Unclear Nuclear Waste Options

By John Fulenwider

Holland Professional Club, December 8, 2005

Introduction

As a graduate student in 1952 I pursued a course of study that included nuclear power engineering, and got familiar with the design and construction of nuclear power reactors. In 1957 I co-authored a conference paper on how to produce radioactive isotopes for medical use by placing certain target materials inside large nuclear power reactors. My enthusiasm for nuclear energy was high. So I am somewhat familiar with the nuclear power industry, but not an expert. Most recently I've had discussions with Dr. Donald H. Williams retired Professor of Chemistry at Hope College, who has brought me up to date on the issues involved in Nuclear Waste. He is an expert in this area.

My position is that Nuclear Energy must be included **as one of the several options** in a mix of energy options for the present and the future. All the other options which include wind, solar, hydro, and biomass have a down side, and for Nuclear Energy it's this pesky radioactive waste problem that won't go away. It has to be solved. For example on November 25 here in Michigan as reported in the Sentinel a truck carrying low-level nuclear waste went out of control, tipped on its side and some of the barrels rolled out. Fortunately this time none of the radio-active waste had spilled out and the clean up was complete.

My paper is a status report on Nuclear Waste and the different approaches being taken towards solving this problem.

The Nuclear Age is Born:

Nuclear power started with the discovery in December 1938 by Otto Hahn, Fritz Strassmann, and Lise Meitner that bombarding an atom of radioactive uranium with neutrons causes the nucleus to split apart, releasing a massive burst of energy.

On August 2, 1939 Albert Einstein wrote President Franklin D. Roosevelt to warn that the U.S. must not fall behind Germany in atomic bomb research. With the bombing of Pearl Harbor on December 7, 1941 we entered World War II, and by September 1942 the "Manhattan Project" was under way. It developed the bombs that were dropped on Japan in August 1945, ending the war. I was 16 then and had we invaded Japan a prolonged bloody conflict would have ensued, and I would probably have been called to serve along side of millions of others. I enlisted in the Army in 1946 at age 17.

Some Basics:

Uranium is a very dense metallic element. In nature it is found in the ore pitchblende. Uranium has three naturally occurring isotopes: U-234, U-235, and U-238 in the proportions 0.006%, 0.72%, and 99.274% respectively. Only the Uranium-235 produces the energy we call nuclear energy. That means U-235 is fissionable.

In the bomb used over Hiroshima, 100% pure U-235 was used as the explosive. (Our first nuclear explosion at Alamogordo, NM , and the Nagasaki bomb used plutonium) Bomb energy was released in microseconds, the equivalent of 20,000 tons of TNT.

In nuclear reactors much less than pure U-235 is used and the energy is released slowly and controllably. Reactor fuel contains uranium in oxide form where the U-235 concentration is between 3% and 5%, somewhat more than the 0.72% found in the ore.

For both these applications extensive, and costly processing of the Uranium ore must be performed to obtain the desired purification, and concentration ratios.

When an atom of U-235 captures a neutron (it has to be a slow neutron) it bursts apart into two fragments, two or more fast neutrons (note the difference in neutron speeds), and gamma rays. Scientists have shown that if the masses of all fragments after the fission are added together the total is slightly less than the mass of a Uranium-235 atom, with the difference in mass having been converted into energy by the well-known E equals M-C-squared relationship.

To keep the reaction going sustainably, the two neutrons speeding away from the fissioned Uranium atom have to be slowed down or moderated so they can produce more fissions. In most nuclear reactors water is both the moderator and heat transfer medium. Nuclear reactors for electric power generation use slow neutrons, also called thermal neutrons, and the reactors are referred to as thermal reactors, which is an interesting use of the word because nuclear reactors are certainly very hot or thermal.

By far the most heat energy created comes from the microscopic kicks the atomic fragments give to the other atoms in the fuel pellets. A tremendous amount of heat is generated in a tiny volume. These millions of kicks heat up the core in the reactor, boil the water, make the steam, which turns the turbine-generator.

What about those fragments? They are highly radioactive, they remain in the fuel matrix of atoms and are the chief constituents of high level nuclear waste. With half-lives of thousands of years this waste is piling up as we speak. Most probable in the stew of radioactive atoms produced from the fission process are lanthanum, barium, bromine, krypton, strontium, molybdenum, rubidium, antimony, tellurium, iodine, xenon, and cesium.

Pandora's Box was Opened, now What?

Soon after WW II the Atomic Energy Commission - - the AEC- -, now called the Nuclear Regulatory Commission - - the NRC - -, sought proposals from industry and academia for peaceful uses of atomic energy. It was President Eisenhower's "Atoms for Peace" program. Numerous ideas came forth on what to do with this new genie that was now out of the bottle, such as blasting excavation holes, sterilizing food, producing radioactive isotopes for medical purposes, but top most on the list were various designs for building nuclear power reactors.

Tough engineering problems had to be solved, such as how to get the uranium to release its energy slowly and controllably at any power level, and how to extract the heat generated and use it to run electric generators.

Over the intervening years many nuclear power plants were built in this country, as well as other countries. Today there are 104 nuclear power reactors at 66 sites in the United States; world-wide the total number of reactors is 440. (336 outside the U.S. and 104 within our borders) About 17% of the world's electric power is from nuclear power plants. See Table I. [2]

With safety being foremost in nuclear power plant design, and operation, they do produce electricity cleanly, without emitting greenhouse gases or other pollution into the atmosphere. Yet memories of the accidents at the Chernobl, and Three Mile Island nuclear power plants linger. Nuclear energy may be accepted by the public as a necessary component of our energy mix, but is viewed with caution.

What is a Nuclear Power Plant?:

Each nuclear power plant or site usually comprises two or more reactor units. Reactor units in the U.S. are basically large pressure vessels filled with light water (H-2-O). (Some of the European reactors use heavy water (D-2-O), some are gas cooled, and three in Russia are liquid metal cooled fast breeder reactors.) (Hydrogen nucleus is one proton; Deuterium nucleus is one proton and one neutron)

Speaking of hydrogen: These two hydrogen atoms were talking. One says to the other "I've lost my electron!" The second hydrogen atom says "Are you sure?" First one says "I'm positive!"

Back to reactors: Made of steel, pressure vessels have walls 8 or more inches thick, with bolted on lids so they can be opened to install or replace the nuclear fuel charge. Reactors operate typically at a pressure of 2,000 p.s.i., and a temperature of 300-degrees Celsius.

A fuel charge is made up of many bundles of fuel cells. A fuel cell is a long tube of zirconium (typically 14-feet) filled with uranium fuel pellets (half-inch long by quarter-inch in diameter) . Bundles of cells nest with neighboring bundles and comprise the core. Water surrounds the tubes and flows freely around them to remove the heat.

Control rods (made of cadmium) fit between the bundles for controlling the amount of power generated in the reactor. Rods are about 15-feet long, and viewed end-wise are cross-shaped. Pulling the rods upwards increases the power out, lowering the rods down into the core decreases the power. Control rods provide a fail-safe mechanism. If control is lost the rods drop under gravity to shut down the reactor. Residual heat must still be removed while the reactor cools in event of a shut-down..

A distinctive feature of a nuclear power plant is the fact that all the fuel necessary for 1-1/2 to 2 years of operation is loaded at once into the reactor pressure vessel and the lid is put on and tightened in place. A coal-fired plant on the other hand continuously consumes coal from the pile outside the plant as it produces power.

We have two kinds of reactors in the U.S. the boiling water reactor (BWR), and the pressurized water reactor (PWR) In a boiling water reactor the intense heat in the core boils the water into high-pressure steam piped directly to operate steam turbines. In a pressurized water reactor the superheated water in the core, does not boil but is piped to a heat exchanger that produces the steam, from a different water supply, that run the turbines. Stationary plants for our electric power grid, and our nuclear navy reactors are based on these designs. The BWRs and PWRs are referred to as light water reactors, or LWRs.

Extracting and Storing Spent Nuclear Fuel:

My nephew Mr. Glenn Kaht was the Zion Nuclear plant operations manager until earlier this year. Both units were permanently shut down on February 13, 1998 and allowed to cool. He has since left the nuclear industry, but I interviewed him, this past summer, to better understand the nuclear waste situation at a typical nuclear power plant. He said: [3]

"Operation of any stationary plant nuclear reactor depends on a fuel charge (containing enriched uranium) that lasts about a 1-1/2 to 2 years. At that time the nuclear fuel gets used up or spent (or depleted). Then the reactor must be shut down, taken off line and allowed to cool, and the spent fuel must be removed.

"Reactor rooms are designed to be flooded with water, up over top of the reactor vessel once it is taken off-line. Plants have these large overhead cranes, and at Zion which is typical, the crane is moved into place over the vessel. After cooling for several days, all lid bolts are loosened and removed; the 20-ton lid is lifted off and placed to the side. The reactor room is flooded with water. Water submerges the reactor deep enough so that the spent fuel assemblies can be removed, keeping them under at least 13-feet of water while still moving them sideways into a spent fuel storage pool adjacent to the reactor vessel. Purified circulating water, containing a solution of boron surrounds and cools the open reactor vessel, and the spent fuel. Each fuel bundle is withdrawn one by one from the reactor vessel and lowered into holding slots down in the water pool."

Highly radioactive, the fuel assemblies are kept underwater for several weeks, then lifted out and placed in large concrete casks. Measuring 12 feet in diameter with walls 2 feet thick and 20 feet high the casks can hold 20 tons of spent fuel bundles. After loading, these casks are moved out of the reactor building and placed in a holding area surrounded by a chain link fence, next to previously placed casks. And there they stay. See Table II for a list of nuclear reactor sites that are storing spent fuel in casks outside their buildings.[6][7]

Incidentally if you hugged one of the casks for 20 minutes, you would receive a dose of radiation equivalent to one chest x-ray.[4] Radiation danger from the casks is minimal. But now they are desirable objects for terrorists, as the spent fuel could be used as the ingredients for "dirty" bombs.

Dr. Williams used to take his Hope College chemistry students on field trips to the Palisades Nuclear Power Plant at South Haven, Michigan. These visits are no longer permitted since September 11, 2001 because of the terrorist threat.[4]

(Incidentally CMS Energy Corp., the parent corporation of the Consumers Energy announced that it would sell the Palisades Nuclear plant. See Holland Sentinel, December 6, 2005 Page B6. Consumers Energy will buy the electricity from the plant by entering into a power purchase agreement with the new owner.)

What is in the Nuclear Waste?

Commonly called Radwaste, nuclear waste comes under two classifications as defined by the NRC: High Level Waste or HLW, and Low Level Waste or LLW.[4]

HLW is spent nuclear fuel, and weapons waste. Typically, spent reactor fuel has these components:[1]

95% of it is Uranium-238
3% of it is Uranium-235
1% of it is composed of transuranic elements – Neptunium, Plutonium, Americium, Curium
1% of it contains fission products – lanthanum, barium, bromine, krypton, strontium, molybdenum, rubidium, antimony, tellurium, iodine, xenon, and cesium

This most dangerously radioactive waste comes from two sources: (1) spent nuclear fuel estimated now at 58,000 tons, growing at the rate of 2,000 tons per year to 72,000 tons by 2012, the year that Yucca Mountain repository is scheduled to be available, and (2) liquid and solid waste from plutonium production estimated 91 million gallons. [7]

LLW is a catchall including radioactive and hazardous wastes from hospitals and research institutions, including remnants of decommissioned power plants, air filters, clothing, and tools, gloves, rags, sludge, containers, old piping, fixtures, dirt, and any other object or material that had been used in handling, and working with radioactive materials. The total volume estimated for this waste is 472 million cubic feet. [7] 780 ft^3

Uranium Mill Tailings would fall under this classification, which are residues left from the extraction of uranium from ore. It is estimated at 265 million tons. This stuff has the largest volume but has the lowest radioactivity.

Show Cartoon of HLW and LLW.

Where the Waste is Stored

Nuclear Power Plant Waste

In the U.S. much of the HLW waste is stored in steel clad concrete casks outside the buildings at some of our nuclear plant sites. See Table II for a list of these sites. [6] Other sites have HLW stored inside the buildings in the water pools, and may eventually need cask storage.

A large quantity of depleted Uranium is stored on a huge concrete pad outside the Gaseous Diffusion Plant at Paducah, KY. [8] This plant is a center for making nuclear fuel from the ore. There are 38,000 barrels of this waste lying in the open on a 50-acre pad. The facility is fenced in.

In France the waste is being vitrified into glass logs at a plant near Marseille. It is shipped for burial near Cherbourg on the northeast coast of the Cherbourg peninsula..

In Germany, which is abandoning its nuclear program with no renewal, is burying its waste in a salt mine near Hamburg. Germany is emphasizing renewable energy, particularly windpower, solar, and biomass.

Sweden is storing its HLW in steel containers coated with copper which doesn't corrode in the absence of oxygen. Containers are embedded in impervious clay at 1800 feet in a granite mountain.

Governments in these nations make their decisions about nuclear waste based on science, and social concerns for their citizens. Then they carry them out.

Bomb Making Waste

Examples of storage of this kind of waste is a litany of bad decisions, followed by partial corrections. Here is where the costs and time needed to accomplish the necessary tasks will keep many people employed well into this century.

Hanford, WA Deadly radioactive cesium, and strontium, byproducts of the production of plutonium for bombs, is stored at Hanford, WA. Also there are:

"53 million gallons of waste from plutonium processing stored in underground tanks,
nearly 2,300 tons of spent fuel,
four and one half tons of plutonium,
25 million cubic feet of solid waste,
38 billion cubic feet of contaminated soil and ground water."[81

At Hanford, processing of plutonium in the early days had released vast quantities of radioactive iodine-131 into the atmosphere because the workers didn't filter the exhaust stacks. It showed up in milk and in vegetation hundreds of miles downwind. A plant to vitrify radioactive waste in glass is now being built at Hanford, at a cost of 4 billion dollars. Sealed hull sections of 92 sub-marines containing nuclear propulsion reactors, emptied of fuel, also rest at Hanford.

Rocky Flats, CO was the site of manufacturing plutonium spheres for triggering thermonuclear weapons. Tens of thousands of them were made. After all we had a stockpile of 32,000 thermonuclear weapons at one time. Rocky Flats is the repository for the wastes and byproducts of this work, and is being cleaned up by a crew of 5,000 workers, at a cost of 2 million dollars a day!

West of Idaho Falls, the Idaho National Engineering and Environmental Laboratory (INEEL) is a repository of waste from Rocky Flats. Locals have prevented operation of the high technology waste separator-incinerator there. It is supposed to burn the PCBs and other chemicals after separating out the plutonium.

Near Carlsbad, NM, at the Waste Isolation Pilot Plant (WIPP) drums of transuranic waste from Rocky Flats is being stored 2,150 below in a salt cavern. Truckloads go there weekly. By 2035 WIPP is expected to have 850,000 drums of this stuff in storage.

Skull Valley, Utah is the home of the Goshute Tribe of native Americans. They have offered to store 44,000 tons of HLW for a rental fee, on a 100-acre site on their Indian Reservation in Idaho. Tribal leaders said the money will go to build schools and a hospital. Other native American nations are against this as it sets a bad precedence.

Yucca Mountain : Yucca Mountain, Nevada is 90 miles northwest of Las Vegas. It was "chosen by Congress in 1987 as a potential resting place for the nation's spent fuel rods and other high-level waste." Note that it was not chosen by people in the scientific community, such as physicists and geologists, but by politicians, as pointed out to me by Dr. Don Williams. He showed me a rock sample from the mountain. The mountain is composed of compacted volcanic ash, and is too porous, he thinks, to contain liquid leakage from the waste, over the tens of thousands of years that it is supposed to stay there. Wrangling continues between the State of Nevada, and the DOE. Yucca had been declared safe by DOE in January 2002. But Nevada thinks it is not. DOE is now aiming for 2012 as the opening date.

It takes about ten half-lives for radiation to decay to what could be considered a safe level. For Plutonium-239 this is 240,000 years.

Fast Reactor could burn spent fuel:

Recently proposals have been made [1][9] by several scientists, three retired scientists from the Argonne National Laboratory, and one from INEEL. The plan is to develop a two-step process that will result in consuming spent nuclear fuel. After separating the bad stuff e.g. fission products like tellurium, iodine by a chemical procecc from our stockpile of HLW spent fuel rods, the remaining material is Uranium 238, Plutonium, and other actinides. These metals would be formed into new fuel rods, once they are electroplated out of the soup.

These new fuel rods would then be used as fuel in fast-neutron reactors. It sounds good on paper. The waste resulting from fission of U-238, and Pu-239 using this new approach, will decay in a few hundred years, instead of tens of thousands of years, plus any Pu-239 that remains would be mixed in with other wastes, and cannot be made into bombs.

The high-level-waste from our "thermal" reactors will be consumed as it provides fuel for this new reactor design. There is no moderating the neutrons from the fissioning U-238, U-235, Pu-239 and other actinides separated from the waste.

Fast neutron reactors use liquid metal such as sodium, or lead-bismuth eutectic alloy. Designs of fast neutron or breeder reactors date back to the 1960's when these reactors were used at Hanford to make plutonium for bombs.

Processing to remove the bad stuff from the spent fuel rods is a pyrometallurgical process, and is based on electroplating uranium and other actinides, all metals, in an electrolytic bath. A pilot plant would first be built and run to test the design. The scientists say that if they began today the first of the fast reactors would come on line in about 15 years. A price tag of a full-scale reactor is estimated to be over 4 billion dollars. It would produce steam to run turbines by heating water into steam in a heat exchanger that isolates the hot sodium or lead-bismuth eutectic from the water.

Concluding Remarks:

It appears that the more technologically advanced a concept is the more it produces unwanted byproducts which demand yet more technologically advanced solutions. Technology begets technology. Nuclear power is a good example as I have shown. It is like the tar-baby in the Uncle Remis story.

Another example: cars, trucks, and other fossil fuel powered vehicles require the refining and 'cracking' of crude oil, but the vehicles themselves produce greenhouse gases that pollute the atmosphere and contribute to global warming.

Another: Plastics are great. What would we do without 'plastics'. They may be molded into various shapes for vessels, containers, tubing, films, car bodies, and complex parts, but produce wastes that include PCBs and solvents, which find their way into ground water causing illnesses and well pollution.

Our example for tonight is that nuclear energy, while producing clean pollution free electricity, produces lethal radio-active waste by-products. Responsible science and technology is continuing that will help solve this problem. A guiding principle for manufacturing worldwide has to avoid the "sweep-it-under-the-rug syndrome" and include in the planning necessary waste control and recycling links in the production chain.

Bibliography:

[1] Loewen, Eric P. "Heavy Metal Nuclear Power" *American Scientist* Volume 92 Number 6

[2] *Nuclear News* Volume 48, Number 3

[3] Personal communication with Mr.Glan Kaht, formernplant operator, Zion Nuclear Power Plant, June 23, 2005

[4] Personal discussions with Dr. Donald H. Williams in November 2005

[5] Talbot, David "Nuclear Powers Up" *Technology Review* Volume 108 Number 9

[6] *Nuclear News* Volume 49, Number 5

[7] Wald, Matthew L. "A New Vision For Nuclear Waste" *Technology Review* Volume 107 Number 10

[8] Long, Michael E. (Photos. By Peter Essick) "America's Nuclear Waste" *National Geographic* Volume 202 Number 1

[9] Hannum, William H., Marsh, George E., Stanford, George S. "Smarter Use of Nuclear Waste" *Scientific American* Volume 293 Number 6 December 2005 pp84

TABLE 1-Nuclear Power Plants-Worldwide

These thirty-three Nations have Nuclear Power Plants in operation ranked by No.of Plants:

Nation:	**Number of Plants**	**Net MWe**(MWe=megawatts-electric)
United States	104	100,460
France	59	63,363
Japan	53	45,218
Russia	31	20,843
United Kingdom	23	11,852
Canada	22	15,222
South Korea	19	15,850
Germany	18	20,643
India	14	2,550
Ukraine	13	11,207
Sweden	11	9,451
Spain	9	7,584
China	9	6,684
Belgium	7	5,801
China (Taiwan)	6	4,884
Slovakia	6	2,442
Switzerland	5	3,220
Bulgaria	4	2,722
Finland	4	2,656
Hungary	4	1,755
Czech Republic	4	1,648
Brazil	2	1,901
South Africa	2	1,800
Mexico	2	1,330
Argentina	2	935
Pakistan	2	425
Lithuania	1	1,187
Slovenia	1	656
Romania	1	655
Netherlands	1	449
Armenia	1	376
North Korea	-has 0 in operation, 2 units rated 2,000 MWe	
Iran	-has 0 in operation, 1 unit rated 915 Mwe	
TOTALS	440	365,769 MWe

TABLE_2-Nuclear Power Plants with CASK STORAGE of Waste

STATE	SITE NAME and LOCATION	MWe	Type	Started	Closed
Maine	Maine Yankee (Wiscasset, ME)	860	PWR	12/72	8/97
Mass.	Yankee (Rowe, MA)	175	PWR	7/61	9/91
New York	Indian Point-1(Buchanan, NY)	257	PWR	1/63	10/74
	Indian Point-2 -ditto-	993	PWR	8/74	--
	Indian Point-3 -ditto-	979	PWR	8/76	--
New Jersey	Oyster Creek (Forked River, NJ)	650	BWR	12/69	--
	Hope Creek (Salem, NJ)	1083	BWR	12/86	--
	Salem 1 -ditto-	1193	PWR	6/77	--
	Salem 2 -ditto-	1131	PWR	10/81	--
Pennsyl.	3-Mile Island-1 (Londonderry, PA)	819	PWR	9/74	--
	3-Mile Island-2 -ditto-	792	PWR	12/78	3/79
	Peach Bottom-2 (Delta, PA)	1138	BWR	7/74	--
	Peach Bottom-3 -ditto-	1138	BWR	12/74	--
Maryland	Calvert Cliffs-1 (Lusby, MD)	845	PWR	5/75	--
	Calvert Cliffs-2 -ditto-	845	PWR	7/78	--
Virginia	North Anna-1 (Mineral, VA)	907	PWR	6/78	--
	North Anna-2 -ditto-	907	PWR	12/80	--
	Surry-1 Gravel Neck, VA)	788	PWR	12/72	--
	Surry-2 -ditto-	788	PWR	6/73	--
N. Carolina	Brunswick-1 (Southport, NC)	972	BWR	3/77	--
	Brunswick-2 -ditto-	975	BWR	11/75	--
S. Carolina	Robinson-2 (Hartsville, SC)	765	PWR	3/71	--
	Oconee-1 (Seneca, SC)	886	PWR	7/73	--
	Oconee-2 -ditto-	886	PWR	9/74	--
	Oconee-3 -ditto-	886	PWR	12/74	--
Georgia	Edwin I. Hatch-1 (Baxley, GA)	885	BWR	12/75	--
	Edwin I. Hatch-2 -ditto-	908	BWR	9/79	--
Ohio	Davis-Besse (Oak Harbor, OH)	906	PWR	7/78	--
Michigan	Big Rock Point (Charlevoix, MI)	67	BWR	11/65	8/97
	Palisades (South Haven, MI)	805	PWR	12/71	--
Arkansas	Arkansas Nuclear One-1 (Russell-	850	PWR	12/74	--
	Arkansas Nuclear One-2 ville, AK)	912	PWR	3/80	--
Illinois	Zion-1 (Zion, IL)	1040	PWR	12/73	1/98
	Zion-2 -ditto-	1040	PWR	9/74	1/98
Wisconsin	Point Beach-1 (Two Rivers, WI)	522	PWR	12/70	--
	Point Beach-2 -ditto-	522	PWR	10/72	--
Iowa	Duane Arnold (Palo, IA)	581	BWR	2/75	--
Minnesota	Prairie Island-1 (Red Wing, MN)	536	PWR	12/73	--
	Prairie Island-2 -ditto-	536	PWR	12/74	--
Colorado	Fort St. Vrain (Platteville, CO)	330	HTGR	1/79	8/89
Arizona	Palo Verde-1 (Wintersburg, AZ)	1265	PWR	1/86	--
	Palo Verde-2 -ditto-	1354	PWR	9/86	--
	Palo Verde-3 -ditto-	1247	PWR	1/88	--
California	Humboldt Bay-3 (Eureka, CA)	63	BWR	8/63	7/76
	Rancho Seco (Sacramento, CA)	913	PWR	4/75	6/89
	San Onofre-1 (San Clemente, CA)	436	PWR	1/68	11/92
	San Onofre-2 -ditto-	1182	PWR	8/83	--
	San Onofre-3 -ditto-	1177	PWR	4/84	--
	Diablo Canyon-1 (Avila Beach, CA)	1103	PWR	5/85	--
	Diablo Canyon-2 -ditto-	1119	PWR	3/86	--
Oregon	Trojan (Portland, OR)	1095	PWR	5/76	11/92
Washington	Columbia (Richland, WA)	1153	BWR	12/84	--