# High level nuclear waste

(2,167 words)

Donald N. Anderson
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*When discussing nuclear power in 2008 I am often asked "What about the waste?" The following would be my answer if the niceties of conversation permitted something beyond bumper sticker platitudes. When questioners wanted more detail, I would refer them to the two books mentioned in the footnotes.*

Production of electricity using nuclear fission leaves as a troublesome byproduct -- a small amount of highly radioactive waste[1]. Most of this dangerous waste is embedded in fuel rods removed from the reactor core after they reach the end of their productive life. In most of the U.S. light-water reactors these fuel rods start out with about:

- 96% uranium-238, non-fissionable
- 4% uranium-235, fissionable[2]

## What's in the radioactive waste?

The radioactive waste consists of a large number of elements and different isotopes. Some waste is formed by splitting uranium-235 or plutonium-239 into smaller elements (via fission) or transforming these atoms into less stable isotopes (via neutron capture). Other waste is formed by neutron bombardment of the uranium-238 that comprises most of the fuel content. Spent fuel rods contain about:

- 95% uranium-238,
- 1 % uranium-235, and
- 1 % plutonium-(mixed isotopes).

The rest is primarily a mixed fission product with some actinides (transuranic elements -- elements heavier than uranium). Most of the material in spent fuel is not waste at all, as we shall discuss below.

## Reprocessing?

Spent fuel rods contain much of the original fuel, but the uranium-235 has become too dilute to sustain a fission reaction. They can, however, be reprocessed to recover uranium and plutonium to fabricate new fuel elements. France and several other countries have reprocessed spent fuel for decades, even though it requires working with highly radioactive materials and is quite expensive.

The U.S. stopped reprocessing over 3 decades ago -- a political decision that grew out of the Carter-Ford presidential campaign, and has a once-through fuel cycle. This means our

[1] I am indebted to Scott W. Heaberlin for his detailed and cogent description of reactor waste in chapter 6 of his 2004 book "A Case for Nuclear-Generated Electricity."
[2] I hope technical readers will excuse me if I bypass a lot of complicating detail and variations in fuel load so I can focus on the essentials of storing nuclear waste.

“waste” not only includes the small amount of really nasty products, but also much fuel that could be reused. The volume of high-level nuclear waste is extremely small compared to the waste generated by a coal plant, but could be made significantly smaller if reprocessing is resumed and carried as far as economically feasible[3]. The amount of really hazardous waste generated while supplying a family of four with power for 20 years would approximately fill a shot glass (1.5 fl. oz.) compared to the roughly 20 tons of fly ash and scrubber sludge from a coal-fired plant.

## That deadly radiation.

Some fission waste products initially have high levels of hazardous radiation, but have short enough half lives, so that they convert to more stable isotopes in a relatively short time. For example, iodine 131 has a half life of 8 days. Therefore after 37 days only 1 percent remains. If fuel rods are to be reprocessed, they are easier to work with if a few years have elapsed since removal from the reactor.

The most troublesome fission products are those with half lives of intermediate length. They emit enough radiation to be dangerous over a much longer period (cesium 137 has a half life of 30 years). They are not, however, going to be around “forever,” as will chemical poisons such as mercury or lead.

## Short term storage.

Fuel rods are usually changed about every 18 months in a light-water reactor (the majority of the U.S. fleet). One third of the fuel rods are replaced with new fuel rods on each occasion. Thus each fuel rod spends about 4 and a half years in the reactor. One minute after a reactor is shut down its fuel produces 2.5% of its full operating heat. After an hour its fuel produces 1%, after a day 0.5%, and after a year only 0.05%.

Over the first few years, the residual heat from the spent fuel rods is dissipated by placing them in large pools of water. The intent is to move the rods to long term dry storage after a few years.

Originally the U.S. government planned to open a long term repository for reactor waste at Yucca Mountain in Nevada. It has collected 20 billion dollars from the nuclear industry, but so far has missed all milestones. Worse, the project has now received a great deal of Nevada political opposition. In early 2009, the Obama Administration asked Congress to stop the Yucca Mountain project and withdrew nearly all funding.

Meanwhile the 104 nuclear reactors that produce 20% of our electricity continue to store spent fuel rods on their plant sites. After the high initial heat has decayed, many plants

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[3] Dr. Phillip J. Finck of Argonne National Laboratory, in testimony before the Energy Subcommittee of the House Committee on Science, 16 June 2005 has an excellent description of the ongoing research into what is called Full Recycle. This has the promise of reducing the dangerous waste still further and virtually eliminating the dangerous transuranics.
http://www.anl.gov/Media_Center/News/2005/testimony050616.html

have opted for intermediate storage in stainless-steel concrete casks. These casks could store the waste for several hundred years, and longer if necessary.

## Seabed storage.

In 1973 Rip Anderson from Sandia Labs and Charles Hollister from Woods Hole Oceanographic Institution put together a team of oceanographic scientists to study deep seabed storage of high-level nuclear waste[4]. Eventually the team grew to 200 members with almost every discipline represented. Most biology team members were selected because they initially opposed the concept and would insure it was properly tested.

Hollister developed a technique for getting long cores from the deep seabed, and found a number of areas in the deep ocean that can only be described as deserts. One of these is at 35N164W about 600 miles north of Hawaii. It is situated in the middle of a tectonic plate under 4 miles of ocean and covers approximately 39 thousand square miles. The ocean floor in that area is a thick blanket of viscous clay about 325 feet deep. No marine life is present – no fish or plants. Currents are feeble and the area has been undisturbed by volcanic or seismic activity for 35 million years.

The clay is a quicksand type material that quickly absorbs any dense material dropping into the area. Thus, any injected waste canisters would be absorbed deeply in the clay. It is ideal for sequestering radioactive products. In spite of this the biologists spent ten years studying what would happen if the radionuclides actually escaped.

After all the research and a high quality risk assessment, the team concluded that seabed disposal was the best possible option and a couple orders of magnitude better than the most widely discussed alternative. Since most of the assessment had been made using retrieved data and models, the scientists proposed a final check. They suggested dropping a couple of pointed steel test canisters into mud at 35N164W to a depth of 100 feet. A twenty year monitoring of the canisters was proposed to calibrate their models.

Politics rather than science ruled, and Congress passed a bill in 1987 that designated Yucca Mountain in Nevada as the nation's long term repository for high level waste. Funding for the seabed storage project was terminated and the final check left undone.

Retrieval of waste fuel for potential reprocessing is not currently feasible from such deep ocean sites.

## Yucca Mountain.

Yucca Mountain is located in a geological basin in a remote part of the government's Nevada test site which has been subjected to over 900 nuclear bomb tests. It has been studied intently, has reams of data describing it, and is very dry.

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[4] Gwyneth Cravens in chapters 16, 17, and 18 of her 2007 book, "Power to Save the World" contains an exceptionally well written description of the seabed studies, the Yucca Mountain repository, and the Waste Isolation Pilot Plant (WIPP).

Unfortunately its geology is quite complex. Critics have taken various researcher's "worst case in 10,000 years events" and estimated that if they all occurred simultaneously some radiation could escape.

Opponents pounced on every imagined weakness. They even got the State of Nevada to oppose the project. A Las Vegas newspaper had visions of delivery trucks overturning or terrorists attacking them on the highways.

The facility has been partially built, but never finished (or used). Court challenges and a requirement for a licensing report to the NRC have held up its opening. The long, tedious process of doing a high quality risk assessment (as was done for the Seabed Project and the Waste Isolation Pilot Plant) with each data point fully pedigreed was underway until the Obama Administration asked for the project's cancellation.

Meanwhile it may be instructive to look at the experience we have had with the only long term nuclear waste facility in the world that is now open and fully operational.

## Waste Isolation Pilot Plant.

The Waste Isolation Pilot Plant (WIPP) located in the Chihuahuan Desert about 20 miles east of Carlsbad, New Mexico is operated by the Department of Energy. WIPP is not currently licensed to handle power plant waste fuel or any waste generating significant internal heat, although research indicates it could do so.

The storage bays and tunnels are 2,150 feet underground in a 2,000 foot thick salt bed that has been stable for over 200 million years.

The storage facility is designed to permanently isolate both contact-handled and remotely-handled transuranics that have been produced in the nation's nuclear bomb program or in research reactors. Contact-handled waste can be safely moved as long as it is in drums and usually consists of clothing and chemicals that have become contaminated by exposure to significant radiation. The remotely-handled materials require those who move it to be shielded.

This military and research waste came from many locations across the U.S. although by 1999 much had been consolidated at the Idaho National Laboratory in eastern Idaho. The portion currently being transported to WIPP was produced as far back as WWII. Interim storage was in drums and shallow graves in isolated sites.

Planning started in 1974 and operation commenced in 1999 with the first shipments of contact-handled waste. By 2006 over 5 thousand shipments had been received. In 2007 the first shipments of remotely-handled waste were received.

Unlike Yucca Mountain, WIPP has the support of local groups and the state of New Mexico. It also benefited from a thorough high-quality risk assessment with open data and computer codes that eventually brought many possible opponents aboard. The much simpler geology also made the risk assessment much easier.

To ease transport fears the special trucks were equipped with casks and demonstrated in towns along the New Mexico routes.

Could WIPP store high-level commercial power waste? Yes. In spite of claims to the contrary, waste with higher heat content can be stored in the salt. The salt bed is so vast that an extremely large number of storage chambers can be excavated. With reasonable spacing salt conducts heat well enough to accept waste commercial reactor fuel.

To date public fears have prevented the inclusion of high-level commercial power waste. Most of the scientists involved think that as more people observe years of safe operation of the transport and storage at WIPP, fears will dissipate.

## Political not technical problems.

Years of exposure to public fears, agonizing court battles, and educating judges in subjects outside their normal areas of expertise have made the nuclear industry extremely safety conscious. This extreme safety orientation, the low fuel cost, plus the small quantities of waste have permitted extraordinary expenditures in the name of safety. Coal power generation simply could not afford a similar attention to waste. Safety procedures that would be rejected as not cost effective by other industries are routinely adopted by the nuclear industry.

This extreme attention to public safety has caused very expensive cleanups. Often the cleaned area becomes less radioactive than its natural surroundings. It has also led to a power generation industry that has a safety track record far better that any alternative.

Radiation levels permitted at a plant's fence are far lower than the natural radiation levels we are exposed to every day. The actual radiation level from an average coal fired plant is about 30 times more than the allowed level from an equivalent nuclear-fueled plant. In addition the coal plant has many other dangerous emissions that are not produced by a nuclear plant.

As with any "new" technology there are many who fear it. But the nuclear industry has gone to extreme lengths to minimize any safety concerns. There is hope that the public will finally allow the nuclear industry's expansion and the gradual opening of suitable long term storage for waste.

Knowledge increases most people's comfort with new technology.

As early as 1980, in polling scientists, knowledge made a difference. When asked if nuclear power generation should be expanded the following percentages responded affirmatively[5]:

- all scientists 89%
- energy scientists 98%
- nuclear scientists 100%

The less informed general public has always been less eager to try the new technology. But by November 2008 a Zogby poll found that 67% of Americans favor building new nuclear power plants in the United States. When given a choice of what type of plant should be built in their community: 43% said nuclear, 26% said natural gas, 8% said coal and 1% said oil.

Public perception, the fear of the unknown and the resulting political obstacles have likewise impeded long term storage of high-level waste. The technical problems that remain are site specific and as we have seen, several alternatives exist.

The principal problem that remains is political.

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Dr. Anderson is an Anchorage, Alaska businessman and physical chemist. He wishes to thanks Ed Johnson of Sunnyvale, California and Scott Heaberlin of Tri Cities, Washington for technical fact checking and editorial suggestions and Dana G. Anderson of Anchorage for her many formatting and readability suggestions. He claims ownership of any remaining errors.

[5] Cravens, page 112.