Radioactive Waste Management: an International Perspective (Part 2)

“Oh—what a journey—what a marvelous and extraordinary journey.”
—Henry Lawson in “Journey to the Center of the Earth” by Jules Verne.
Germany

17 reactors created about 25% of the electricity used before 2011. Today 43% of electricity comes from coal, the majority of that from lignite.

Because of pressure from anti-nuclear forces, 8 of the oldest reactors were shut down in 2011. Nine are still in operation.

The current government wants the remaining 9 reactors shut down by 2022.

No new reactors are planned.
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>46% supported the nuclear phase out policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>Germans strongly supported nuclear power.</td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>After Chernobyl the Social Democratic Party wanted to abandon nuclear power by 1998.</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>46% wanted the country to continue using nuclear energy;</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>The Christian Democrat government decided put the nuclear energy phase-out on hold.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nuclear viewed as an option to reduce CO$_2$ emissions.</td>
<td></td>
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<tr>
<td>2011</td>
<td>In 2011, Chancellor Merkel decided to revive the phase-out plan. Public does not support building new plants.</td>
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</tbody>
</table>
Potential ramifications

According to a report by Deutsche Bank, Germany will not meet its carbon emission targets.

Face higher 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.*
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).

Radioactive wastes issues . . .
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 Pit

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 mine closed, the German government bought the mine to develop an 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 $1.2 \times 10^{15}$ Bq, and about 125,000 drums of low-level waste containing $1.7 \times 10^{15}$ Bq were deposited.
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 m³ 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 not be regarded as an “experimental repository” but as an “operational repository” which requires “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.
From 1981 to 1998, LLRW and ILRW 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.
In 2002, the Konrad site received a license to be a repository for LLRW and ILRW.
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.

http://www.endlager-konrad.de/Konrad/EN/home/home_node.html
KONRAD REPOSITORY MILESTONES

- May 22 – July 15, 1991 Konrad plan presented to the public
- 289,387 objections raised
- 1994 – 1996 License Procedure completed...
Konrad may be ready for LLRW and ILRW by 2019
SNF in Germany

Germany had reprocessing contracts with France and the UK until 1989.

SNF now stored at power plants and reactor sites.

Wet storage for 3 to 10 years.

Dry storage in some areas. Off-site surface facilities planned.
Future site: Gorleben

A salt dome at Gorleben is being evaluated at the storage of all radioactive wastes—LLRW, ILRW, SNF, HLW, and decommissioning wastes.

The site was first selected in 1977 and studies begun in 1979. On hold from 2000 to 2009. New government approved resumption of excavation.

Site may be operational by 2025 to 2030.
Gorleben Geological Repository
China

20 commercial reactors.
28 under construction.
About 148 proposed.
Electricity from 80% coal (2% nuclear)
Serious air pollution, coal transport issues driving interest in nuclear power.
China now the major source of CO₂ emissions.
Uranium in China

China has low-grade U ore.
Resources of 100,000 tons (90,720 tonnes) of U.
Produces about 840 tons/year (760 tonnes/a)
Also imported from Kazakhstan, Russia, Namibia, and Australia.
Advanced trials on leaching U from coal ash.
USGS database: the mean concentration of U in US coals is $0.69 \pm 5.28$ pCi/g based on 6,923 samples.
Uranium in China

USGS database: average ash content of coal combusted in the US is $10.06 \pm 6.33\%$, based on 6,665 coal samples.

Thus, $0.69 \text{ pCi/g} \times 10 = 6.9 \text{ pCi/g}$ of ash.

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.
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).

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

Intermediate-low level solid waste (I/LLSW) at the Northwest Repository in the Gansu Province.

Located near the Gobi Desert.

Few details and no photographs located.
Described only as “10 to 20 meters underground.”

Run by the China Nuclear Everclean Corporation or Everclean Environmental Engineering Corporation?

http://www.nti.org/facilities/734/
LLRW in China

Intermediate-low level solid waste (I/LLSW) at the Beilong Repository in the Guangdong Province near the Daya Bay nuclear plant. Few details and no photographs located. Described “built as an above ground tank.” Intended power plant wastes. Run by the China Nuclear Everclean Corporation.
SNF in China

SNF is currently being moved from source power plants to pools in the Lanzhou Nuclear Fuel Complex.

Figure 6: NAC International shipment of Spent Fuel From Daya Bay
The Chinese plan to reprocess SNF using a modified PUREX process at the Lanzhou Nuclear Fuel Complex. Reprocessing may begin in about 2020. Vitrified HLW from reprocessing may be placed in a geological repository in the Gansu province by about 2050. An underground research lab will be built in 2015 to 2020 and operated for 20 years.
Taiwan

There are six nuclear power reactors.

Two more reactors are under construction (ready by 2017)

Nuclear provides about 17% electricity.

Expected to increase.
In 1974, the Atomic Energy Commission of ROC decided to create a site for LLRW on the southern tip of the Orchid Island.
Orchid Island (Lanyu) is populated by the Yami people.

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

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

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
NIMBY in Taiwan

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 Taiwan, 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 Taiwan) and Wangan Township were LLRW candidates.
Chief of Daren Township in favor of proposal because of US $153 million in compensation. Paiwan and Puyuma Aborigines are opposed.
Officials and residents in Wangan are opposed.
2010
Nantian Village
http://www.youtube.com/watch?v=0OuMgLLgJrw
LLRW in Taiwan

New LLRW is now being stored in above-ground facilities located at each power plant.

A Volume Reduction Center is operating at one power plant in which LLRW are compacted and incinerated prior to disposal.
Wet storage for SNF for now

<table>
<thead>
<tr>
<th>Unit</th>
<th>Year Of Commercial Operation</th>
<th>Capacity (Assembly)</th>
<th>Storage Inventory Fuel Assembly</th>
<th>MTU</th>
<th>Expected Year of Full Occupation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinshan</td>
<td>#1 1978</td>
<td>3,083</td>
<td>2,564</td>
<td>442</td>
<td>2010</td>
</tr>
<tr>
<td></td>
<td>#2 1979</td>
<td>3,083</td>
<td>2,540</td>
<td>438</td>
<td>2011</td>
</tr>
<tr>
<td>Kuosheng</td>
<td>#1 1981</td>
<td>5,026</td>
<td>3,488</td>
<td>586</td>
<td>2015</td>
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<tr>
<td></td>
<td>#2 1982</td>
<td>5,026</td>
<td>3,376</td>
<td>567</td>
<td>2016</td>
</tr>
<tr>
<td>Maanshan</td>
<td>#1 1984</td>
<td>2,151</td>
<td>1,054</td>
<td>424</td>
<td>2025</td>
</tr>
<tr>
<td></td>
<td>#2 1985</td>
<td>2,159</td>
<td>1,004</td>
<td>404</td>
<td>2026</td>
</tr>
</tbody>
</table>

*MTU (Metric Tonnes Uranium)
SNF management in Taiwan

Dry storage anticipated soon for two power plants in above-ground casks.

There seems to be little interest in reprocessing SNF.

The Atomic Energy Council is conducting a feasibility study for deep, geological disposal of SNF.

A geological repository may be constructed in 2032.
Sweden

Sweden has 10 nuclear power reactors that provide about 40% of its electricity. In 2010, Parliament approved replacing the present ten units; part of the government's climate program, which stipulates that by 2020, renewable sources should supply half of all energy produced, and the country should be carbon-neutral by 2050.
LLRW and ILRW in Sweden

An underground repository since 1988 near Formark

Four tunnels.

Receives about 1,000 m$^3$/year.

Available for next 40 years.
Clab – Central interim storage facility for spent nuclear fuel

No reprocessing.
SNF stored underwater in “caverns.”
Receives 300 tons U/year.

Capacity for 8,000 tons (about half full).

http://www.youtube.com/watch?v=29mFPPv8ksA (5:00)
Clab–Central Interim Storage Facility for Spent Nuclear Fuel
A geological repository for SNF

In June 2009, The Swedish Nuclear Fuel and Waste Management Company (SKB) announced its decision to locate a geological repository for SNF at Forsmark, on the basis of it having the best geology. SKB applied for a license to construct the repository in 2011. It plans to begin site work in 2013, with full construction starting in 201?, and operation in 2023. Sweden and Finland may be the first countries to have a geological repository for SNF. Followed by France.
Strong local support for the final repository in Östhammar municipality

<table>
<thead>
<tr>
<th>Year</th>
<th>Against (%)</th>
<th>For (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>27</td>
<td>65</td>
</tr>
<tr>
<td>2004</td>
<td>20</td>
<td>71</td>
</tr>
<tr>
<td>2005</td>
<td>20</td>
<td>71</td>
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<td>2006</td>
<td>19</td>
<td>73</td>
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<tr>
<td>2007</td>
<td>18</td>
<td>77</td>
</tr>
<tr>
<td>2008</td>
<td>16</td>
<td>77</td>
</tr>
<tr>
<td>2009</td>
<td>15</td>
<td>79</td>
</tr>
</tbody>
</table>

The poll 2009 was taken in April and May, i.e. before SKB announced its site selection on June 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
In the final repository, radionuclides are prevented from reaching the ground surface by the canister, the buffer and the rock.
The copper/iron canisters being tested to store SNF
There are 6 nuclear reactors that generate about 33% of the country’s electricity.

Strong government commitment. Four new reactors proposed.

Czech U mining in decline.
LLRW and ILW in the Czech Republic

Radioactive Waste Repository Authority

There are three LLRW repositories.

The Richard Site began as a limestone mine.

Used as a repository for radioactive wastes since 1964.
LLRW and ILW in the Czech Republic

Richard Repository can store about 5,096 m$^3$.

About 61% filled. Expected closing in about 2070.

Newest and largest facility: the Dukovany repository. Above ground concrete vaults

Opened in 1995. Built to contain 180,000 400-L drums.
The Dukovany Repository
SNF in the Czech Republic

SNF reprocessing perceived as uneconomical at this time.

SNF stored at the source power plants by wet and dry methods. New dry storage facility being built now.

A deep, geological repository in granite is being studied.

Site selection completed. Construction to begin after 2050.
Generic drawing of a Czech geological repository for 2050
Finland has four reactors and provide 30% of the electricity used. A fifth reactor is under construction. One more is planned. A recent (2010) poll indicated that 48% of Finns were positive about nuclear energy.
LLRW and ILRW ("operational wastes")

Low-level wastes are placed in geological repositories next to the source power plant. The repository at Olkiluoto has been in operation since 1992. The repository is situated at the depth of 70 to 100 meters. 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.
SNF Management

No interest in reprocessing.

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

40 meters deep into igneous rocks.

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 2020, then seal the repository in 2120.
Onkalo (on kah lah) is an underground rock characterization facility that began research in 2004. It will eventually grow in the repository as the research progresses.
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 40% 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).
LLRW/ILW in Hungary

Have been stored at Paks.


Has both surface storage and underground vaults are under construction as needed to accommodate new waste containers.
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.
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 reprocessing.
Deep geological storage being considered in Mecsek Hill.
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)
Ófalú: - Site investigations for a LLW/ILW repository in the 1980’s
Brazil has two reactors that generate 3% of its electricity.

A third reactor is under construction.

Four more are planned.

Brazil has known resources of 278,000 tonnes of uranium – 5% of world total.

The high dependence on hydroelectric power gives rise to some climatic vulnerability which is driving policy to diminish dependence on it.
NUCLEAR POWER FACILITIES

- ELECTRICITY PRODUCTION
- URANIUM MINING AND MILLING
- URANIUM ENRICHMENT
- RECONVERSION AND PELLET FABRICATION
- FUEL ELEMENT FABRICATION

* Nuclear Energy represented 3% of installed capacity and 5% of energy production in 2004.
STORAGE OF LOW AND MEDIUM RADIOACTIVE WASTE IN BRAZIL

Initial

Final repository: EBRR
STORAGE OF HIGH RADIOACTIVE WASTE IN BRAZIL

SWIMMING POOLS within the Angra site

Reprocess or dispose is under discussion.
The Netherlands

One PWR reactor. One more proposed. Generated about 4% of its electricity. Depletion of natural gas fields. Increased interest in nuclear power.
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.

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

Low- and Intermediate-Level Radioactive waste (LILW)

Disposal protective clothing, plastics, paper, filters and resins.

LILW are “conditioned” with concrete then stored in drums at the COVRA facility.
LILW in concrete
SNF in Holland

SNF 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 the HABOG facility which is also located at COVRA.

SNF 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?

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.
National energy and global warming policies.
Radioactive waste management

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

How much capacity each country has for storing LLRW, SNF, and HLW before action is required.