005, the Gyeongju site was selected on the east coast with about 90% approval by the residents.

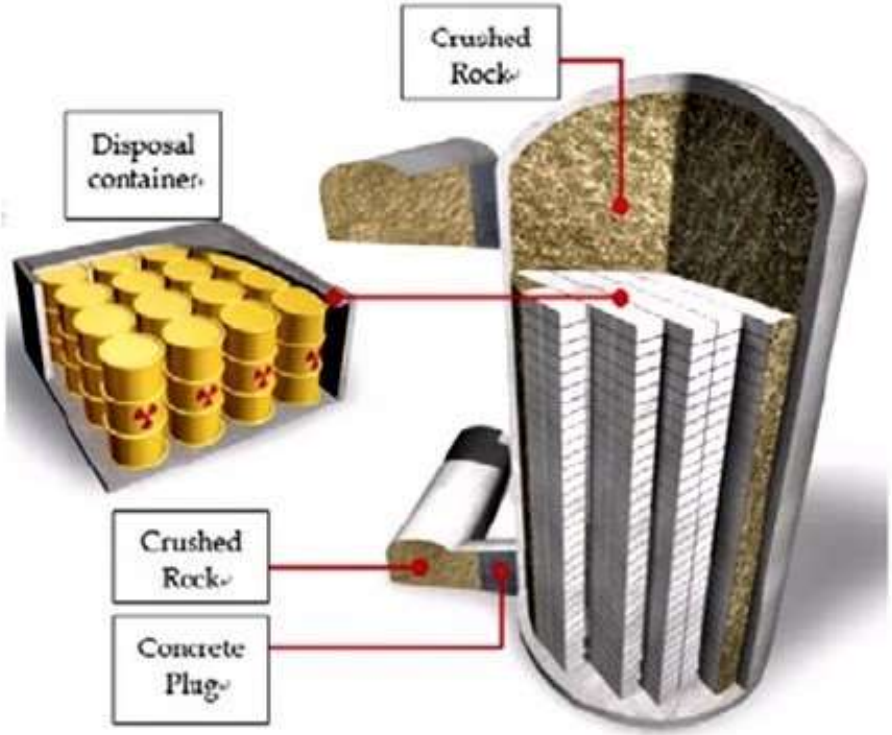
The Wolsong LILW Disposal Centre

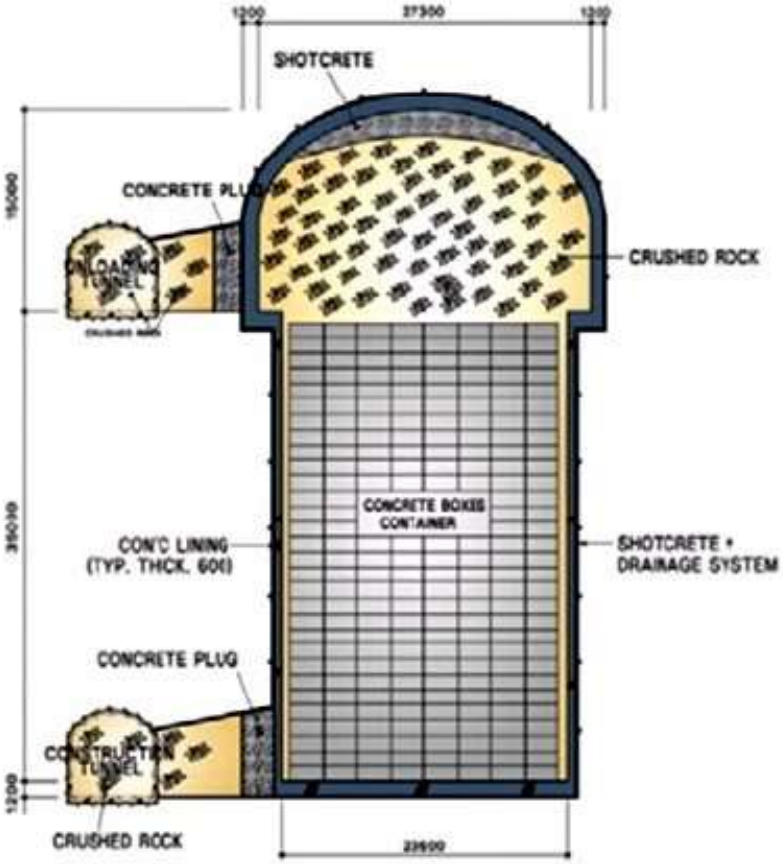


A bird's – eye View of Wolsong LILW Disposal Fac

KRMC

Underground Silo





KRMC

LILW and spent fuel

Spent fuel is stored by wet (14,000 tonnes) and dry cask storage. MACSTOR modules in use.

https://www.youtube.com/watch?v=u3aNvmshpYQ (5:25)

SNF management

KORAD plans to build a “centralized interim storage facility” by 2035 (no details located).

KORAD plans to build a geological repository for spent fuel. They plan to use a consent-based approach. Site selection completed by 2028, and the repository available by about 2055 (no details located).

United Kingdom of Great Britain and Northern Ireland

9 reactors (8 advanced gas-cooled, one pressurized-water) in 4 power plants that generate 15% of UK's electricity.

Two new reactors are under construction. Four new reactors are planned for the future.

36 are shutdown.

Need to limit CO_2 emissions said to be important by the government.

UK and uranium

The UK has the ability for uranium conversion, enrichment, fuel fabrication, chemical reprocessing of used fuel, and vitrification, mostly at Sellafield. Reprocessing is currently on hold.

The UK has only minor uranium deposits. There are no active mines. Uranium is imported from Australia.

Sellafield facility in NW England

Waste classification in the UK

	Spent fuel
	High-Level Waste. Also called Higher Activity Waste (HAW) **Significant decay heat**
↑ ***Activity***	**Intermediate-Level Waste (also HAW)** **> 4 GBq/tonne alpha sources and/or** **> 12 GBq/tonne beta and gamma sources**
	Low-Level Waste **< 4 GBq/tonne alpha sources and** **< 12 GBq/tonne beta and gamma sources** **Very Low-Level Waste (high volume and low volume)** **Out-of-Scope (not subject to regulatory control)**

Low-Level Wastes

All solid low-level wastes are disposed at the UK's national facility called the Low Level Repository at Drigg in Cumbria.

In operation since 1959.

Initially a landfill for drums, bags, and debris buried in soil trenches.

Evolved into surface concrete vaults.

The Drigg facility

ILLW, SNF and HLW

Intermediate LLW stored at Sellafield.

Spent/used nuclear fuel stored by wet storage, and dry cask storage.

Used fuel was chemically reprocessed at Sellafield using the Purex process. Currently on hold.

HLW from reprocessing are vitrified based on the French procedure and stored in stainless steel containers in silos for 50 years to allow cooling at Sellafield.

A geological repository

Radioactive Waste Management Ltd plans to construct a deep geological repository for spent fuel, HLW, and some intermediate-level wastes.

The site selection process in on-going. Oddly, there appears to be no plans for establish an underground research laboratory first as done in most other countries.

A geological repository in England but not in Scotland

A geological repository may be available by about 2040 in England. Somewhere.

The Scottish government does not support the development of a geological repository. Their policy to manage higher-activity wastes in "near-surface facilities." No details are available.

Canada

19 Candu (Canada deuterium uranium) reactors in four power plants that produce 15% of Canada's electricity. No new reactors planned. Six are shut down.

Canada has about 8% of the world's uranium resources. Canada has uranium mines and mills and can convert uranium and fabricate reactor fuel. Canada does not chemically reprocess spent nuclear fuel.

Waste classification

Table 10. Broad Classification of Radioactive Wastes, Management Time Frame and Disposal Options (Mostly from IAEA)					
Category	**Exempt and very Low Level Wastes**	**Low Level and Intermediate Level Wastes (LILW) - heat output less than about 2kW m^{-3}, and activity - ILW > 4000 Bq g^{-1}**		**High Level and Transuranium Wastes (HLW) (high radioactivity and >2kW m^{-3} heat output)**	
Half-Life	**Long or short half-lives**	**Half-lives <30y**	**Half-lives >30y**	**Half-lives <30y**	**Half-lives >30y**
Material	Uranium mine and other tailings. Some coal ash. Some wood ash. Phosphate wastes.	Most nuclear maintenance wastes contaminated with fission nuclides. Some hospital and medical wastes.	Some nuclear maintenance wastes, and by-product wastes containing transuranium nuclides.	Separated fission products (Cs-137 and Sr-90 are the significant nuclides). Some retired medical, industrial and research devices.	Spent fuel, if not reprocessed. Retired military plutonium warheads, if not used as reactor Mixed Oxide (MOX) fuel. Defense wastes.
Management or Security Time Frame	Not required. Usually low radioactivity.	Typically less than 20 years, and half-life dependent.	Hundreds to thousands of years, based upon nuclides and half-lives.	Several hundred years, more or less, depending upon half-lives.	Thousands of years. Security of plutonium is the issue, rather than radiation.
Disposal Options	No radiological restrictions, disposal as for other mine wastes	Enclosed surface, or near-surface facility.	Near surface facility or intermediate geological facility	Geological disposal facility.	Deep geological disposal facility.
Radionuclides with half-lives longer than 30 years are regarded as long-lived wastes; those with half-lives less than 30 years are considered short-lived. Intermediate Level Wastes, although containing significant radioactivity relative to low-level wastes, do not give rise to notable heating effects, as do High Level Wastes for the first few years.					

Radioactive Waste in Canada

At present, radioactive waste is generated in Canada from:

uranium mining and milling

refining and conversion

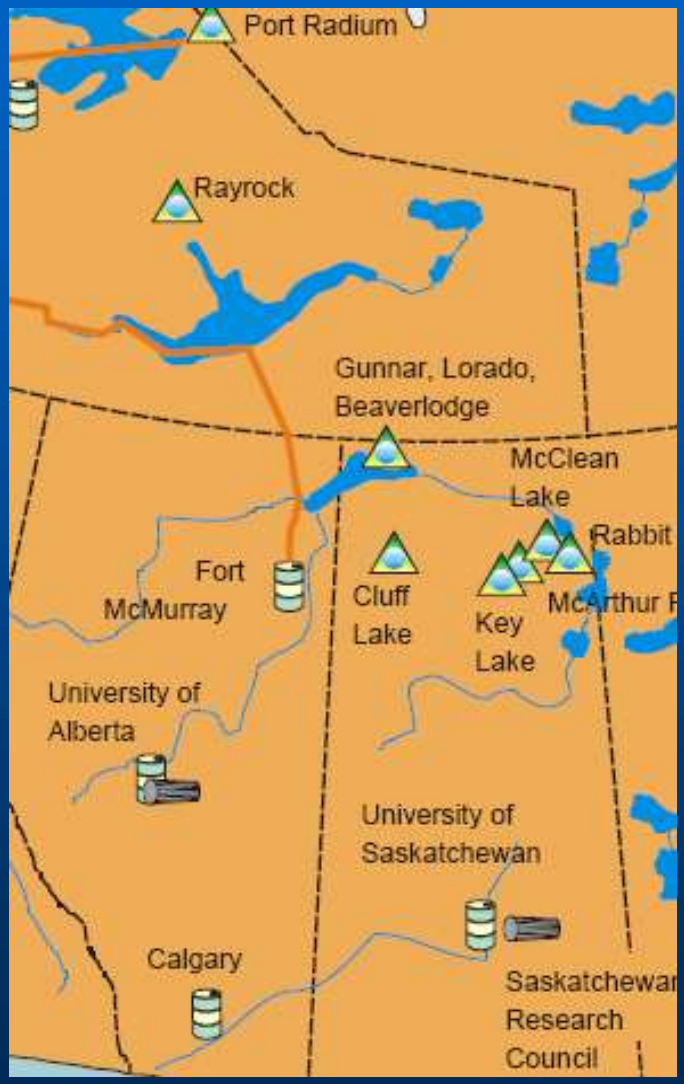
nuclear fuel fabrication

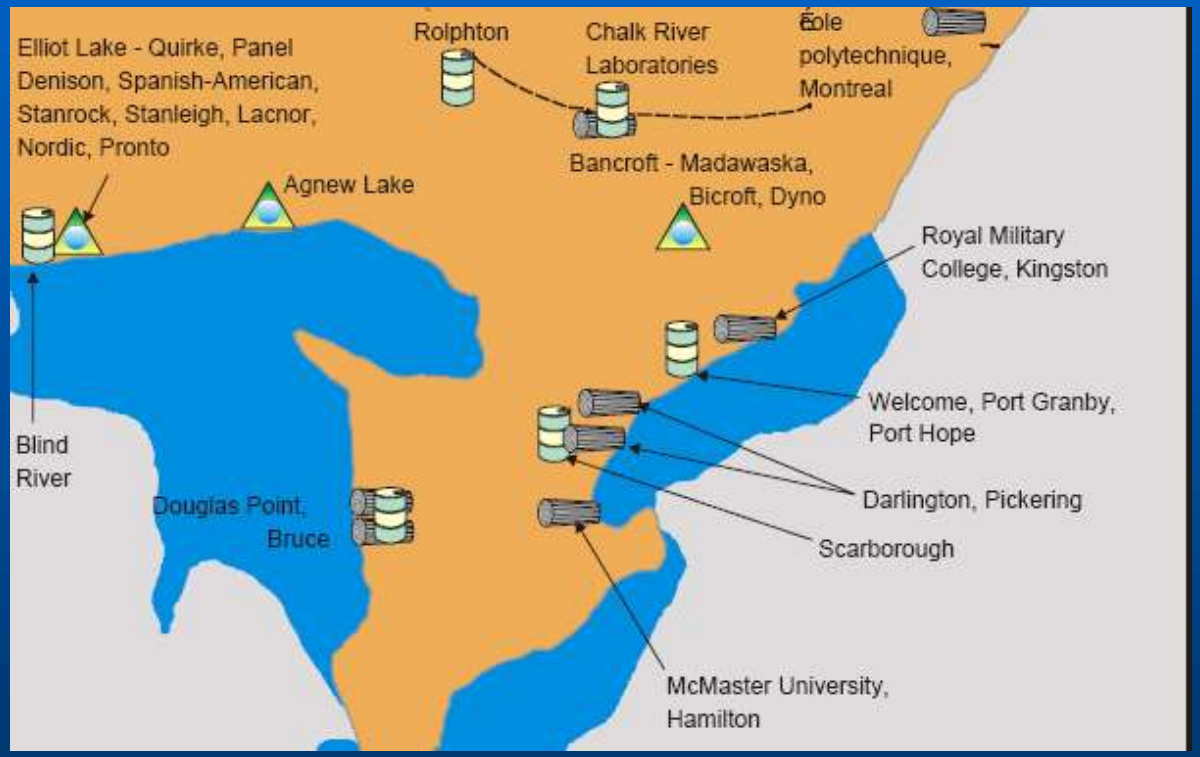
nuclear reactor operations

nuclear research, and

radioisotope manufacture and use.

Radioactive Waste in Canada





LILW management

The nuclear utilities and Canadian Nuclear Laboratories (CNL) are responsible for managing all low- and intermediate-level wastes.

Currently stored in an above-ground concrete warehouse called the Western Waste Management Facility.

The Western Waste Management Facility

Located in Ontario.

LILW may be incinerated or compacted.

Placed in above-ground concrete warehouses.

About 88,000 m^3 of LLRW stored as of 2020. Intermediate waste (such as resins and filters) is stored in steel-lined concrete containers that are set into the ground.

New storage structures are added when needed.

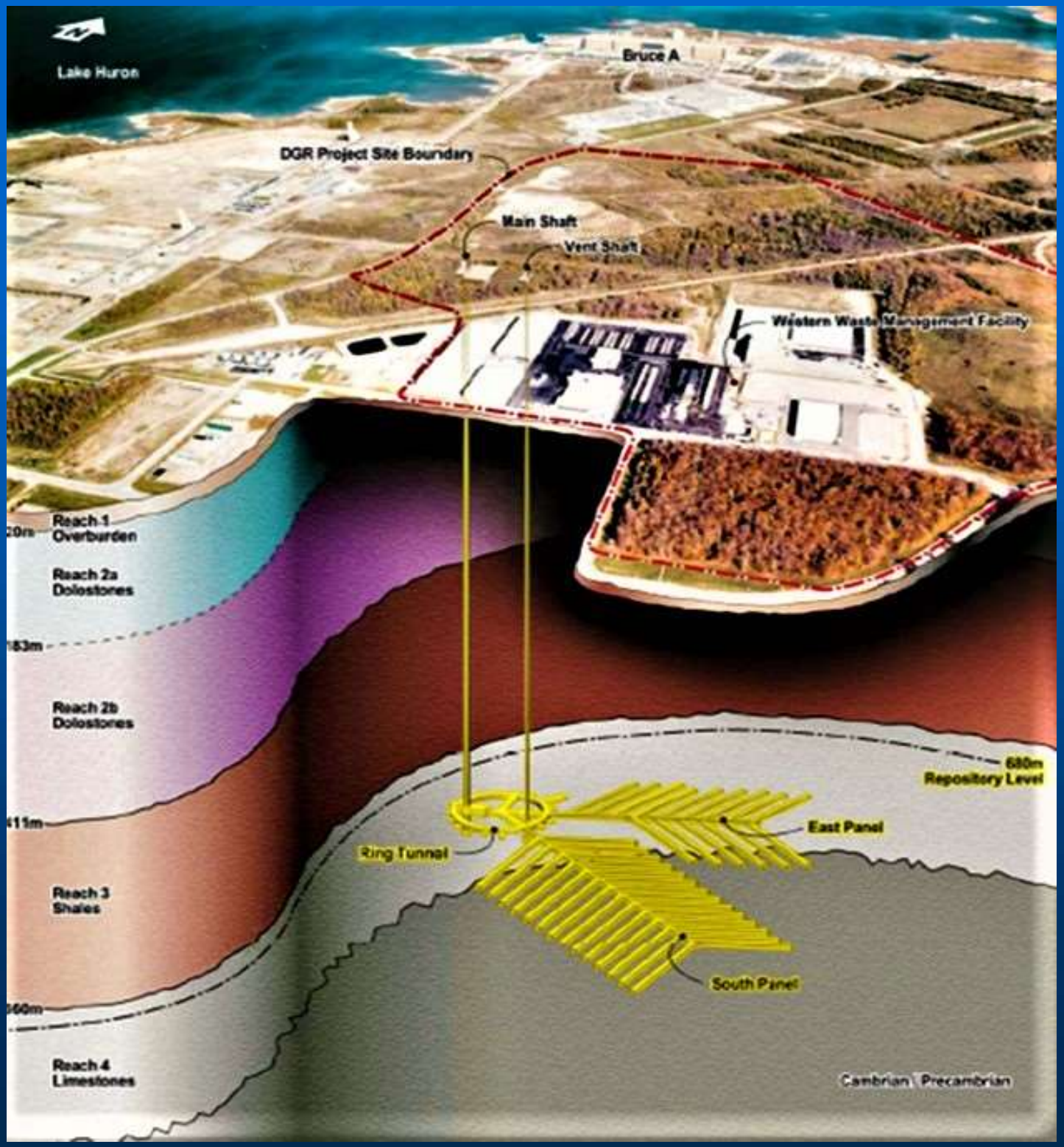
The Western Waste Management Facility

Ontario Power Generation staff carefully lower intermediate level waste into an in-ground storage container.

Low level waste at the WWMF is handled by trained personnel before processing by either incineration or compaction.

A geological repository for LLRW

Following a strong positive response to polling of local residents, Ontario Power Generation (OPG) in 2005 proceeded with plans to construct a Deep Geological Repository for 200,000 m^3 of its low- and intermediate-level wastes. The repository was to be located 680 meters beneath OPG's Western Waste Management Facility, which it has operated since 1974.


Lake Huron
Bruce A
DGR Project Site Boundary
Main Shaft
Vent Shaft
Western Waste Management Facility
Reach 1
Overburden
Reach 2a
Dolostones
Reach 2b
Dolostones
Reach 3
Shales
Reach 4
Limestones
680m
Repository Level
East Panel
Ring Tunnel
South Panel
Cambrian | Precambrian

A geological repository for LILW

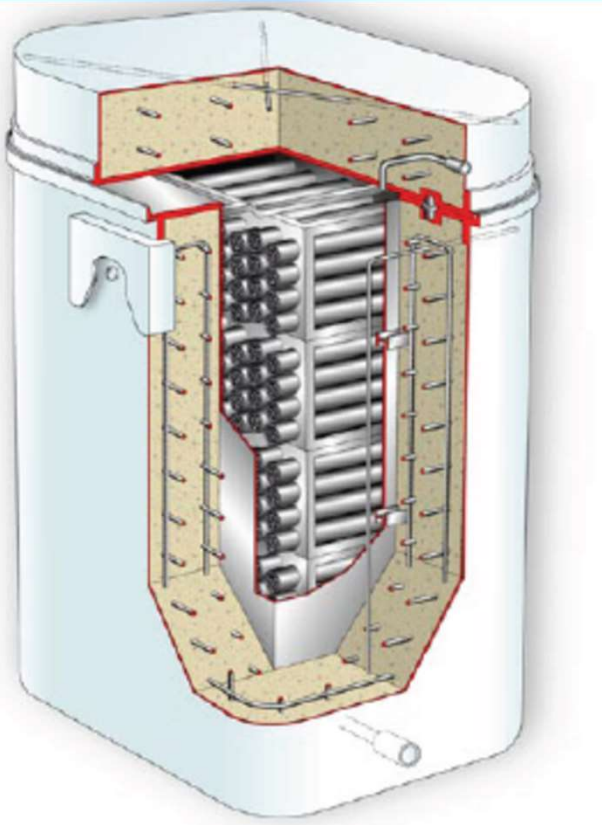
Environmental assessment and licensing has proceeded since, and in 2011 OPG submitted its 12,500-page environmental assessment to Canadian Nuclear Safety Commission.

Unfortunately, because of the objections of local native Canadian tribes (First Nation), the proposed location was cancelled in 2020.

Spent fuel management

After cooling by wet storage, all SNF is dry stored.

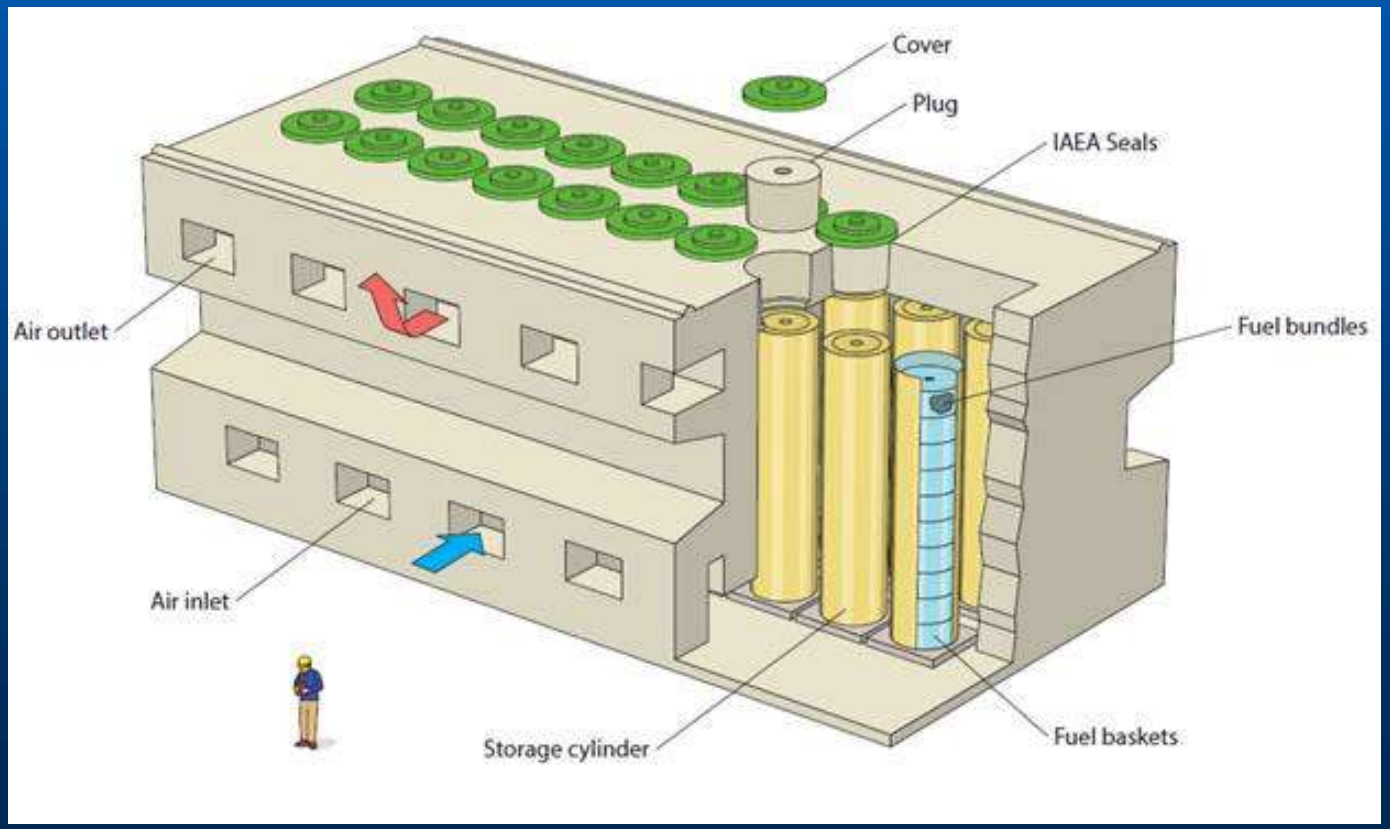
After weld-sealing, painting and installation of the International Atomic Energy Agency safeguard seals, the dry storage containers are placed in the storage building.



Each dry storage container (DSC) is made of reinforced high-density concrete approximately 510 mm (20 inches) thick and is lined inside and outside with 12.7 mm (half inch) thick steel plate. This thickness of concrete provides an effective barrier against radiation.

Spent fuel management

MACSTOR (Modular Air-Cooled Canister Storage): concrete vaults.

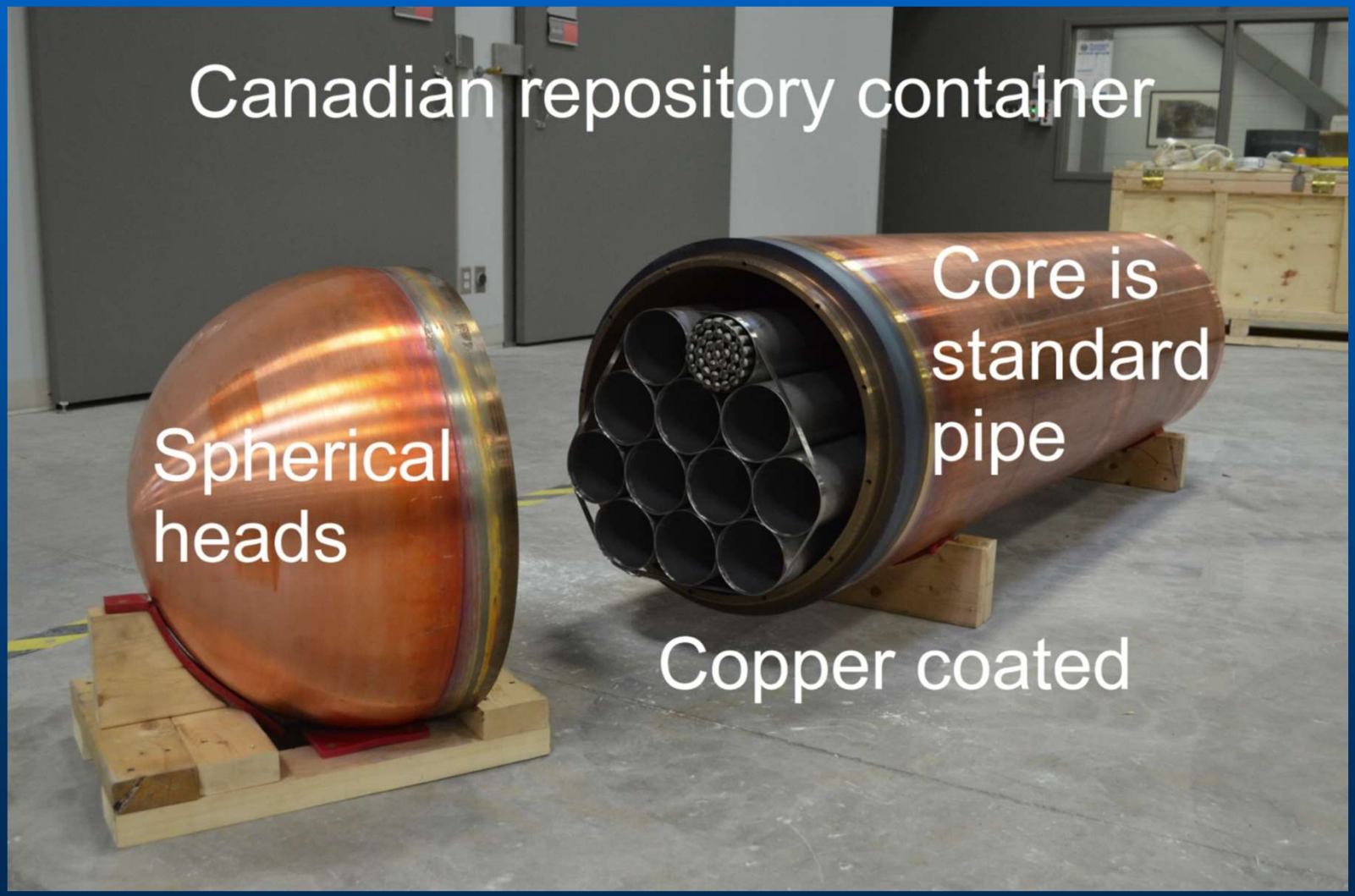


Geological repository for spent fuel

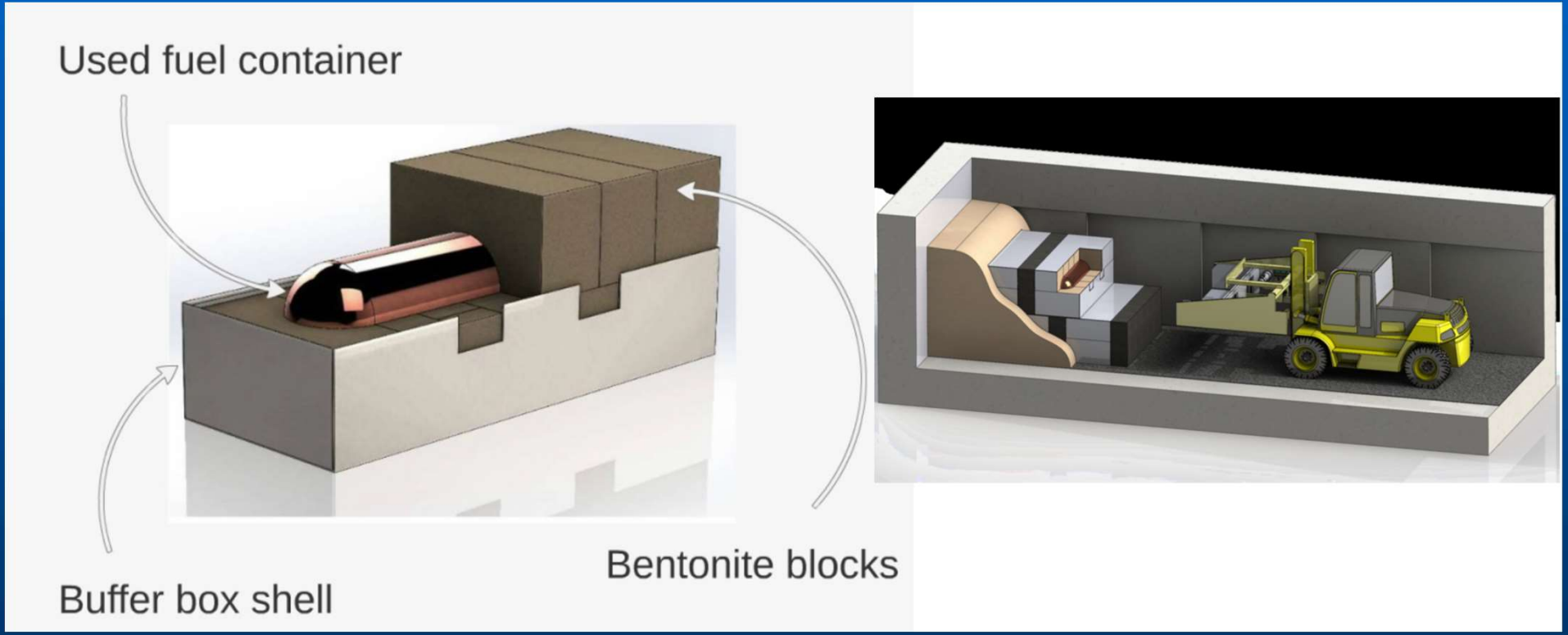
A deep geological repository is planned for SNF 500 to 1,000 m deep in the stable rock of the Canadian Shield, the large formation that extends northward across central and eastern Canada.

The SNF would be placed below the water table in containers packed in bentonite clay. The waste may consist of used fuel bundles or sealed in copper or titanium containers.

Prototype of the Canadian repository container



Prototype of the Canadian bentonite-buffer box



Geological repository high-level wastes (SNF)

Canada's Nuclear Waste Management Organization stated that a repository would probably be in Ontario, Quebec, New Brunswick or Saskatchewan, and host localities would need to volunteer for the role.

NWMO expects to have a repository available by 2035.

Spent nuclear fuel in Canada

https://www.youtube.com/watch?v=OcN7nGQMKyc (5:44)

Federal Republic of Germany

The last three nuclear power reactors were shut down this month. They were generating 12% of the country's electricity. 36 reactors are shut down. No new reactors are planned.

The future of nuclear energy is bleak. All German uranium mines are now closed. Uranium was imported from Canada, Australia, and Russia.

Current status of nuclear energy

Germany could enrich uranium and fabricate fuel. It no longer reprocesses used nuclear fuel. It was a world leader in nuclear energy.

Why the shut down? Anti-nuclear politics.

Public opinion is opposed to nuclear energy.

German has a long history of vacillating between supporting and rejecting nuclear energy.

Indecisive Germany

1974. Germans strongly supported nuclear power.

1986. After Chernobyl the Social Democratic Party wanted to abandon nuclear power by 1998.

2008 poll: 46% wanted the country to continue using nuclear energy;

46% supported the nuclear phase out policy.

2009. The Christian Democrat government decided put the nuclear energy phase-out on hold. Nuclear viewed as an option to reduce CO_2 emissions.

In 2011, former Chancellor Merkel decided to revive the phase-out plan. Public does not support building new plants.

What is fueling the phase-out?

The Green Party (of Germany). Active since the 1970s and anti-nuclear (were actually anti-nuclear weapons at first). Now pro-alternative energy and has gained political power.

(Wind energy is a priority to many Germans).

Chernobyl in 1986.

Fukushima (but not as much as people think).

Likely also fueled by the government's poor record for managing radioactive wastes.

What is fueling the phase-out?

2022: Russia's war with Ukraine led to pressure to rethink, or at least delay, the phasing out of nuclear power with soaring energy prices and the end of gas supplies from Russia prompting fears of blackouts and energy security questions. Following a 'stress test ' of the grid in September 2022, the coalition government - which includes the Green Party - agreed to keep Emsland, Isar 2 and Neckarwestheim 2 on standby until mid-April 2023.

What has the German government said?

Steffi Lemke, Federal Minister for the Environment and Nuclear Safety said the phase-out made the country "safer" saying "with the shutdown of the last three nuclear power plants, we are entering a new era of energy production. So let's continue to work on solutions for a nuclear repository and put all our energy into expanding renewable energies".

Potential ramifications

Germany will not meet its carbon emission targets.

Face greater electricity prices.

Increase its dependence on natural gas imports from Russia. Germany already imports coal and oil.

Will have to import electricity from France, Netherlands, Denmark, Poland, and Russia. *Ironically mostly from nuclear sources.*

Waste classification in Germany

Radioactive waste classification in Germany does not use the IAEA system.

There are only two broad categories:

Heat-Generating Wastes (spent fuel and reprocessing wastes).

Non-Heat Generating Wastes (very low-, low- and intermediate-level wastes).

Waste management in Germany

The Federal Company for Radioactive Waste Disposal is responsible for all wastes.

Germany chose not to have near-surface disposal sites.

They chose to adapt former salt and iron mines as repositories for non-Heat Generating Wastes.

Salt domes in Germany

A salt dome is a type of structural dome formed when a thick bed of salt found at depth flows upward into surrounding rock in response to pressures at depth.

Asse 2 Mine

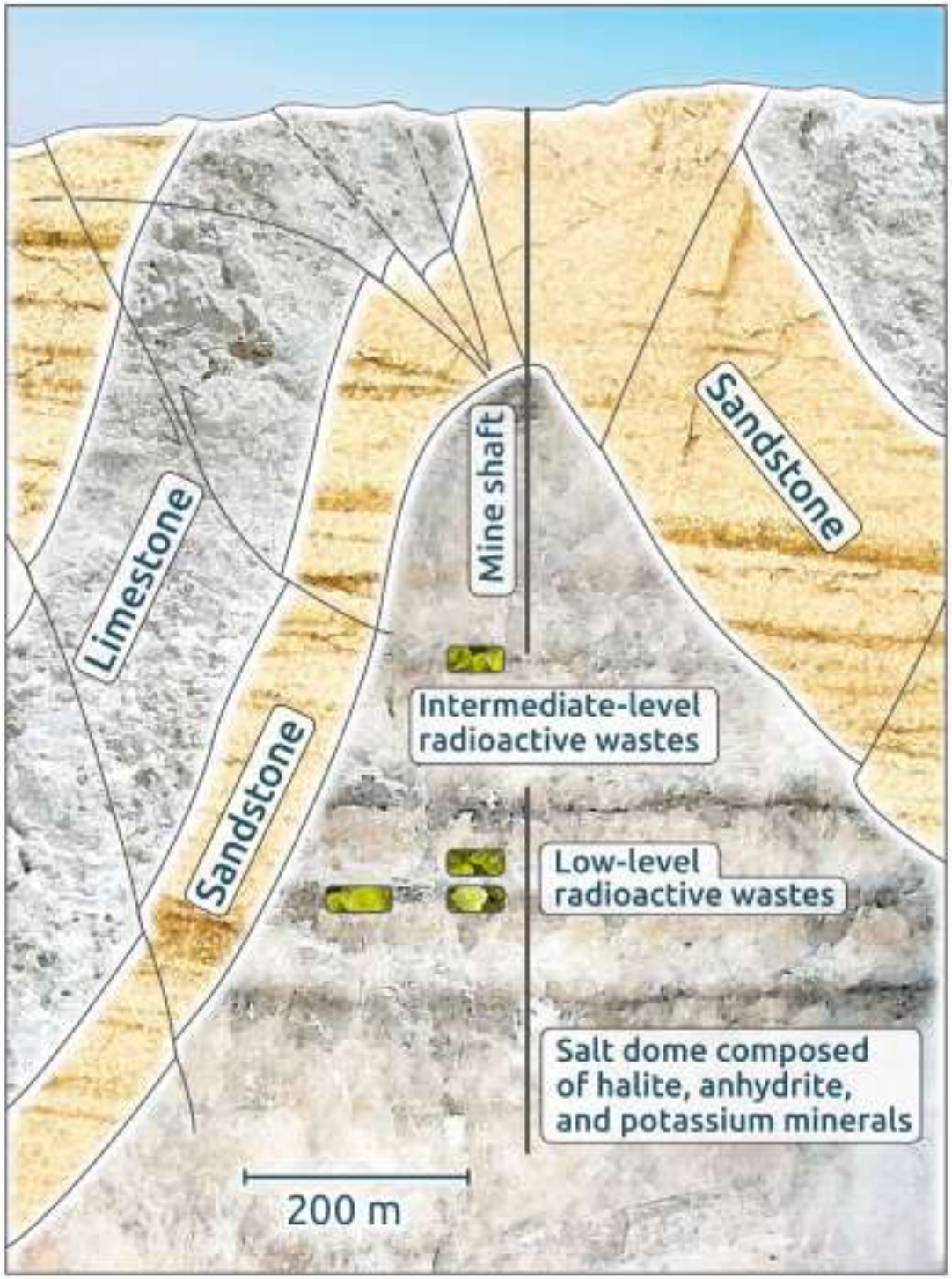
In 1963, the German government recommended salt formations for radioactive waste disposal.

Asse 2 was a former salt mine; used as a geological repository from 1967 to 1978.

Asse as an experimental repository

After the salt mine closed, the German government bought the mine to develop a pilot repository. The mine had a 765 m shaft which was later extended to 950 m for research.

About 1,300 drums of medium-level waste with 1.2×10^{15} Bq, and about 125,000 drums of low-level waste containing 1.7×10^{15} Bq were deposited.


Limestone
Sandstone
Mine shaft
Sandstone
Intermediate-level radioactive wastes
Low-level radioactive wastes
Salt dome composed of halite, anhydrite, and potassium minerals
200 m

Problems at Asse 2

Because it was a former salt mine, some of the walls and ceiling were unstable and collapsed.

(*The mine was not operated to be a waste disposal facility later*).

Because of the structural failures, parts of the mine were flooded with groundwater at a rate of about 12 m^3 per day.

From 1995 to 2004, mine openings were back filled with salt wastes from another mine.

Because of public pressure . . .

In 2009, the German government decided that Asse should show "proof of long-term safety." Because it did not, the site was to be decommissioned. They chose to remove the wastes during the next 15 years at a cost of 3.7 billion Euros.

The waste containers and contaminated salt are to be disposed of at the Konrad Repository.

The Morselben Repository

From 1981 to 1998, non-HGW were placed in the Morselben Repository, a former potash and salt mine. Closed because of public pressure.

Stability problems

Since 1998 the stability of the salt dome at Morsleben deteriorated; a collapse could occur. Since 2003 4,480,000 m³ of salt-concrete have been pumped into the repository to stabilize it. The site is to be decommissioned in the next 15 to 20 years

The Konrad Repository

In 2002, the Konrad site received a license to be a repository for non-Heat Generating Wastes.

The site is a former iron mine.

The application was first submitted in 1982

Now need to convert mine to a repository.

Planned capacity of 650,000 m^3 of wastes.

https://www.bge.de/

KONRAD REPOSITORY MILESTONES

- May 22 – July 15, 1991 Konrad plan presented to the public
- 289,387 objections raised
- 1992 – 25 – 09 / 1993 – 03- 06 Konrad hearing (longest ever)
- 1994 – 1996 License Procedure completed...

DBETEC

DBE

Konrad may be ready for non-HGW by 2027

DBETEC DBE

N
W
E
S
Hamburg
GORLEBEN
SALZ
Bremen
Elbe
Ems
Berlin
Hannover
Braunschweig
MORSLEBEN
SALZ
KONRAD
TON/ERZ
Salzgitter
Magdeburg
ASSE
SALZ
Weser
Elbe
Dresden
Rhein
Bonn
Fulda
Werra
Main
Main

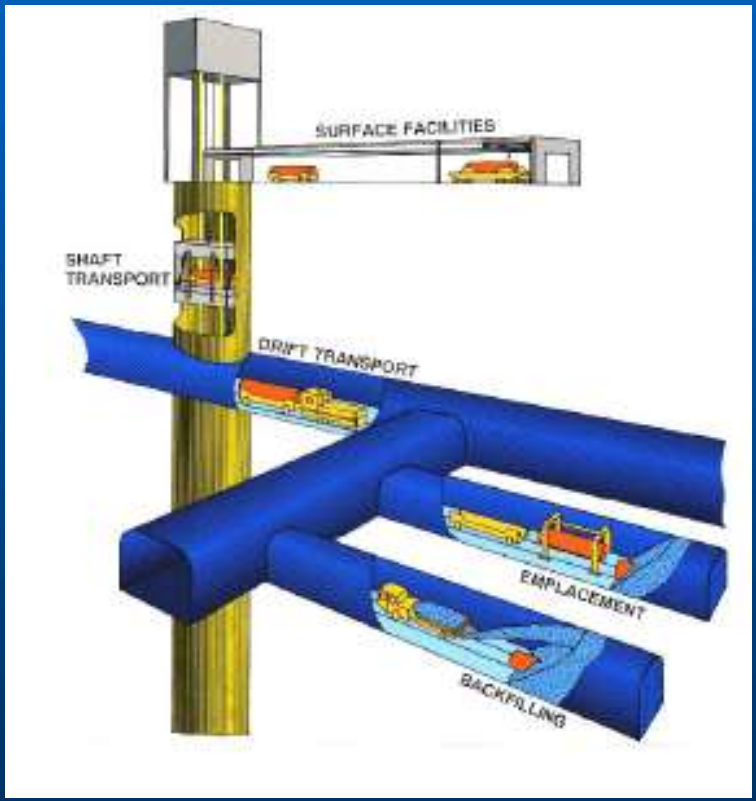
Gorleben

A salt dome at Gorleben was being evaluated at the storage of all both HGW and non-HGW.

The site was first selected in 1977 and field studies started in 1979, then funding for the project decreased.

The project has been suspended for political reasons.

The Gorleben Geological Repository vision



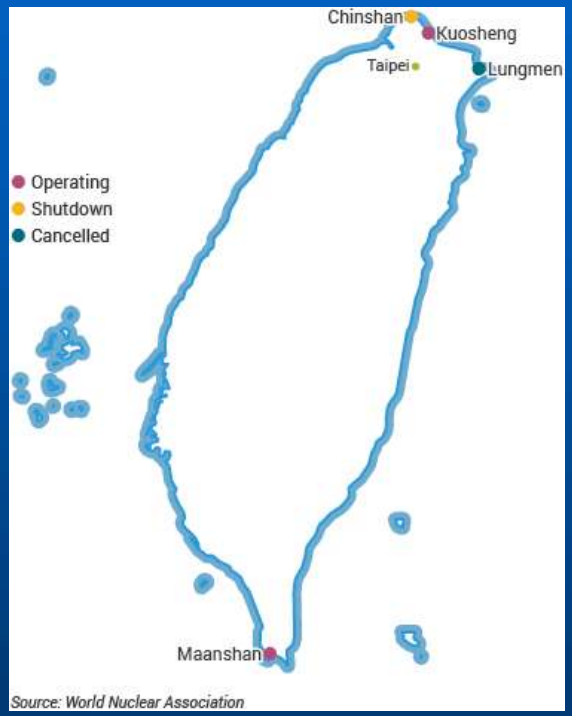
Heat-Generating Wastes in Germany

Spent fuel now stored at power plants in pools and by dry-cask storage.

Germany currently has no definite plans for the disposal of Heat-Generating Wastes.

A site for some type of geological repository might be selected by 2031, and commissioned by 2050. Maybe.

Republic of China

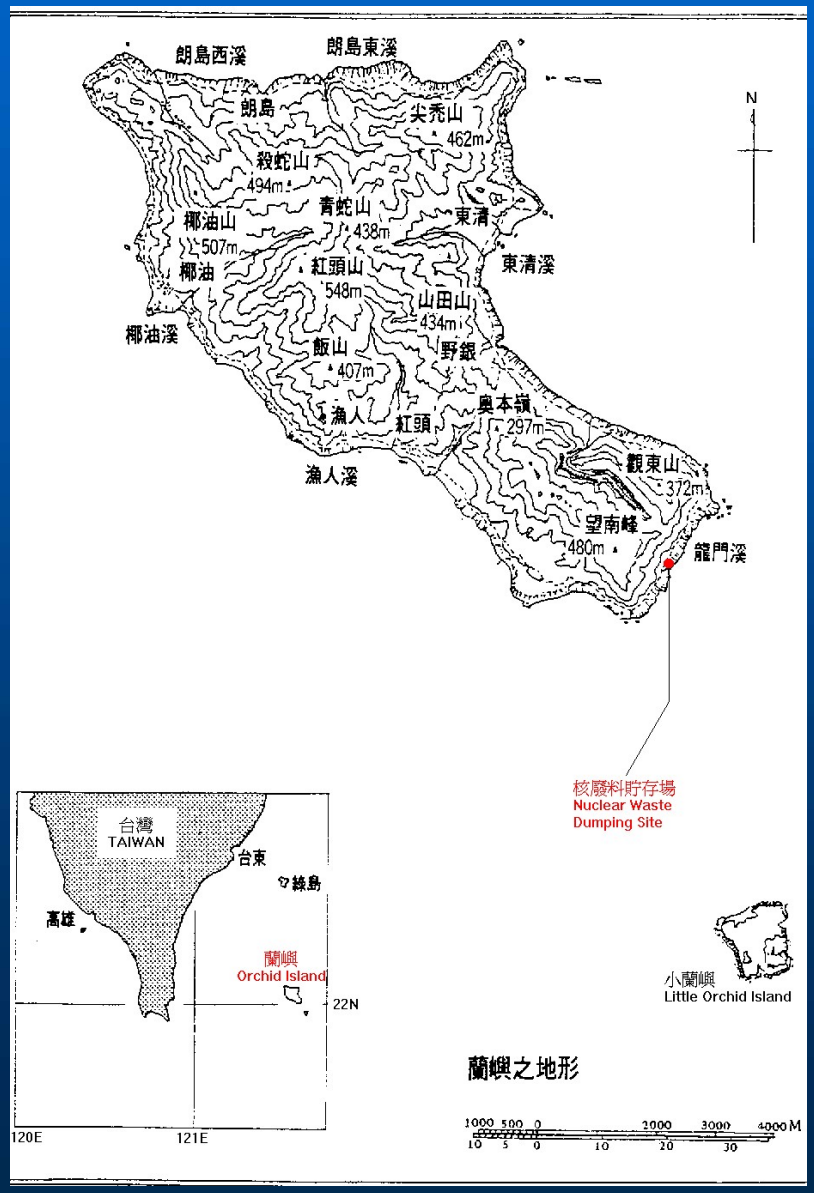


There are two nuclear power reactors located in one power plant that provide 11% of the island's electricity. Four are shut down.

Future of nuclear energy in ROC in doubt. The current government want to phase out nuclear power and increase wind and solar power by 2025.

Low-level waste management in ROC

In 1974, the Atomic Energy Commission of ROC decided to create a site for LLW on the southern tip of the Orchid Island.



Orchid Island (Lanyu) is populated by the Yami people.

The district commissioner was illiterate, and the Atomic Energy Commission told him that they wanted to build a fish cannery.

The commissioner signed off, and site construction began in 1980.

LLW in ROC

From 1982 to 1996, LLW was placed in 23 concrete trenches; AEC had planned to dispose of LLW for 50 years and store as much 340,000 barrels.

Islanders learned the true nature of the site and protested. Because of public pressure, Taipower stopped shipping LLW in 1996. 97,960 barrels had been stored.

http://www.youtube.com/watch?v=7tw1a7OvpFA (3:34)

NIMBY in ROC

In 1997, Taipower tried to pay North Korea to accept 1,000,000 LLW drums for $1,150 per drum. The drums were to be stored in old coal mines. South Korea objected.

Taipower then considered the village of Dawu in ROC, but no agreement was reached.

In 1998, AEC considered another island: Wuqui, but Beijing objected.

NIMBY in Taiwan

2009 Taipower announced that Daren Township (southern ROC) and Wangan Township were LLW candidates.

Chief of Daren Township in favor of proposal because of US $153 million in compensation. Paiwan and Puyuma Aborigines were opposed. Officials and residents in Wangan are opposed.

LLW still has no home

Currently, there are no permanent disposal facilities in ROC for LLW therefore commercial radioactive waste is stored at the source power plants.

Spent fuel is managed by both wet storage at the source power plants, and by dry storage casks.

Spent fuel management in ROC

There is some interest in sending spent fuel to other countries for chemical reprocessing with the understanding that the vitrified HLW will be returned to the ROC.

The Atomic Energy Commission is conducting a feasibility study for deep, geological disposal of spent fuel and the vitrified HLW. A geological repository in granite may be available in 2055.

Kingdom of Sweden

Sweden has 6 nuclear power reactors that provide about 40% of it's electricity. Seven are shutdown.

Sweden does not have uranium mines and does not enrich uranium nor fabricate reactor fuel. Reactor fuel is imported from France and Russia. Sweden does not reprocess spent nuclear fuel.

Radioactive waste classification

Waste category	Characteristics	Disposal
Very low-level short-lived waste (VLLW-SL)	Power plant operational wastes. Decommissioning wastes. "Short" defined as a half-life of < 31 years. Contact dose rate < 0.5 mSv/hr.	Shallow land disposal
Low-level short-lived waste (LLW-SL)	Contact dose rate < 2 mSv/hr.	SFR
Intermediate-level short-lived waste (ILW-SL)	Contact dose rate < 500 mSv/hr.	SFR
Low- and Intermediate-level long-lived waste (LILW-LL)	"Long" defined as a half-life of > 31 years	SFR
High-level waste (HLW)	Spent nuclear fuel	Clab, then a deep geological repository

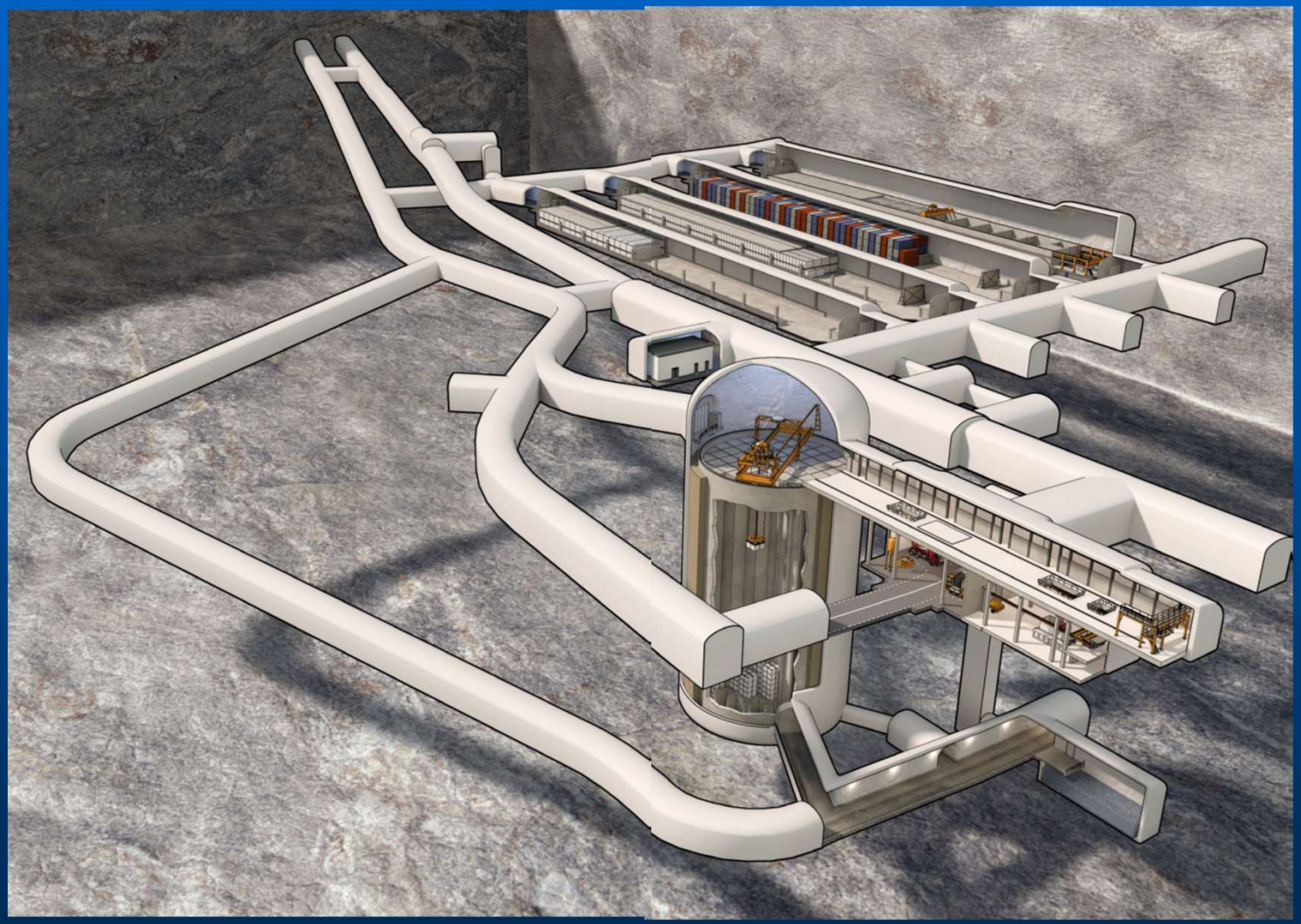
Waste management

The Swedish Nuclear Fuel and Waste Management Company (SKB) is responsible for managing and disposing all radioactive wastes.

All three power plants bury their VLLW-SL above ground on concrete pads. All low-level and intermediate-level wastes are disposed in a geological repository called the Final Repository for Short-Lived Waste (SRF).

Very low-level short-lived waste burial at the Oskarshamn Nuclear Power Plant

The SRF for low-level and intermediate-level wastes



Spent nuclear fuel management

All Swedish spent fuel is stored in an interim repository at Oskarshamn called Central Interim Storage Facility for Spent Nuclear Fuel (Clab).

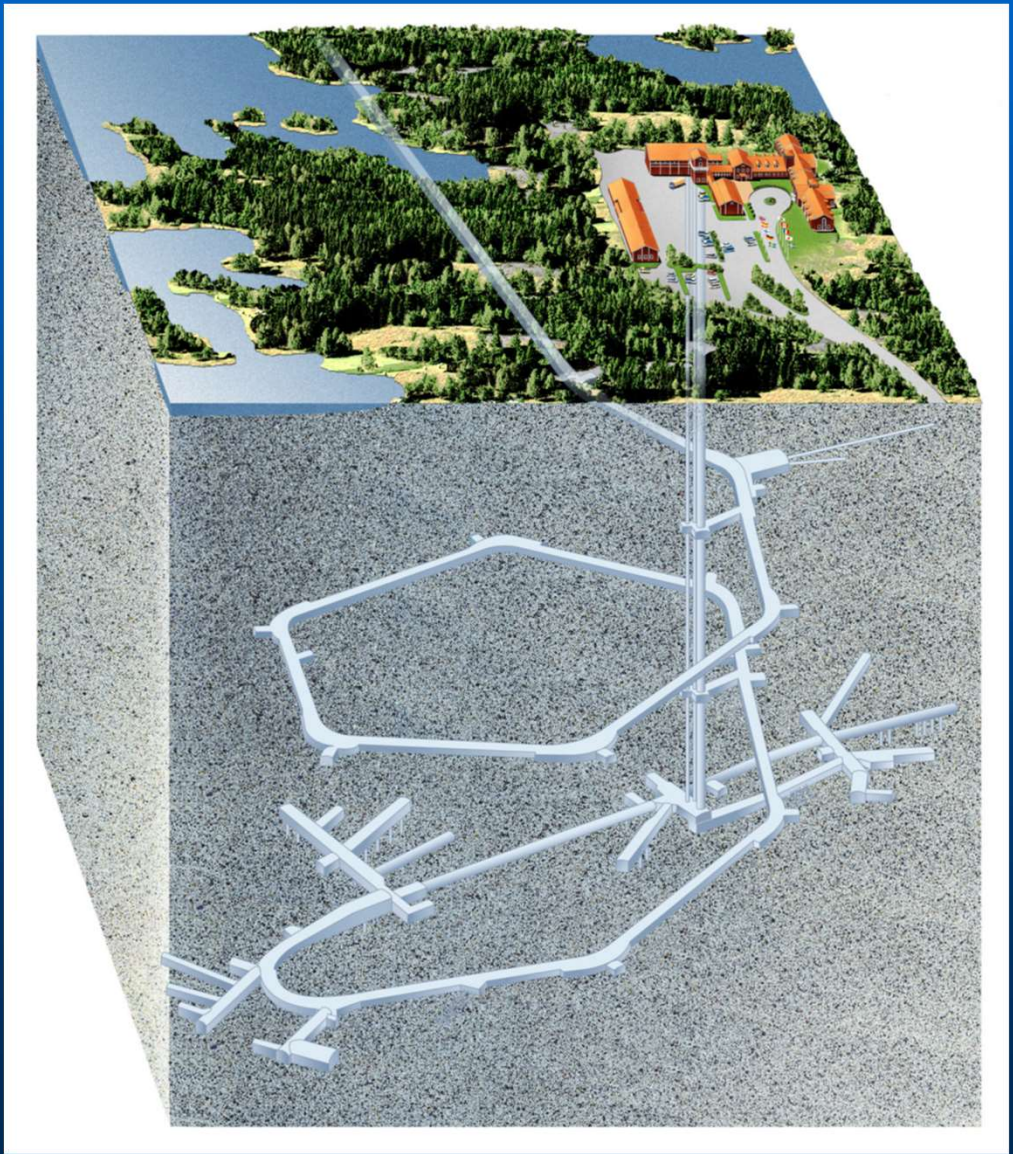
It is a geological repository that uses wet storage in an excavation that is 30 m below the surface in granite.

Clab

http://www.youtube.com/watch?v=29mFPPv8ksA (5:00)

An underground research laboratory (URL)

Sweden is constructing a geological repository for spent fuel. An URL was constructed from 1990 to 1996 called the Äspö Hardrock Laboratory (HRL). It is 460 m deep in Pre-Cambrian granite.



Research at the Äspö HRL

Geochemical investigations
Radionuclide transport processes
Sorption and diffusion of radionuclides
Impacts of oxidization-reduction reactions on radionuclides
Impacts of oxygen depletion and sulfide production
Hydrogeological investigations
Flow paths of groundwater within fractures
Groundwater tracer tests
Repository design, construction and performance
Behavior of the bentonite seals and backfill when in contact with groundwater, gases, elevated temperatures, and bacterial growth.
Geotechnical rock mechanics
Placement and retrieval of the SKB-3 copper canisters
Field-scale experience, training, and presenting information to technical audiences and to the general public.

A geological repository for SNF

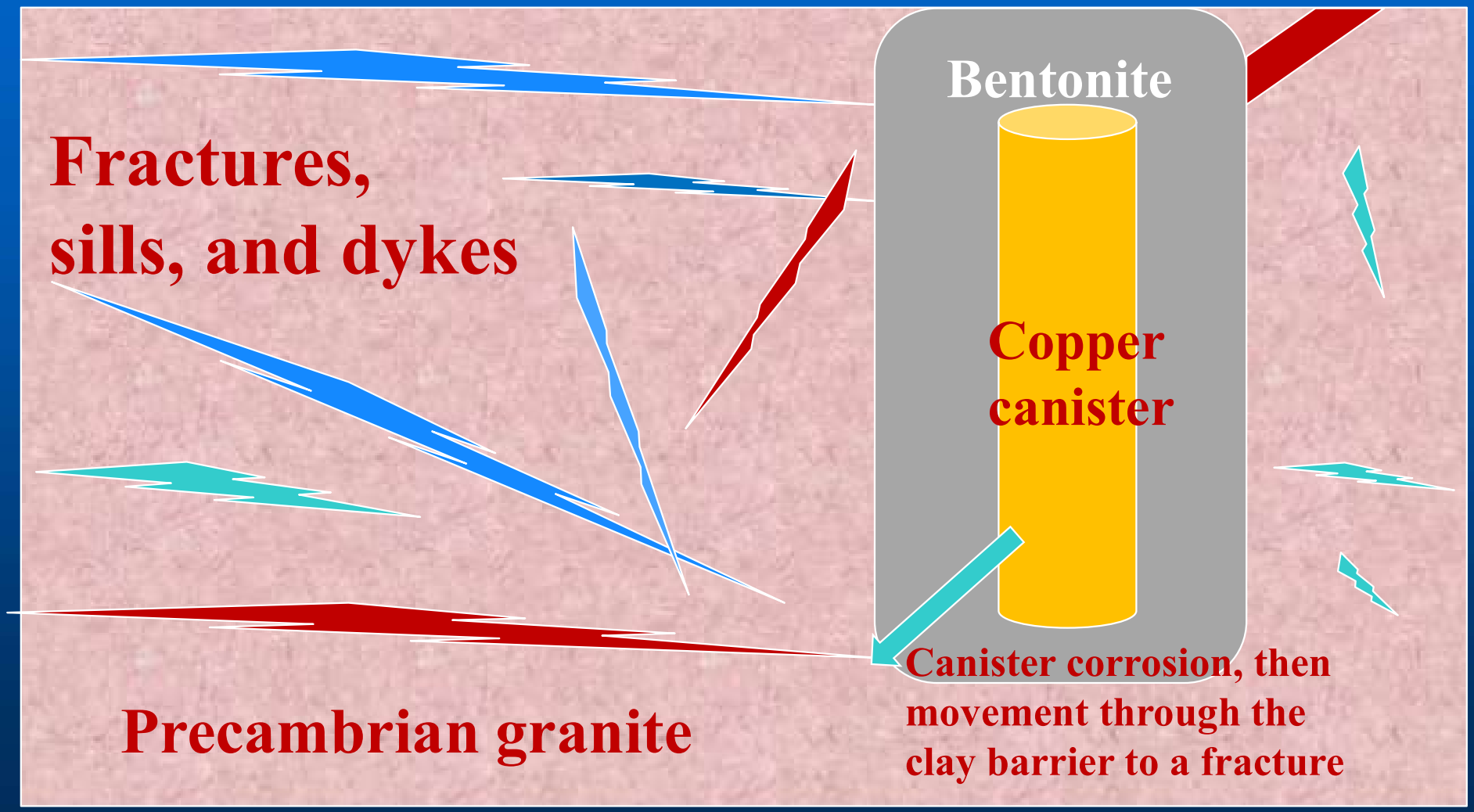
After an extensive site-selection process with local consent, SKB announced its decision to locate the repository at Forsmark (Östhammar) on the basis of it having the <u>best geology</u> of two candidate sites.

The planned disposal zone is about 500 m.

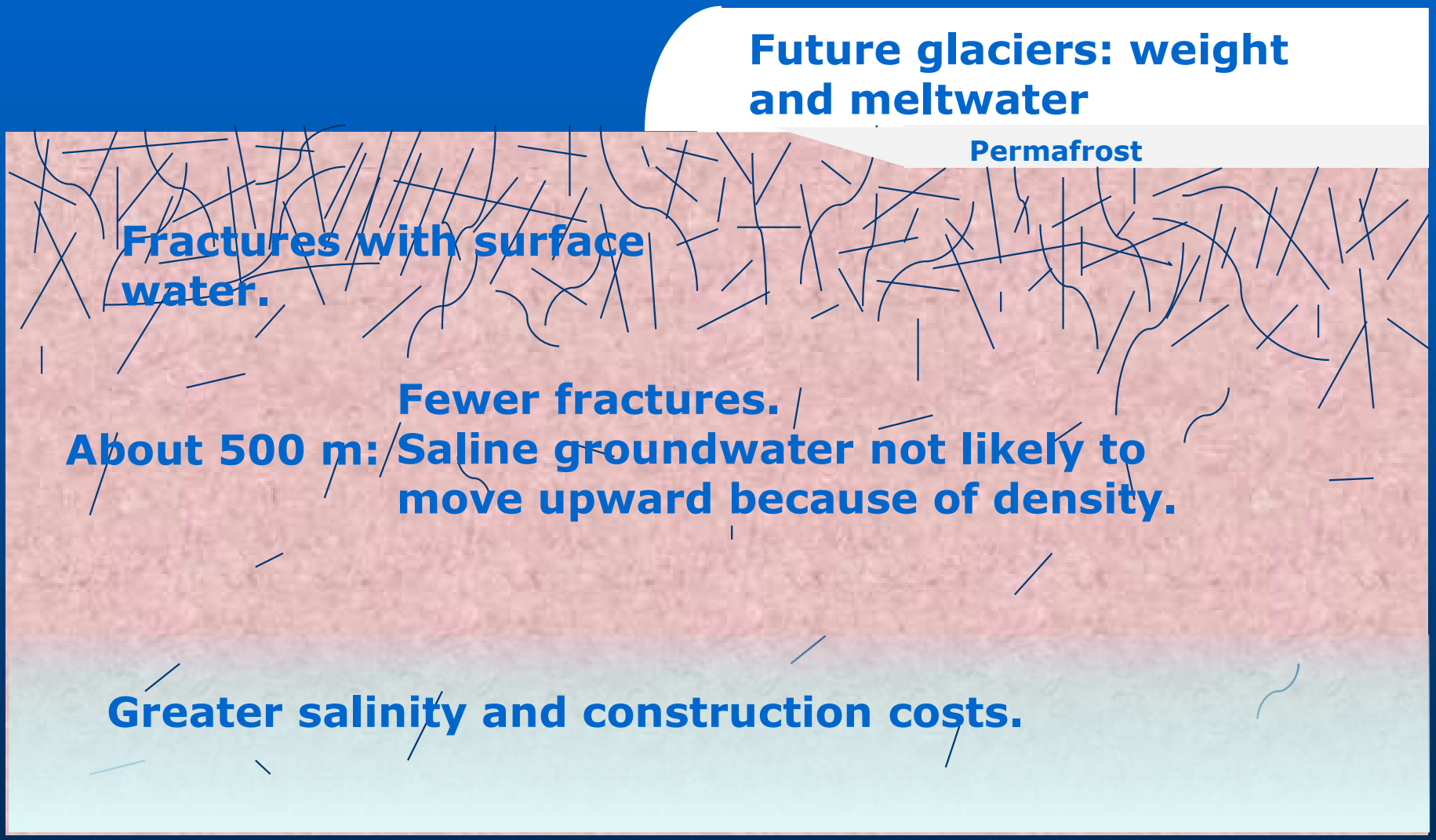
*Fewest fractures.

*Driest conditions.

Potential pathways for radionuclides



“The Goldilocks Zone”

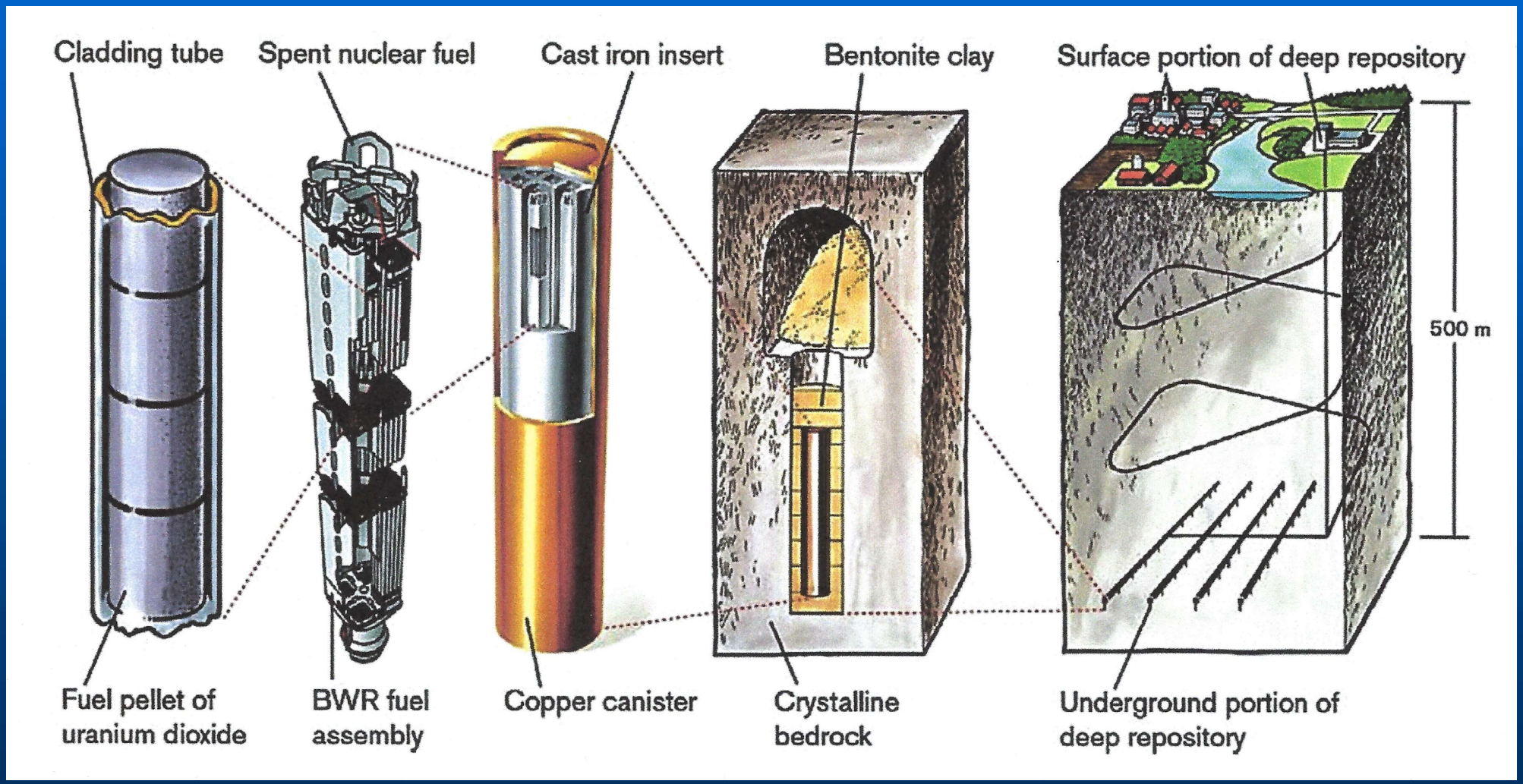


The copper/iron canisters being tested to dispose spent fuel

KBS-3

A major component of the waste management program in Sweden is the KBS-3 Method. In the Nuclear Activities Act of 1984, the Swedish Government advocated the use of the KBS-3 Method. KBS is derived from Kärn Bränsle Säkerhet, or “nuclear fuel safety” in Swedish.

KBS-3


Cladding tube
Spent nuclear fuel
Cast iron insert
Bentonite clay
Surface portion of deep repository
500 m
Fuel pellet of uranium dioxide
BWR fuel assembly
Copper canister
Crystalline bedrock
Underground portion of deep repository

A geological repository for SNF

SKB applied for a license to construct the repository in 2011, and it was approved in January of 2022! *Sweden and Finland will be the first countries to have a geological repository for SNF. Followed by France.*

Äspö Hard Rock Laboratory - 2015
Exploring Swedish solutions for nuclear spent fuel management

Kingdom of Spain

There are 7 power reactors (6 pressurized and 1 boiling water) that generate 21% of the country's electricity. The current socialist government has not been supportive of nuclear energy, but that may be improving.

Kingdom of Spain

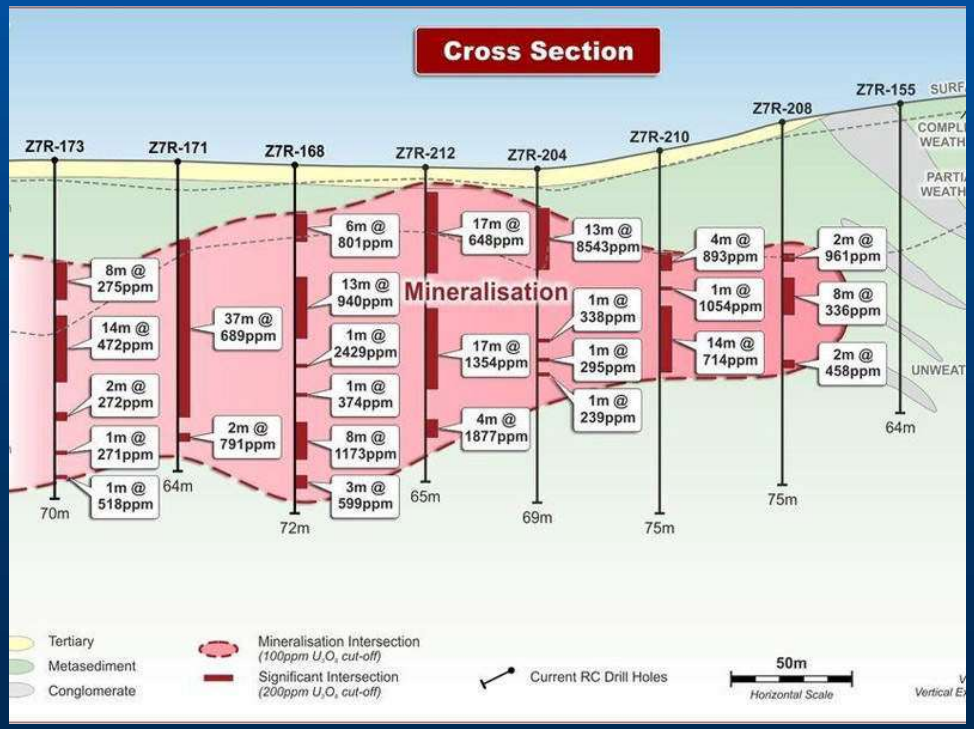
Spain has uranium deposits. The major mining area is the Salamanca Uranium Project. The deposits are vein-type uranium deposits hosted in fine-grained sedimentary sequences, adjacent to granitic intrusives.

Resources estimated to be 34,500 tonnes U.

Average grade 0.04%.

Kingdom of Spain

There are currently no active conversion or enrichment facilities. Spain relies on France, Russia, UK, U.S., and Canada for reactor fuel.

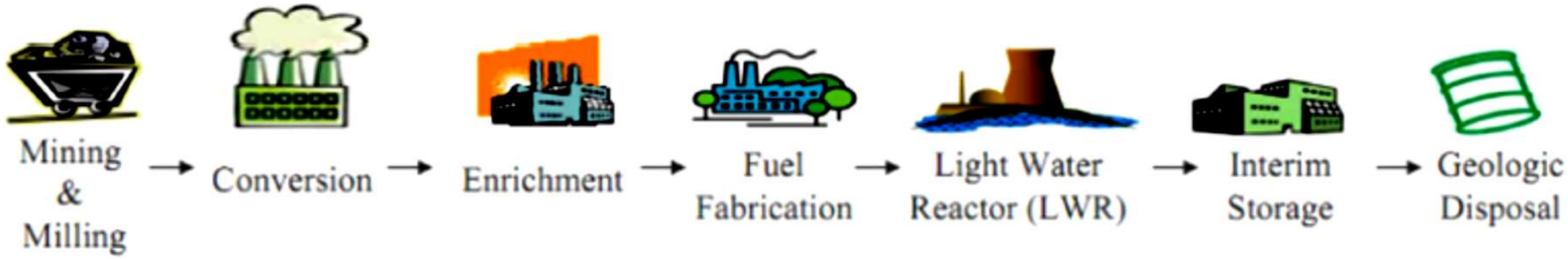


Waste Management

ENRESA (Empresa Nacional de Residuos Radiotivos) is a state-owned company. In charge of managing radioactive and decommissioning of power plants. Radioactive waste in Spain is classified according to the radioactive waste classification criteria adopted by the International Atomic Energy Agency (IAEA).

Waste Management in Spain

Open (or Once-Through) Nuclear Fuel Cycle



WASTE CLASSIFICATION

CRITERIA: Form, treatment, type of radiation, half life, heat generation, etc.

SPAIN: RR and NN Wastes are classified following the IAEA criteria and the EC criteria adopted in 1994 and 1999, respectively:

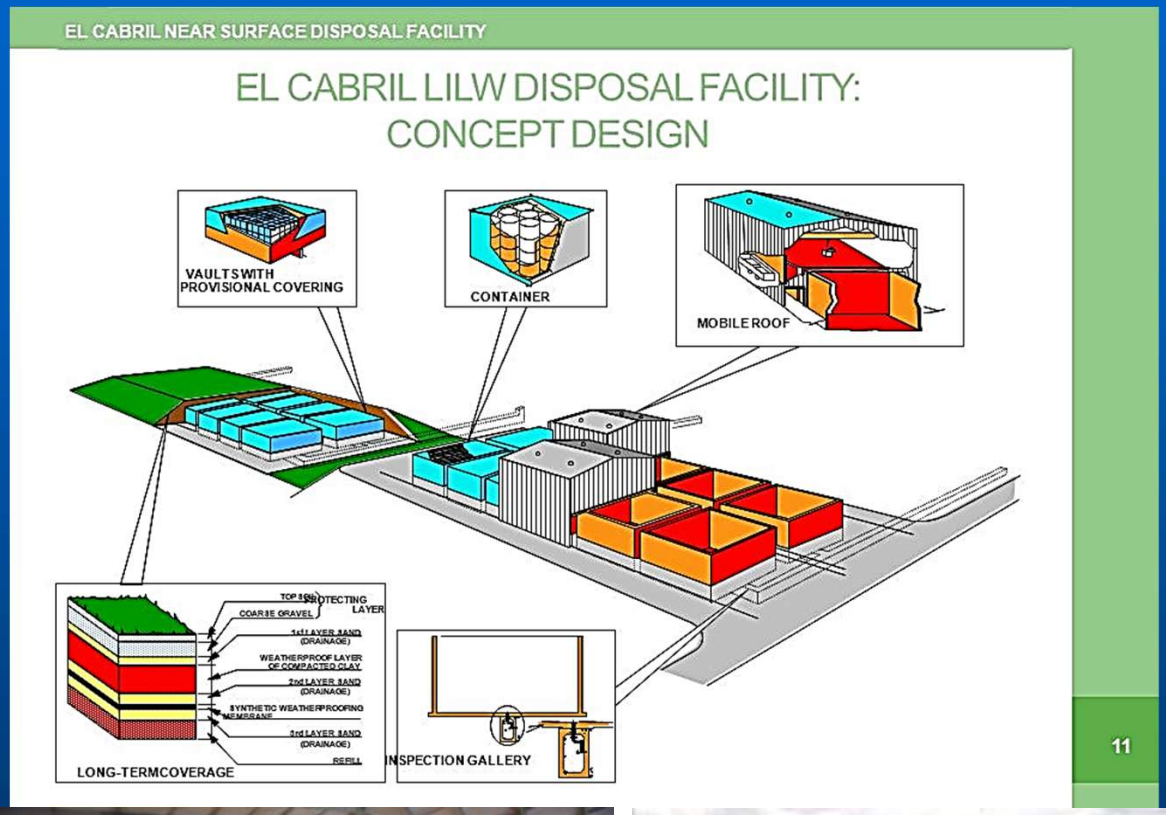
- **Low and Medium Radioactive Wastes (LMRW):** low specific activity, no heat generation, only contains beta-gamma emitters $t_{1/2}$ < 30y. They can be treated and definitively stored in El Cabril.

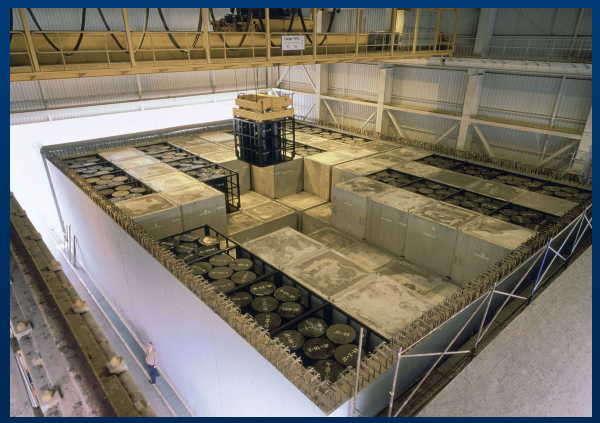
- **High Active Wastes (HAW):** Contains alpha emitters $t_{1/2}$ > 30y and/or beta-gamma emitters in a very high specific concentration. They require specific facilities for their final disposal.

Inventory of wastes as of 2016

	Type	Total Amount
LILW + VLLW	LILW	56,000 m^3
	VLLW	120,000 m^3
	TOTAL LILW+VLLW	176,000 m^3
ILW-LL (Special Waste)	Canister CSD-B	12 m^3
	Canister CSD-C	2 m^3
	Waste from reactors dismantling	530-600 m^3
	TOTAL Special Waste	544-614 m^3
SF (UO2)	PWR	5136 tU
	BWR	1504 tU
	TOTAL SF	6640 tU

El Cabril Disposal Facility





Low and Medium Radioactive Wastes

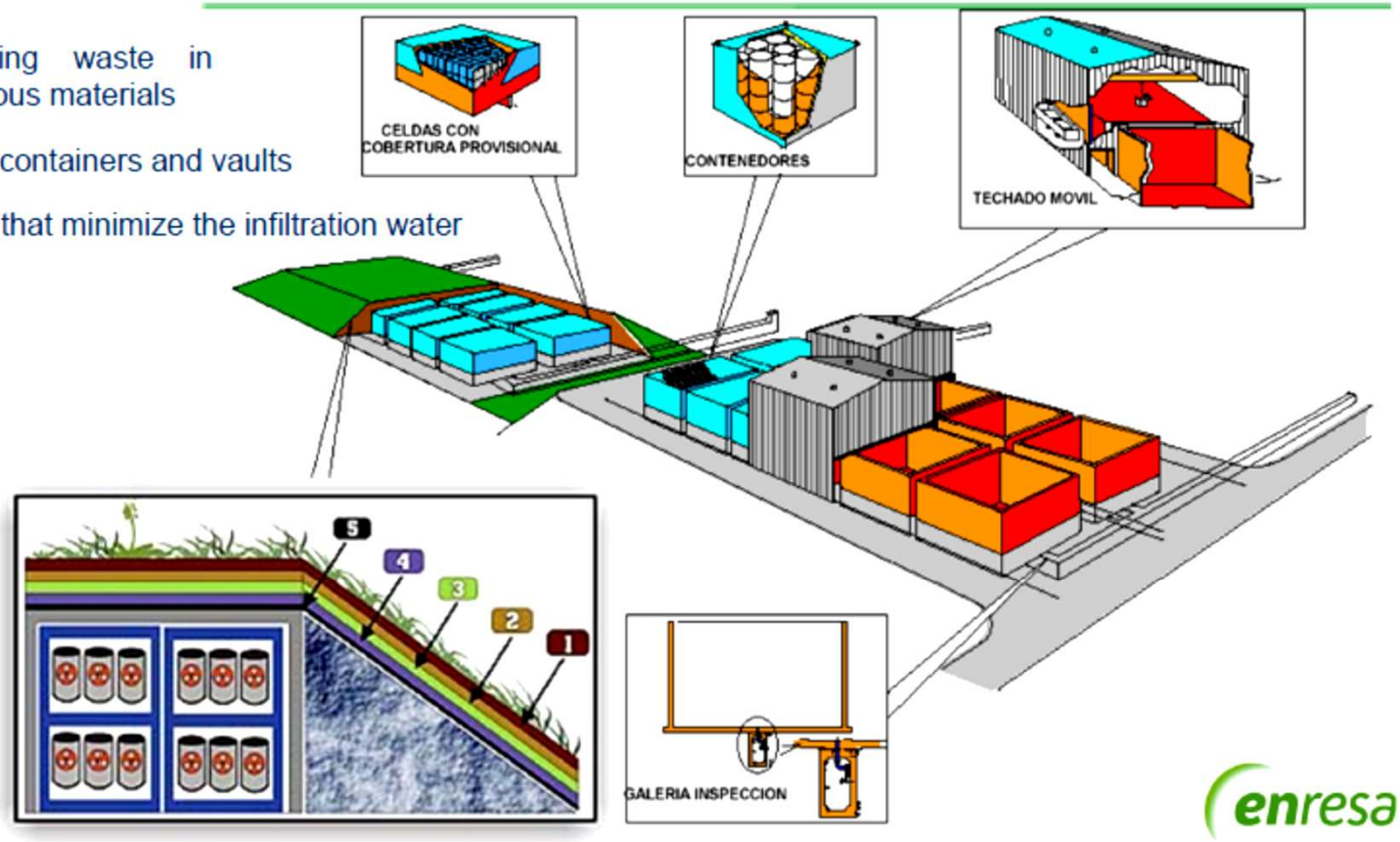
El Cabril facility project was launched in 1986. Construction begun in January 1990 and Operation in October 1992

DISPOSAL DESIGN IS BASED ON ENGINEERING BARRIERS FORM BY:

Conditioning waste in cementitious materials

Concrete containers and vaults

Final cap that minimize the infiltration water



enresa

Spent fuel management.

Chemical reprocessing of spent fuel is not considered economical and Spain has U mines.

Spent fuel is currently stored by wet and dry storage as the source power plants.

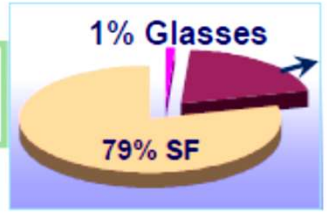
ENRESA proposed to build a surface facility for 60 years of storage for all of Spain.

No final date is available for when it will be available.

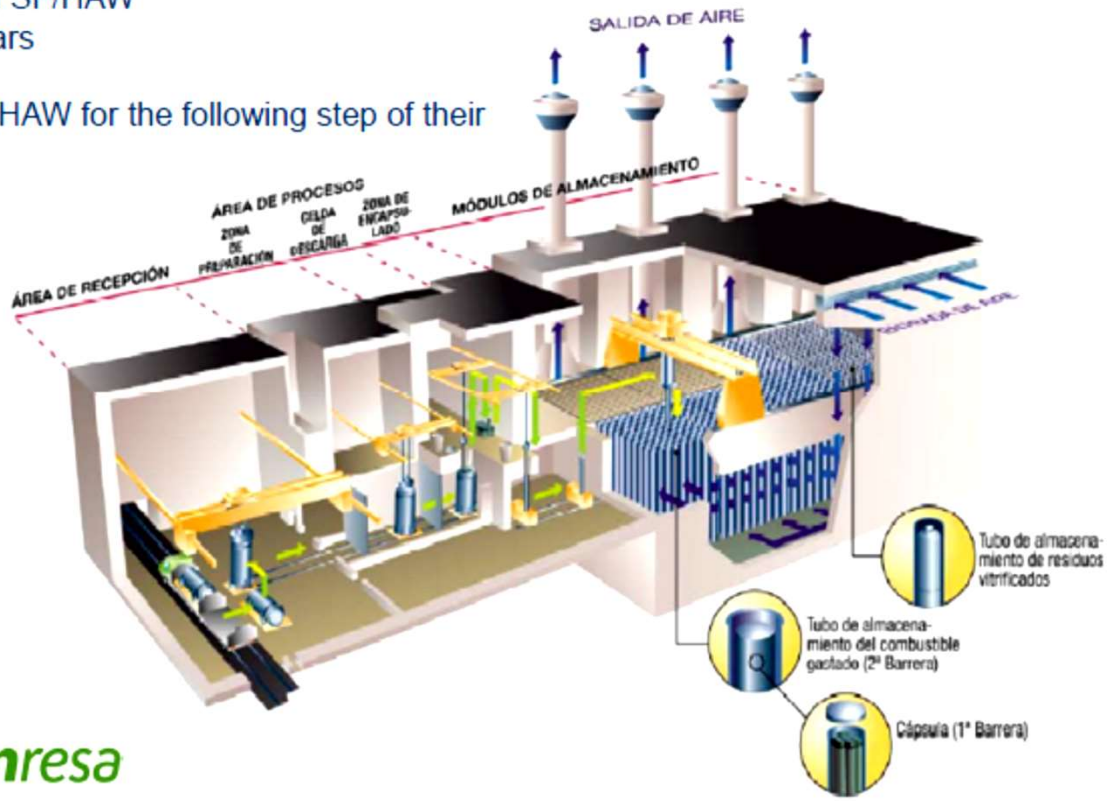
Centralised Temporary Storage facility

The Centralised Temporary Storage facility is an installation designed to house the SF/HAW produced in Spain at a single location.

SF/HAW
12.800 m^3



- Ensure control and isolation of SF/HAW
- House the materials for 60 years
- System of modular spaces
- Allows the recovery of the SF/HAW for the following step of their management

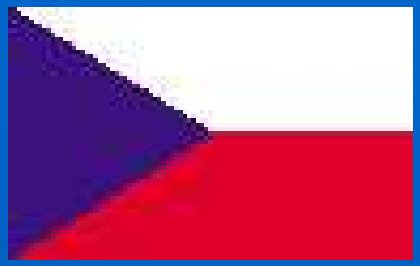


GOBIERNO DE ESPAÑA · MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD · Ciemat · enresa

Spent fuel management.

A Deep Geological Repository (DGR) is considered the best solution for SNF management, but ENRESA placed greater priority for planning the Centralized Temporary Storage facility.

Candidate sites (location and geology) or repository designs have not been proposed.
A DGR may be available in circa 2070.



Czech Republic

There are 6 water-water energetic nuclear reactors that generate about 36% of the country's electricity.

Strong government commitment. One new power plant reactor proposed.

Czech uranium mines are depleted. Fabricated fuel imported from Russia.

Waste management

Waste classification follows the IAEA system. The Radioactive Waste Repository Authority (RAWRA) is responsible for the management of all wastes. The Czech Republic has four repositories for low- and intermediate-level wastes.

LLW and ILW management

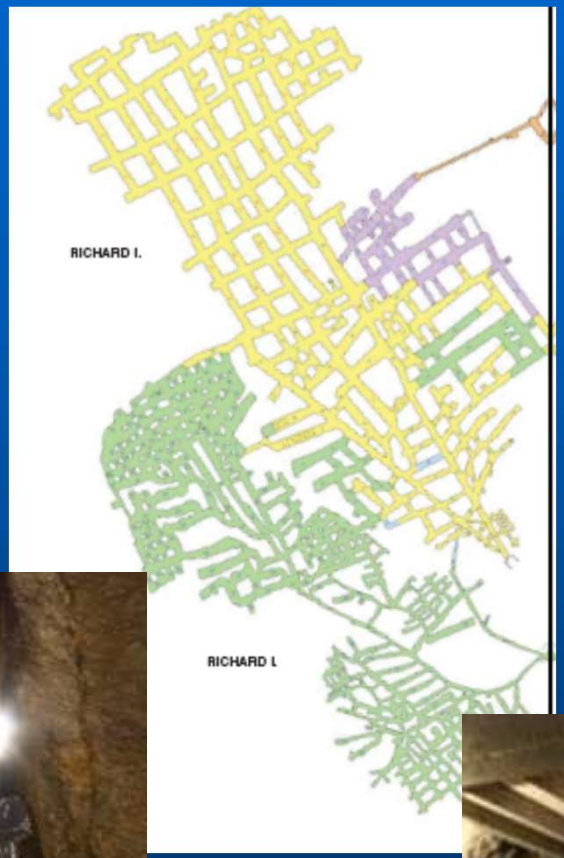
The Richard Repository. Originally an underground limestone mine. In use since 1964, and will be used until about 2070.

The Hostim Repository. Another former limestone mine. Now closed.

The Bratrstvi (bra-trist-vee) Repository. A former uranium mine. Still in use.

The Dukovany Repository. Above-ground concrete vaults.

The Richard Repository



The Dukovany Repository

When emplaced in the vault, the precise position of each drum is recorded.

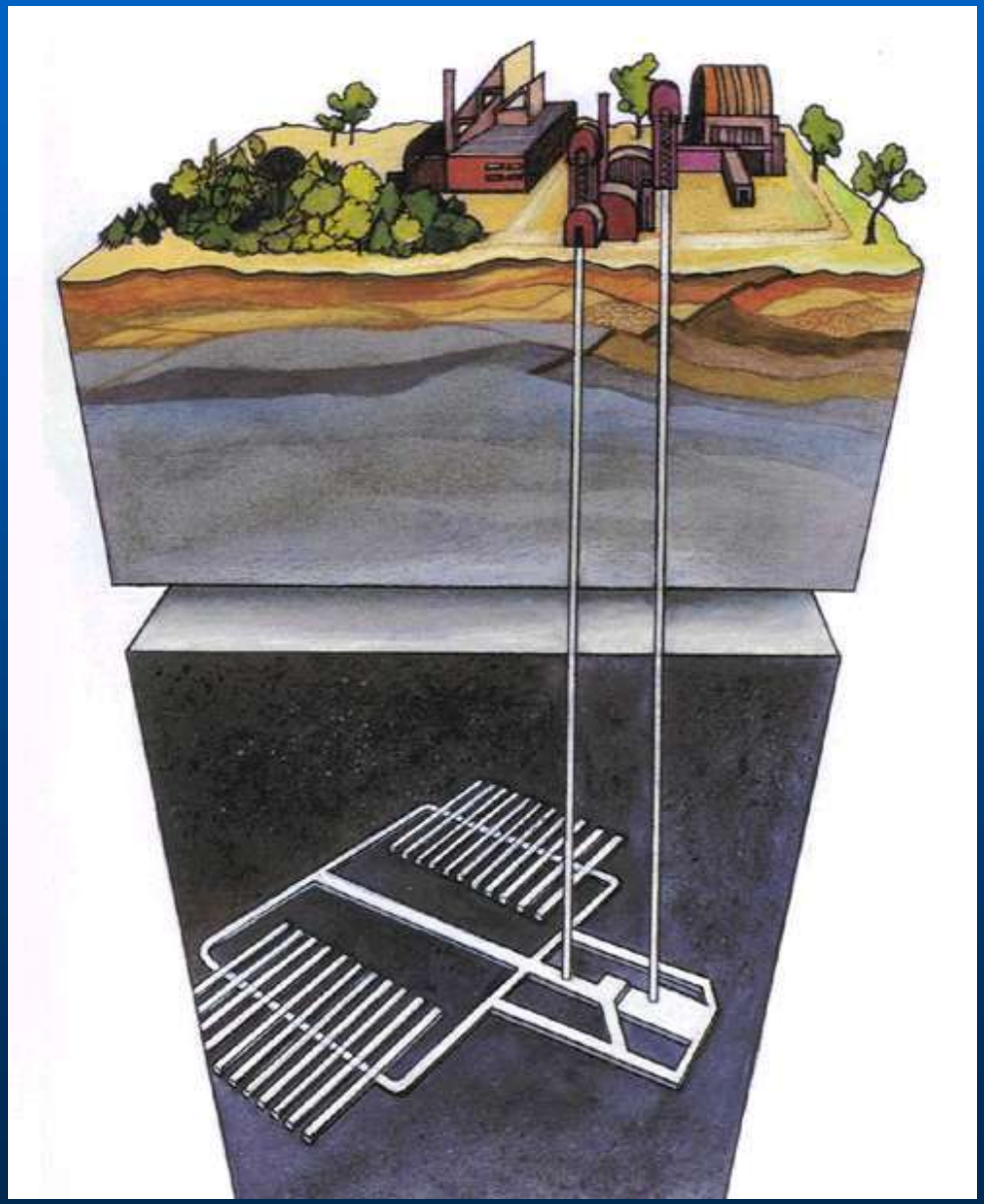
Spent fuel management

Chemical reprocessing perceived as uneconomical at this time.

Spent fuel is stored at the source power plants by wet and dry methods. The Dukovany Independent Storage Facility for Spent Fuel:

Generic drawing of a Czech geological repository for 2065

A deep, geological repository in granite is being studied. A disposal depth of 500 m is envisioned. Site selection on-going. RAWRA plans to have an operational repository by about 2065.



Finland

Finland has five reactors (2 boiling water, 3 pressurized-water) in two power plants that provide 34% of the electricity used. 60% is planned to replace Coal. One more power plant is planned.

Finland has no uranium mines. It depends on Canada, France, Sweden and Spain for reactor fuel fabrication.

Waste management

In Finland, the electric utilities are responsible for radioactive waste management. Waste classification follows the IAEA system.

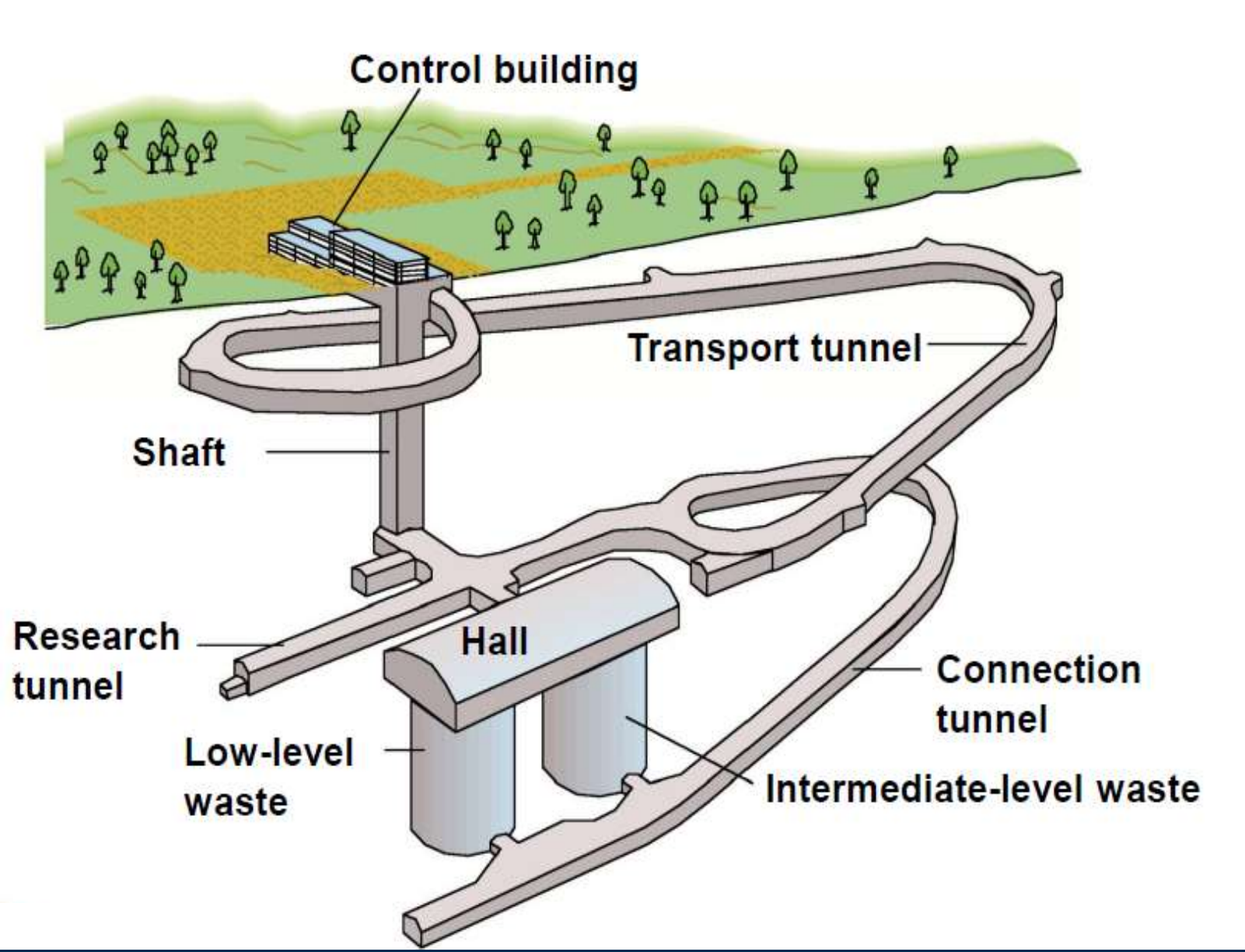
Finland has two near-surface geological repositories for low- and intermediate-level wastes:

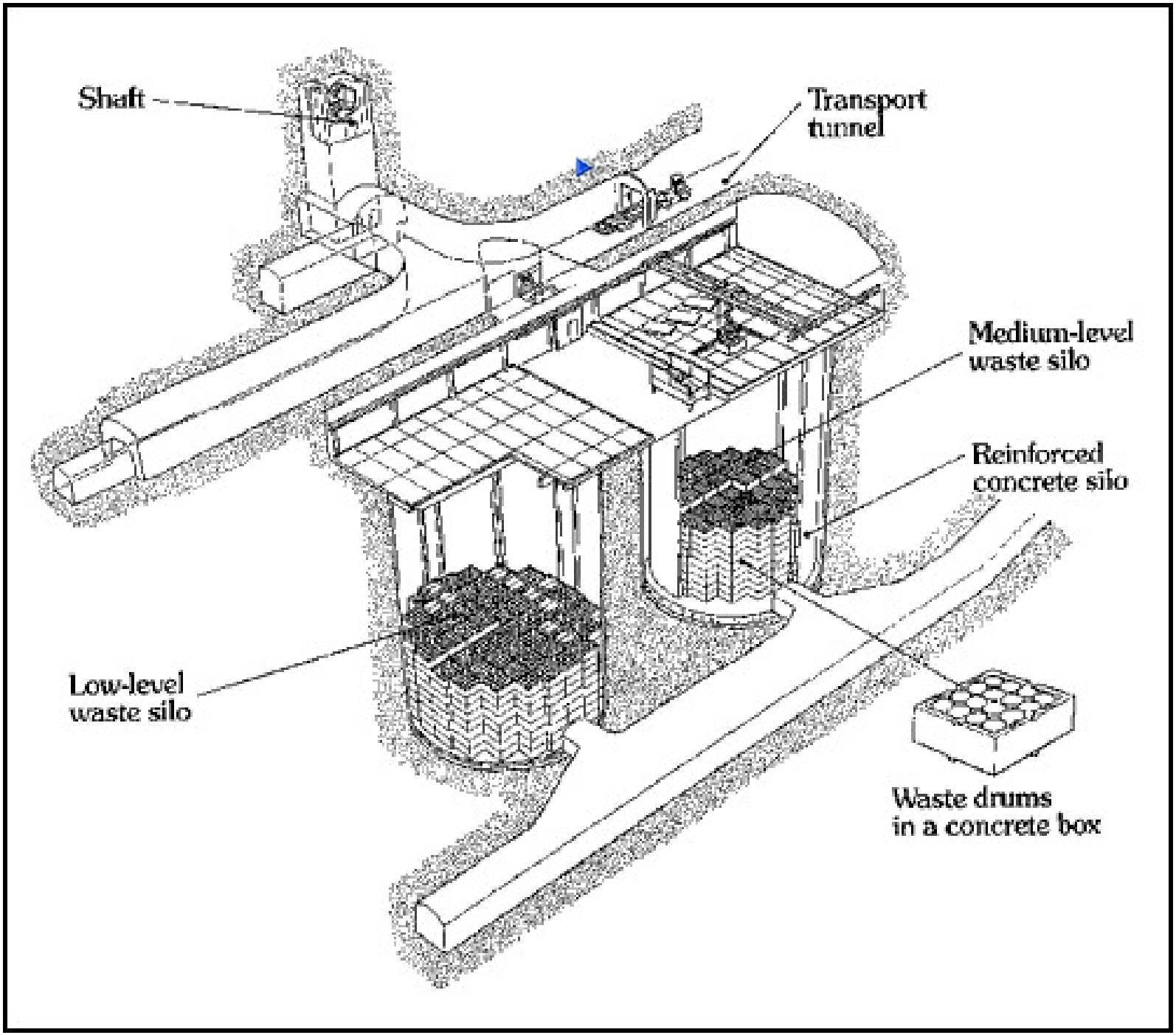
Okiluoto (oh-kil-loo-toh) VLJ Repository and the Loviisa VLJ Repository. VLJ means “reactor operating waste.”

Okiluoto VLJ Repository

The LL-IL wastes are placed in geological repositories next to the source power plant. Olkiluoto Repository has been in operation since 1992. The repository is situated at the depth of 70 to 100 meters in a micaceous gneiss. It has two separate silos, one for low-level and the other for intermediate-level waste. The total capacity of the silos is about 40,000 drums.

Okiluoto VLJ Repository




Shaft
Transport tunnel
Medium-level waste silo
Reinforced concrete silo
Low-level waste silo
Waste drums in a concrete box

Spent fuel management

No interest in chemical reprocessing.

Plans for deep geological repository are well advanced for a site at Olkiluoto.

400 meters deep into gneiss.

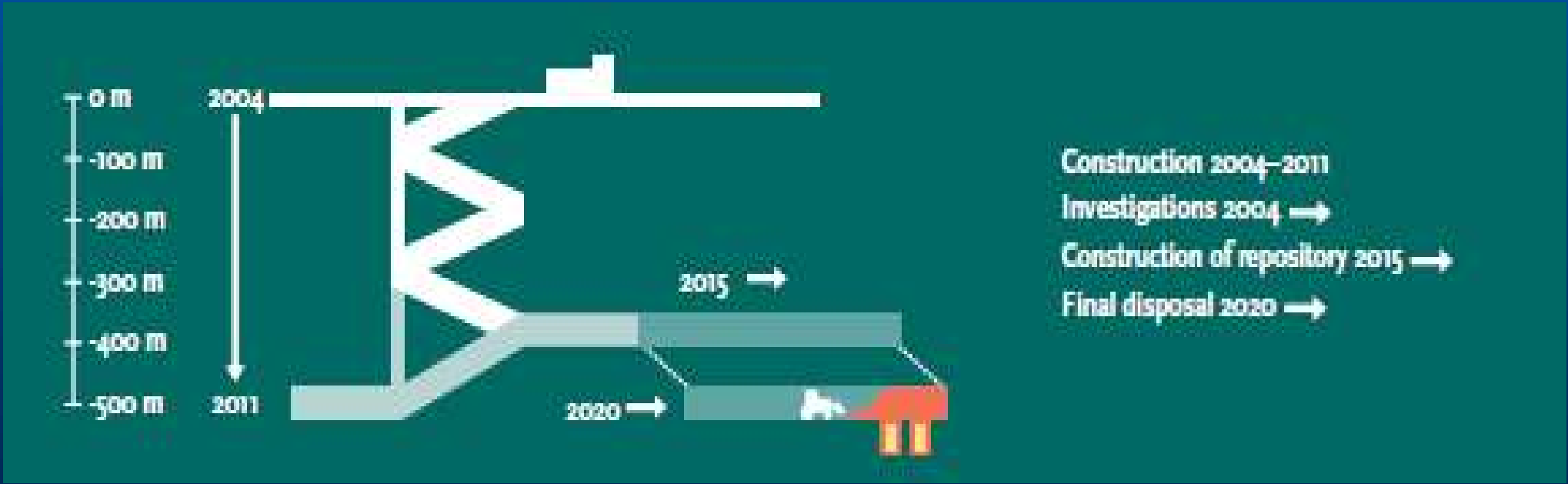
Site selection began in 1983.

In 2001, the proposed site had strong local community support which volunteered to host the site.

Plan to begin operation in 2023.

Onkalo

Onkalo (on kah lah) is an underground research laboratory that begin in 2004. It grew into the repository as the research progressed.



Blast signifying the start of work on the tunnel in September 2004

Hungary

Hungary has four reactors (PWR), all in one facility (Paks) that generates about 46% of the electricity used. First reactor started in 1982. Two new reactors are planned. Government support for nuclear energy is strong. Wants to increase nuclear to 60%. Waste management the responsibility of the Public Agency for Radioactive Waste Management (PURAM).

Classification of waste 1 – HLW, SL, LL

The Decree of the Minister of Health 47/2003 – Licensing procedure of RW storage & disposal facility – regulates the classification of RW:

High-level waste (HLW): whose heat production shall considered during the design and operation of storage and disposal.

Short lived (SL): that **LLW/ILW** in which the half-life of the radionuclides is 30 years or less, and it contains long-lived alpha emitter radionuclides only in limited concentration.

Long lived waste (LL): that **LLW/ILW** in which the half-life of the radionuclides and/or the concentration of the alpha emitter radionuclides exceed the limits concerning SL RW.

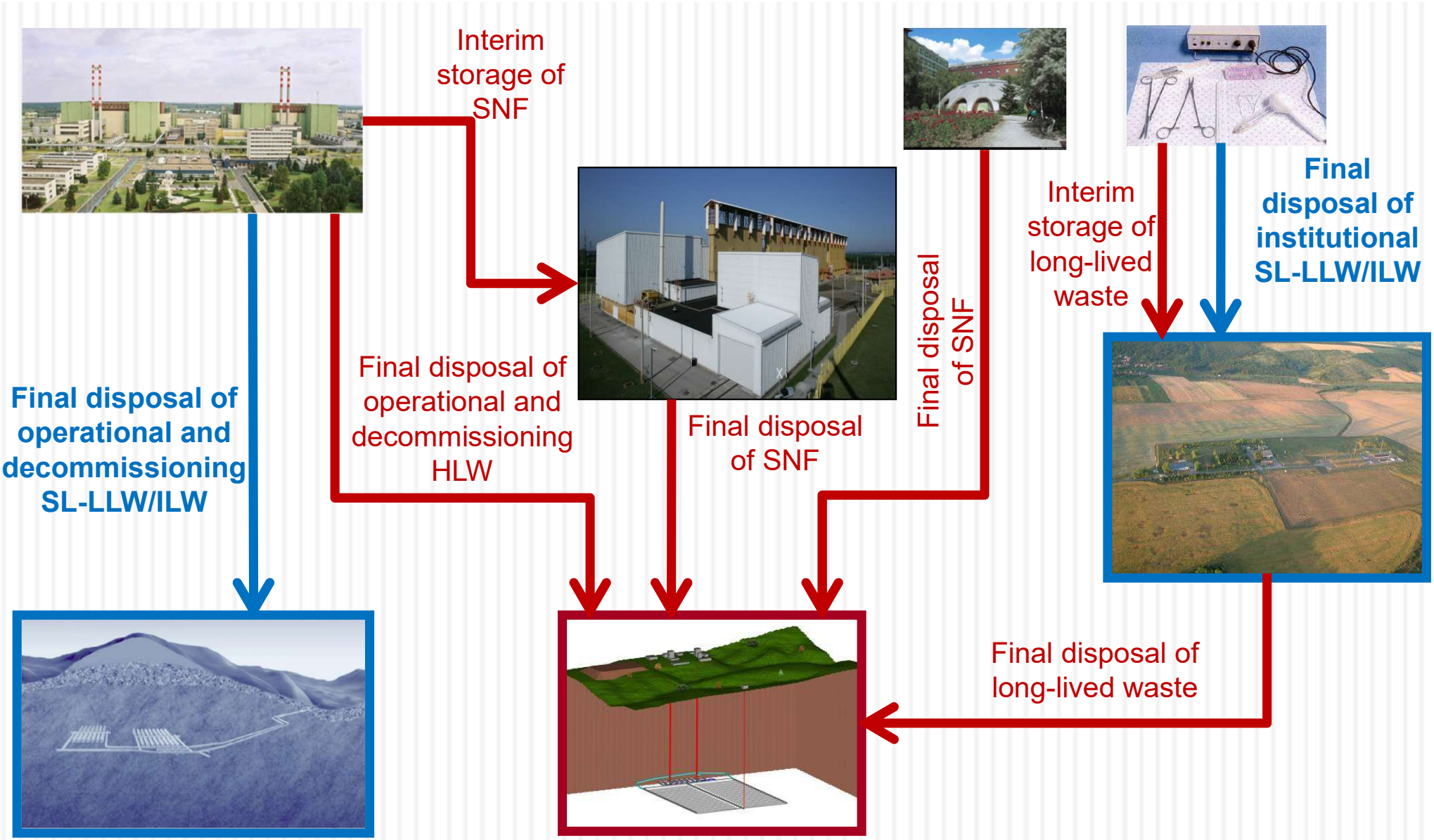
National programme and practice (2)

Hungary's largest waste producer, the Paks NPP

- Operational and decommissioning waste

	Long Term Policy	Funding	Current Practice	Planned Facilities
LILW-LL HLW	Deep geological disposal in Hungary	CNFF*	Storage on-site	Future HLW/SF repository (Mecsek Hills)
LILW-SL	Intermediate-depth disposal in the NRWR (Bátaapáti)	CNFF*	Storage on-site and storage and disposed of in the NRWR (Bátaapáti)	NRWR (Bátaapáti) underground part is in operation from 2012
*Annual payment from the Paks NPP				

Overview and End Points



Site 1 Püspökszilágy Repository 1

- Radioactive Waste Treatment and Disposal Facility was commissioned in 1976, is a typical near-surface facility with concrete vaults for institutional LLW/ILW waste, disposal capacity (5040 m^3), practically full.

Construction of surface facilities near Bataapati. Note the tunnels.

Tunnels at Bataapati.

A pair of tunnels inclined into the hill side with give access to disposal caverns.

The caverns will be backfilled with a combination of clay and concrete with crushed granite.

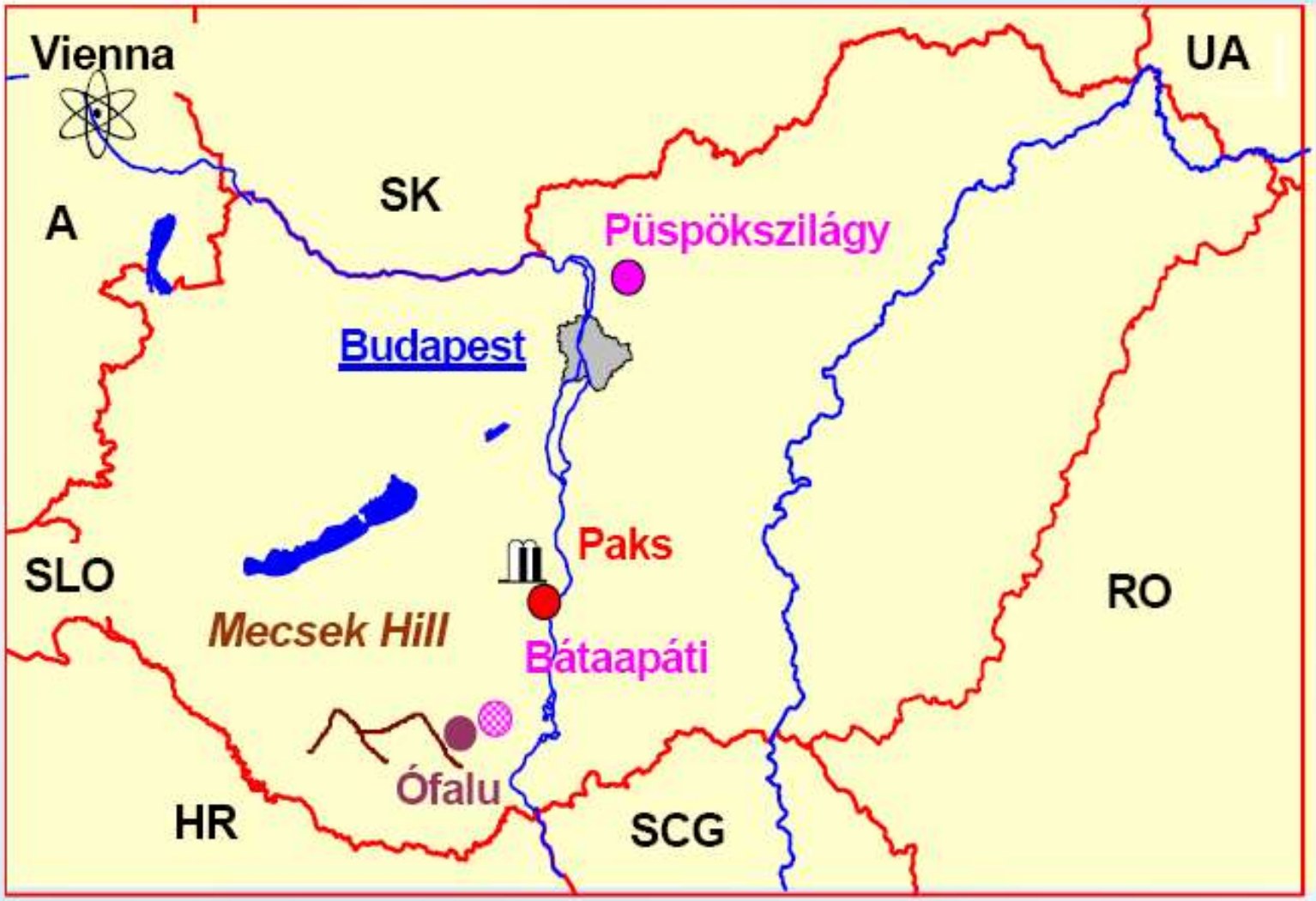
Waste drums have already been taken to the facility.

Below: The site of the Bátaapáti waste repository.

Attila Nagy, Index.hu, Hungary

SNF management in Hungary

All U fuel purchased from Russia
May resume U mining in Mecsek Hill.
SNF currently being stored by wet and dry methods.
Does not seem to be an interest in chemical reprocessing.
Deep geological storage being considered in Mecsek Hill for about 2065.



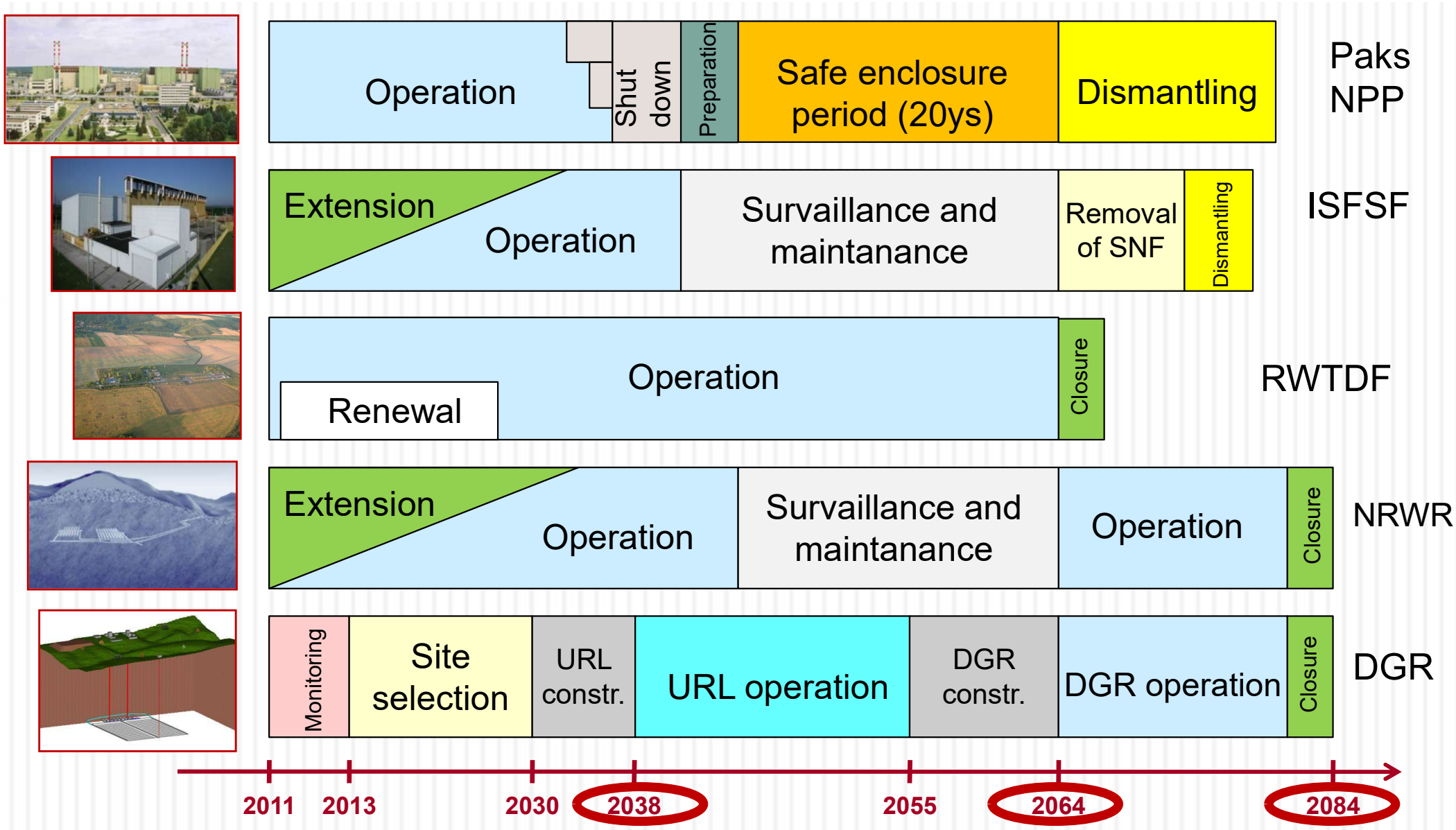
Paks: - Nuclear Power Plant, Interim Spent Fuel Storage Facility

Mecsek Hill: - Investigations for a future URL, deep geological repository for HLW/SF

Bátaapáti: - Site for a new LLW/ILW repository (under construction)

Ófalu: - Site investigations for a LLW/ILW repository in the 1980's

Timescales of the facilities



Kingdom of the Netherlands

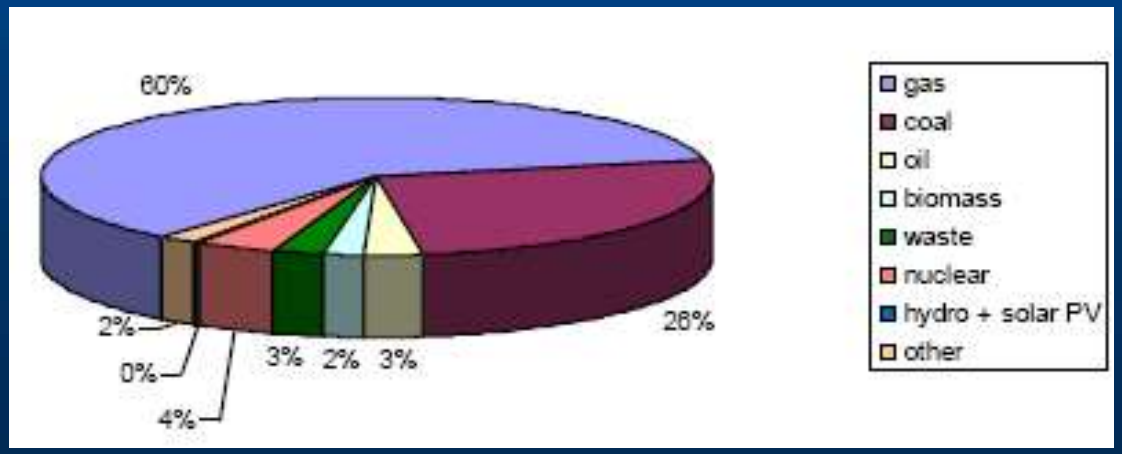
One pressurized-water reactor.

One shutdown reactor.

Generates 3% of its electricity.

Depletion of natural gas fields.

Increased interest in nuclear power.



Waste classification

Does not closely follow the IAEA system.

Low-and Intermediate-Level Wastes (LILW).

Category	Type of radioactivity
A	Alpha emitters
B	Beta/gamma contaminated waste from nuclear power plants
C	Beta/gamma contaminated waste from producers other than nuclear power plants with a half-life longer than 15 years
D	Beta/gamma contaminated waste from producers other than nuclear power plants with a half-life shorter than 15 years

Table 1. Low- and intermediate-level waste classified by type of radioactivity

No distinction between short and long half-lives.

High-Level Wastes (heat-generating and non-heat-generating wastes).

Waste management policies

In 1993, the Dutch government advocated the use of a deep, geological repository in salt beds for all radioactive wastes.

A lack of public acceptance and funding for research has, however, delayed the development of geological repository indefinitely.

Waste management policies

Instead, it was decided to build an engineered, surface-storage facility with sufficient capacity for 100 years for <u>all</u> radioactive wastes.

One facility for all wastes

Central Organization for Radioactive Waste Facility. *Centrale Organisatie Voor Radioactief Afval* (COVRA) is responsible for all wastes.

Spent nuclear fuel in Holland

Spent fuel from the current power plant is sent to France and/or the UK for reprocessing.

Vitrified HLW is sent back to Holland to be stored at HABOG (high-level radioactive waste treatment and storage building) which is also located at COVRA. Spent fuel from two research reactors is also sent to the HABOG facility.

The HABOG Facility

Opened in 2003

1.7-m thick

concrete walls

Radioactive waste as Art?

Former Queen Beatrix of the Netherlands commissioned the HABOG facility. However, she and COVRA proposed that the building be something more than a white box. They contacted Dutch artist William Verstraeten

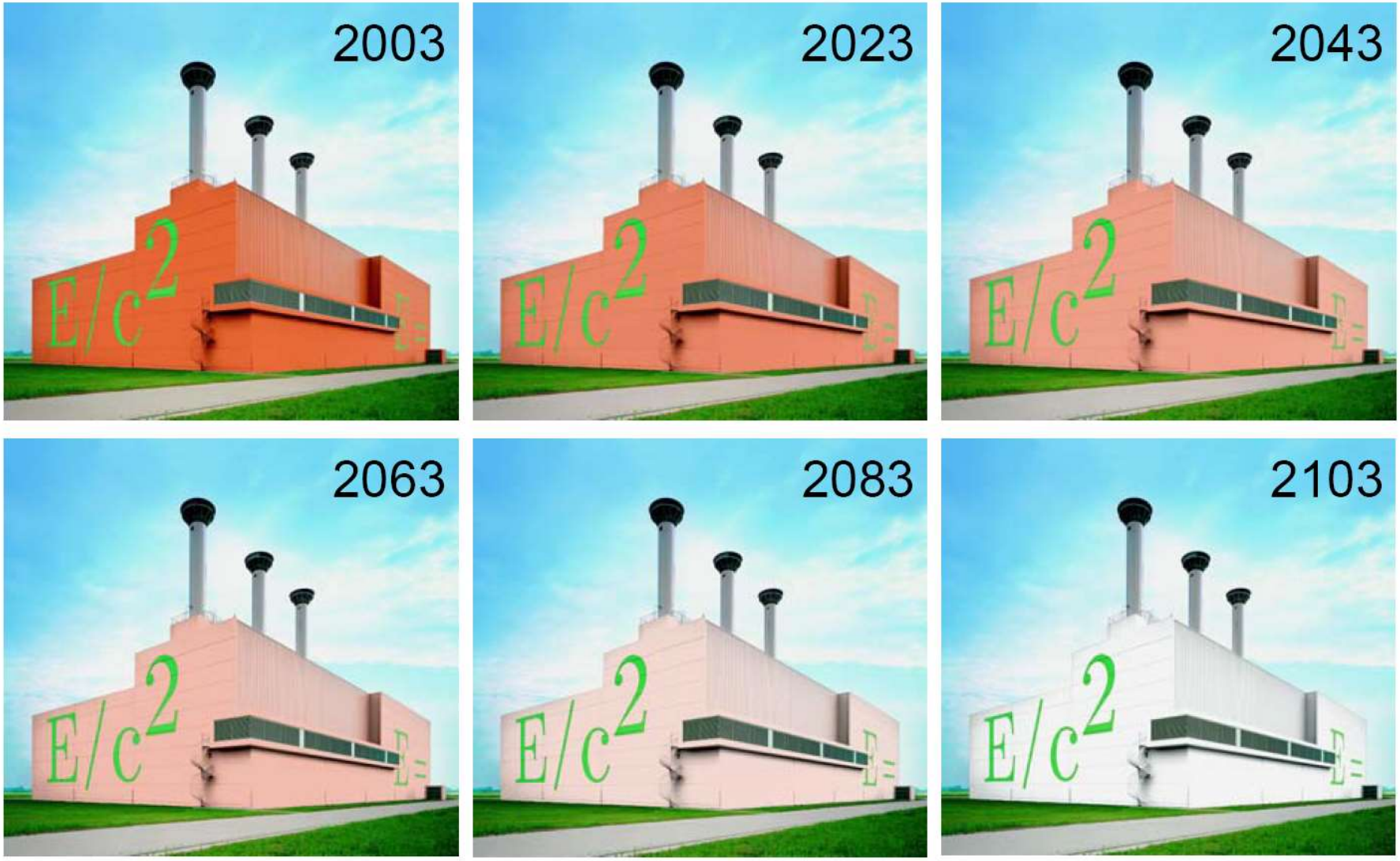


Figure A.8 Repainting HABOG's exterior every 20 years in lighter and lighter shades of orange until reaching white symbolises the decrease radioactivity of the waste stored inside.

HABOG Today

We could go on, but . . .

It appears that how different countries manage radioactive wastes depends on:

We could go on, but . . .

It appears that how different countries manage radioactive wastes depends on:

*Level of government support.

*Level of public support. Level of public education.

*National energy and global warming policies.

Radioactive waste management

The geology of the country such as
*availability of uranium versus coal, water for power plants, type of rocks (salt, granite, tuff), groundwater movement, and climate (present and future).
*Other sources of energy such as natural gas and hydroelectric power.
*Mining history and experience.

Radioactive waste management

How much capacity each country has for interim storage of low-level and high-level wastes and spent nuclear fuel before action is *required*.

Questions?

Äspö Hard Rock Laboratory - 2015
Exploring Swedish solutions for nuclear spent
fuel management