REDUCING THE RISKS OF SPENT POWER REACTOR FUEL

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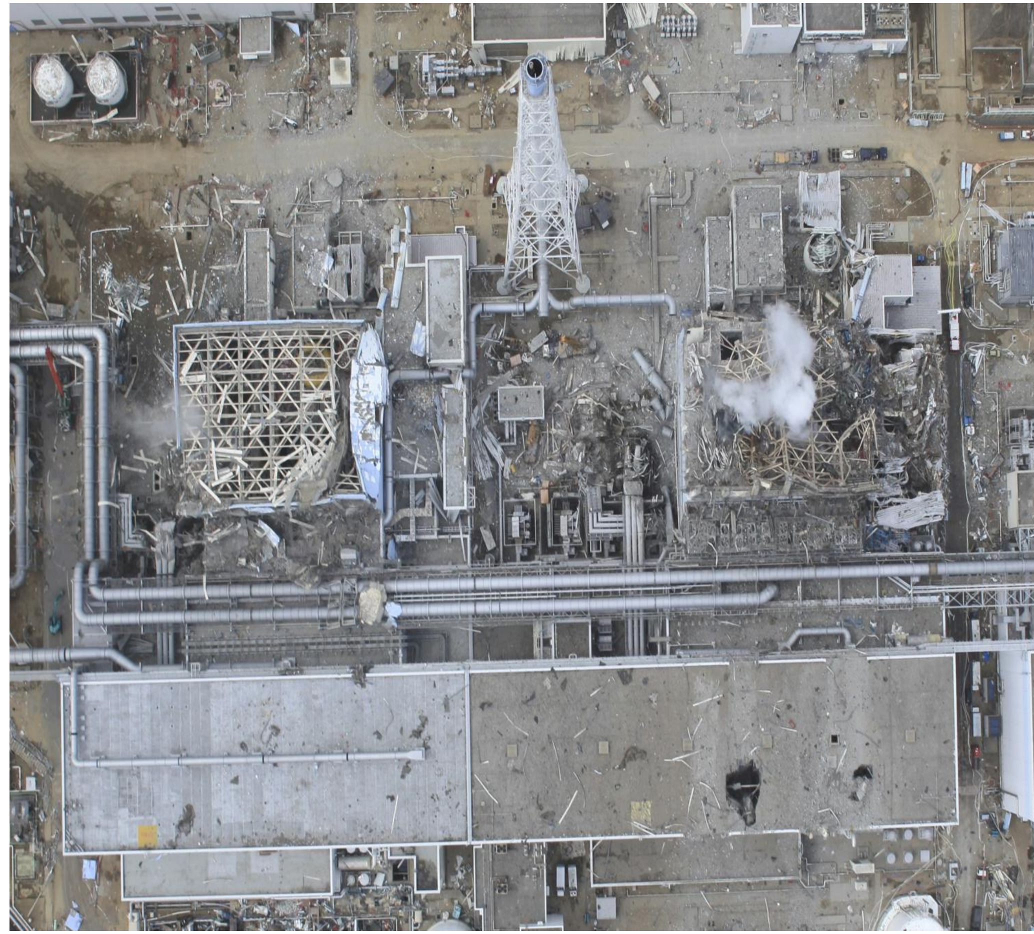
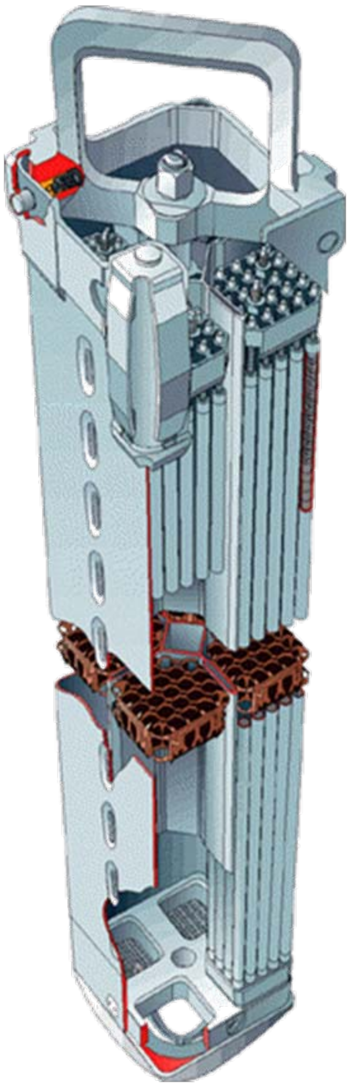
The nuclear crisis at the Daiichi complex in Fukushima, Japan has turned a spotlight on the dangers of spent nuclear fuel in pools.



Source: http://cryptome.org/eyeball/daiichi-npp/daiichi-photos.htm

Radiation dose rates in the vicinity of the pools were life-threatening and required remotely-controlled water cannons in an attempt to restore lost water.



typical boiling water reactor fuel assembly

Irradiated nuclear fuel, also called "spent fuel," is extraordinarily radioactive. In a matter of seconds, an unprotected human one meter away from a single freshly removed spent fuel assembly would receive a lethal dose of *radiation within seconds.*

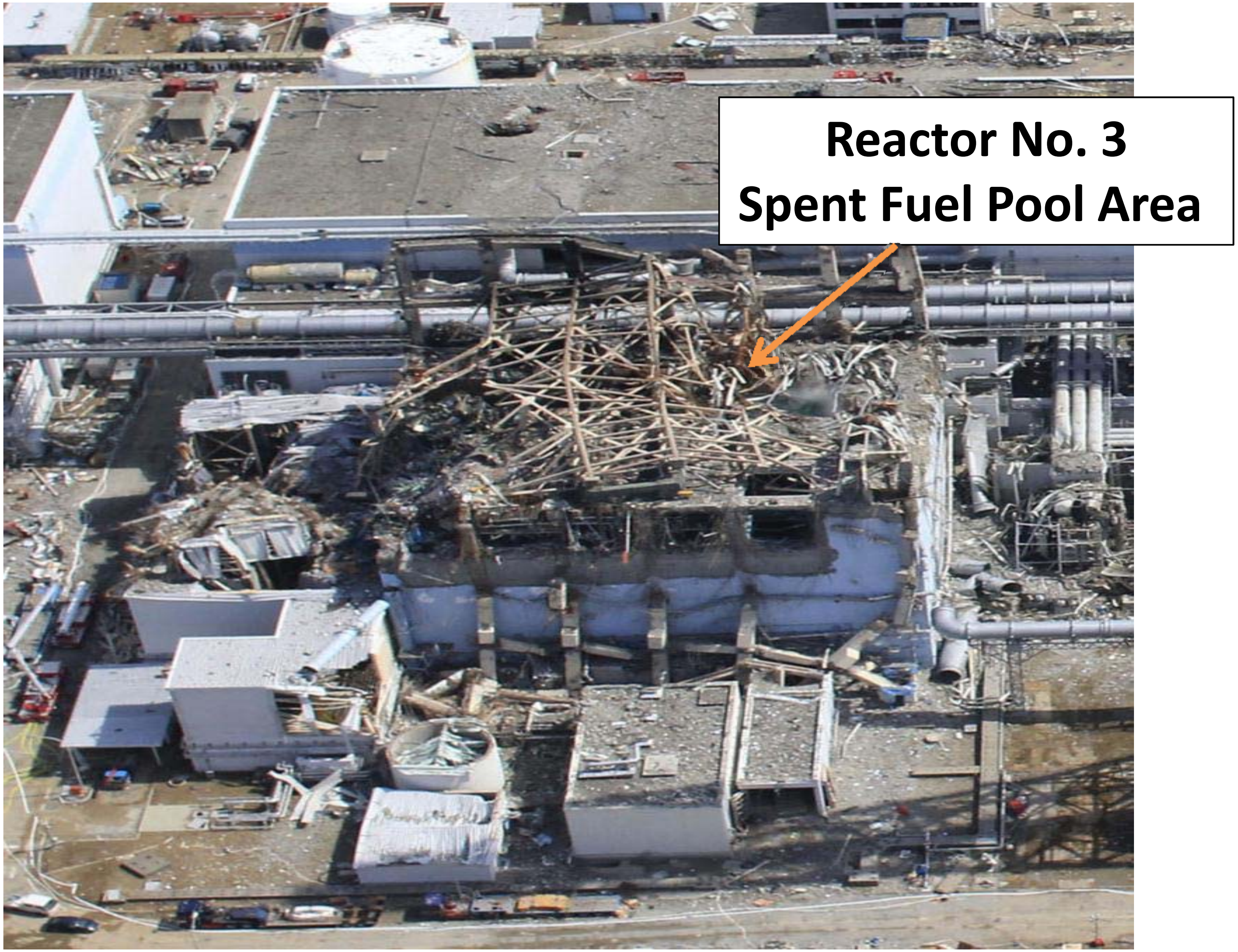
At the Fukushima Dai-Ichi nuclear complex, the molten cores of units 1, 2 and 3, are of great long-term concern.

But the radioactive inventory of all the irradiated nuclear fuel stored in spent fuel pools at Fukushima is far greater and even more problematic than the molten cores -- in terms of potential offsite consequences.

Why Spent Fuel Pools Pose Greater Consequences

(1) each pool contains the irradiated fuel from several years of operation, making for an extremely large radioactive inventory;
(2) the pools do not have a strong containment structure that enclose the reactor cores;
(3) several pools are now completely open to the atmosphere because the reactor buildings were demolished by explosions;
(4) the pools are about 100 feet above ground and could possibly topple or collapse from structural damage coupled with another powerful earthquake;
(5) the blast of penetrating radiation from the unshielded spent fuel pool would prevent human access;
(6) the loss of water will result in overheating of the fuel which can cause melting and ignite its zirconium metal cladding – resulting in a fire that could deposit large amounts of radioactive materials over hundreds of miles.

Source: Associated Press



Source: Air Photo Service Co. Ltd., Japan, March 24, 2011

The Common Pool at the Dai-Ichi Site contains 6375 assemblies (~60% of SNF at the site) and is at 80% storage capacity.

It is not clear if this pool was damaged.

This pool contains about 192 million curies (7.03E+18 Bq) of long-lived radioactivity.

Of that, about 80 million curies is cesium-137 –or about <u>50 times the amount released at Chernobyl.</u>

The spent fuel rods in pool No. 4 contain roughly 37 million curies (~1.4E+18 Bq) of long-lived radioactivity.

If an earthquake or other event were to cause this pool to drain this could result in a catastrophic radiological fire involving about 10 times the amount of Cs-137 released by the Chernobyl accident.

In order to prevent severe radiation exposures, fires and possible explosions, spent reactor fuel must be transferred at all times in water and heavily shielded structures into dry casks.

Removal of the spent fuel from the pools at the damaged Fukushima-Dai-Ichi reactors will require major construction and take several years.

A total of 11,329 spent reactor fuel assemblies are at the Fukushima-Dai-Ichi site.

2,524 assemblies containing about 76 million curies of long-lived radioactivity (2.182E+18 Bq) are in the four damaged reactors, with <u>nearly 20 times the amount of Cs-137 released at Chernobyl.</u>

<u>All of the spent fuel assemblies at the site contain about 85 times the amount Of Cs-137 released at Chernobyl.</u>

Spent Fuel Storage Cask at the Dai-Ichi Site

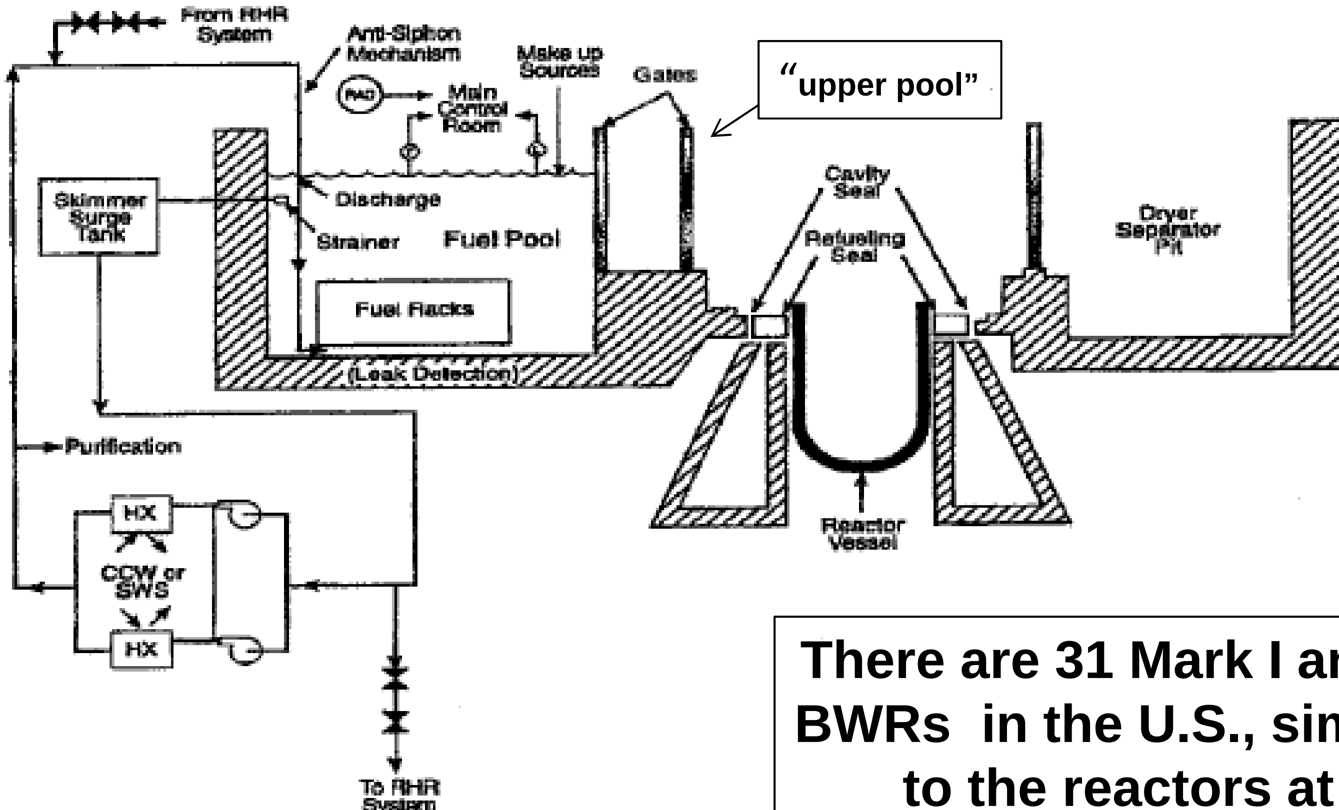
Nine dry casks hold 408 assemblies at the Fukushima-Daichi Site.

The casks were unscathed by the earthquake and Tsnunami.

About 3 percent of the spent fuel at the Dai-Ichi site is in dry storage.

Source: Shirai and Saegusa- 2012

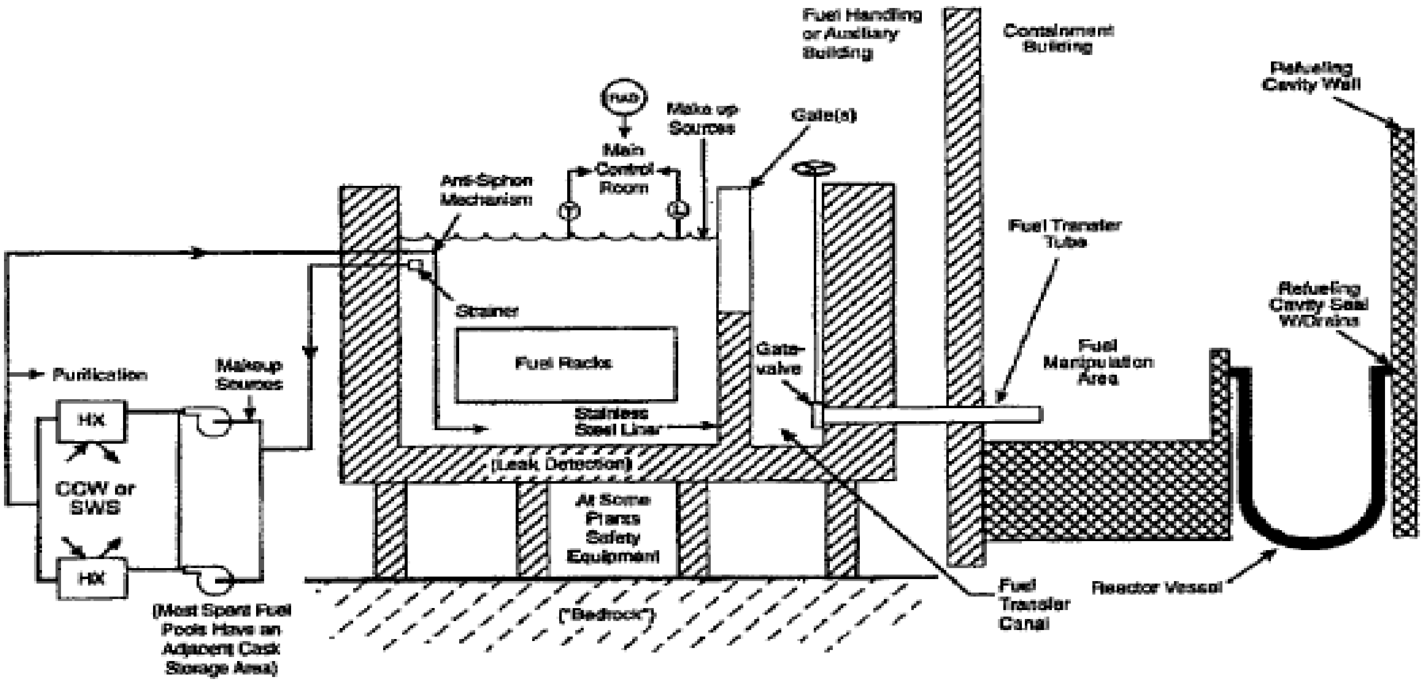
Layout of spent fuel pool and transfer system for boiling water reactors (BWR)



There are 31 Mark I and II BWRs in the U.S., similar to the reactors at Fukushima, with spent fuel pools ~100 feet above ground.

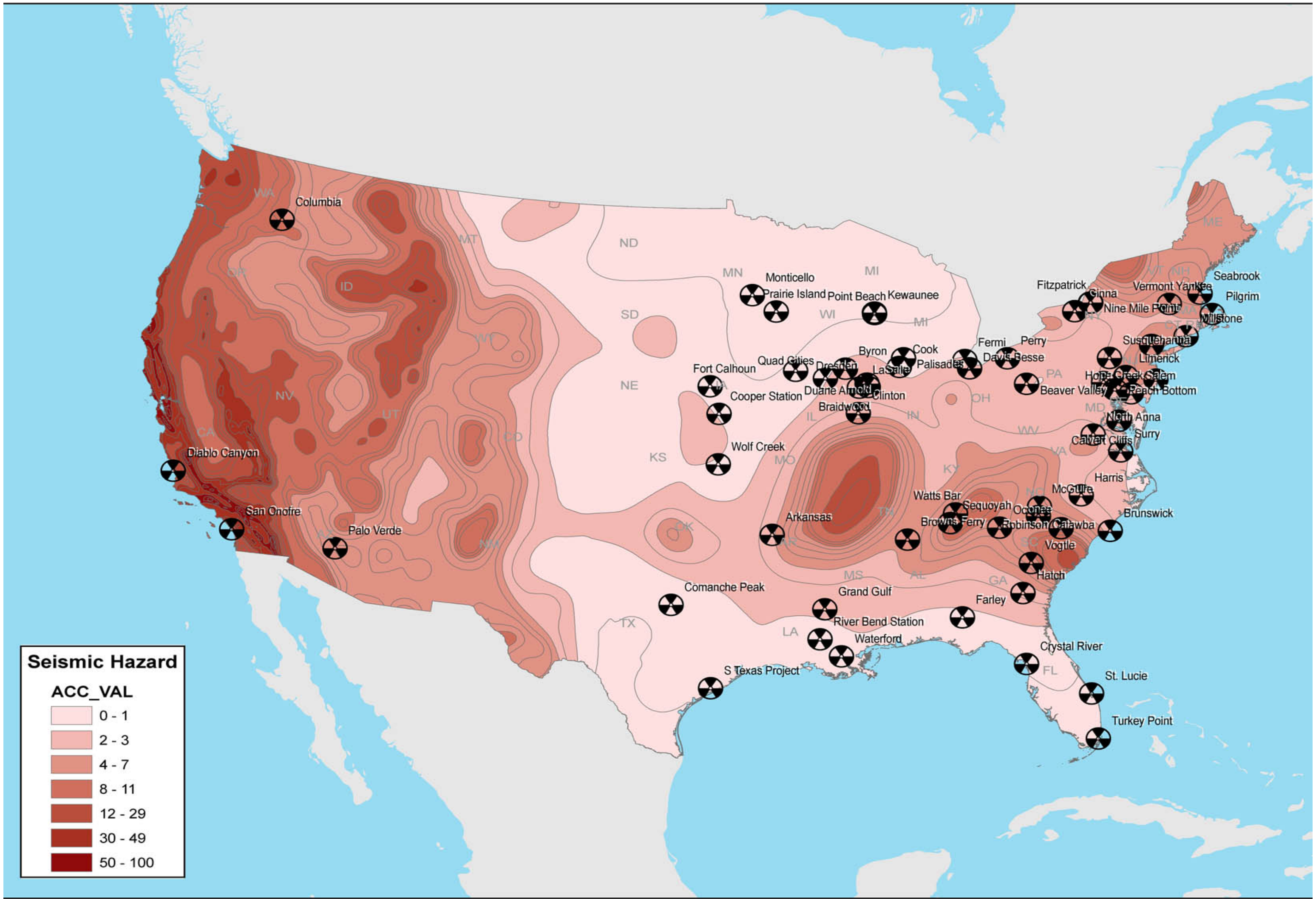
Source: U.S. Nuclear Regulatory Commission, NUREG-1275.

Layout for spent fuel pool and transfer system for pressurized water reactors



Source: U.S. Nuclear Regulatory Commission, NUREG-1275.

Figure 5 U.S. Nuclear Power Reactors in Earthquake Zones



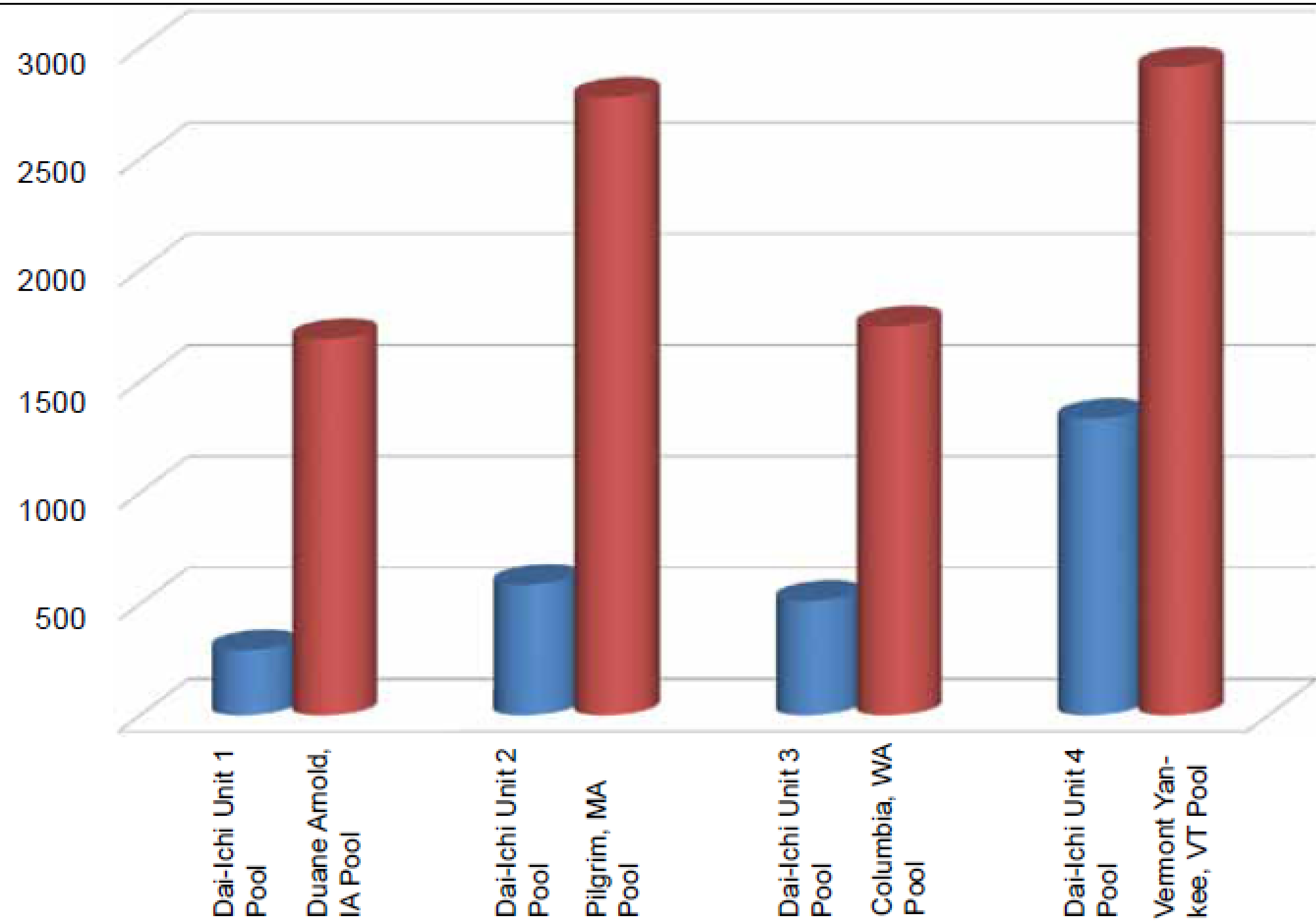
Sources: U.S. Geological Survey, Energy Information Administration

High Density Power Reactor Spent Fuel Pool

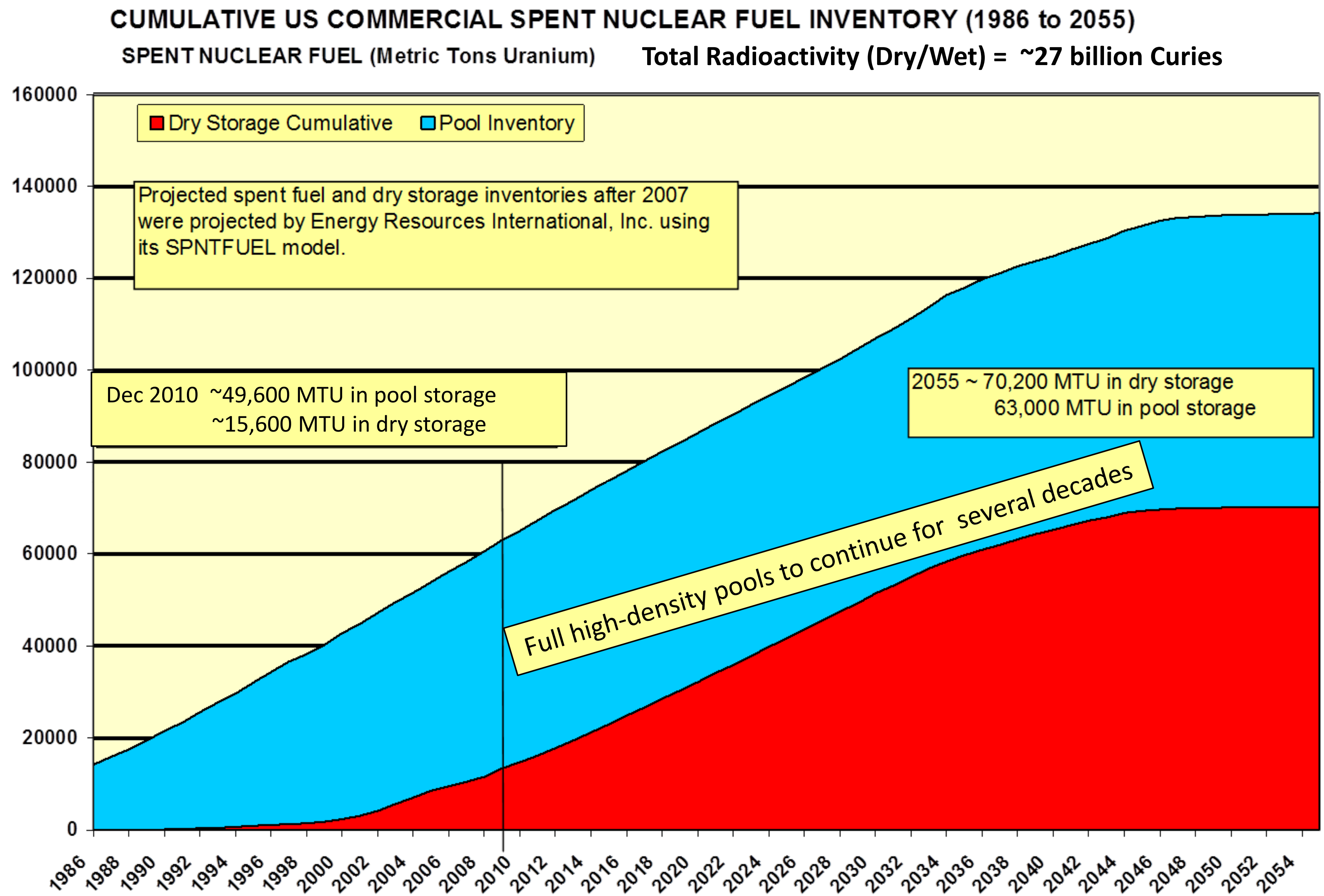
The U.S. Nuclear Regulatory Commission permits U.S. Spent reactor fuel pools to hold, on the average, four to five times the amount in the Fukushima reactors.

Like the Fukushima reactors, U.S. spent fuel pools are located outside of the containment structure that holds the reactor pressure vessel

Spent Fuel Assemblies in Pool at the Dai-Ichi Nuclear Site in Fukushima and individual Boiling Water Reactors in the United States



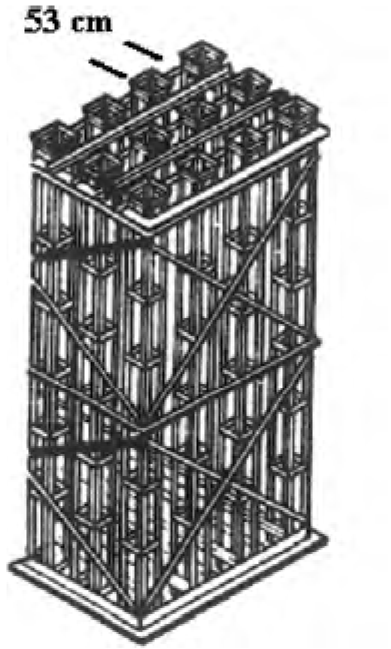
Sources: All Things Nuclear, Union of Concerned Scientists, March 21, 2011; NEI, March 2011; DOE/EIS-0250, Appendix A, Table A-7, Energy NW, March 29, 2011.



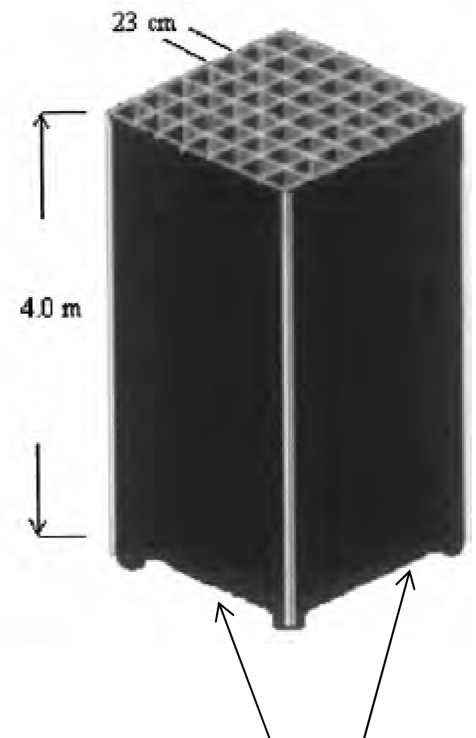
By 2055: >485,000 assemblies (per ACI Nuclear Energy Solutions)

Adapted from Kessler/EPRI - June 2010

Open and dense-pack PWR spent fuel racks



Source: NUREG/CR-0649



fixed neutron-absorbing panels

Isotope	Half Life (yrs)	Radioactivity (Ci)
Hydrogen-3	12.3	10,200,000
Carbon-14	5,700	95,000
Chlorine-36	300,000	750
Iron-55	2.7	420,000
Cobalt-60	5.3	27,000,000
Nickel-59	76,000	160,000
Nickel-63	100	22,000,000
Selenium-79	64,000	30,000
Krypton-85	10.7	150,000,000
Strontium-90	29	3,000,000,000
Zirconium-93	1,500,000	160,000
Niobium-93m	16	110,000
Niobium-94	24,000	56,000
Technetium-99	210,000	950,000
Ruthenium-106	1	4,700
Palladium-107	6,500,000	8,800
Cadmium-133m	14	1,500,000
Antimony-125	2.8	3,600,000
Tin-126	1,000,000	59,000
Iodine-129	17,000,000	2,400
Cesium-134	2.1	5,800,000
Cesium-135	2,300,000	36,000
Cesium-137	30	4,500,000,000
Promethium-147	2.6	18,000,000
Samarium-151	90	25,000,000

Isotope	Half Live (yrs)	Radioactivity (Ci)
Europium-154	8.6	120,000,000
Europium-155	4.8	22,000,000
Actinium-227	2.2	0.97
Thorium-230	75,000	18
Protactinium-231	33,000	2.1
Uranium-232	69	2600
Uranium-233	160,000	3.9
Uranium-234	250,000	84,000
Uranium-235	720,000,000	1,000
Uranium-236	23,000,000	18,000
Uranium-238	4,500,000,000	20,000
Plutonium-241	14	3,200,000,000
Plutonium-238	88	240,000,000
Americium-241	430	220,000,000
Curium-244	18	120,000,000
Plutonium-240	6,500	36,000,000
Plutonium-239	24,000	24,000,000
Americium-243	7,400	1,900,000
Americium-242/242m	140	1,600,000
Curium-242	0.45	1,300,000
Curium-243	29	1,300,000
Plutonium-242	380,000	140,000
Neptunium-237	2,100,000	30,000
Curium-245	8,500	29,000
Curium-246	4,800	6,300
		~12 billion Ci

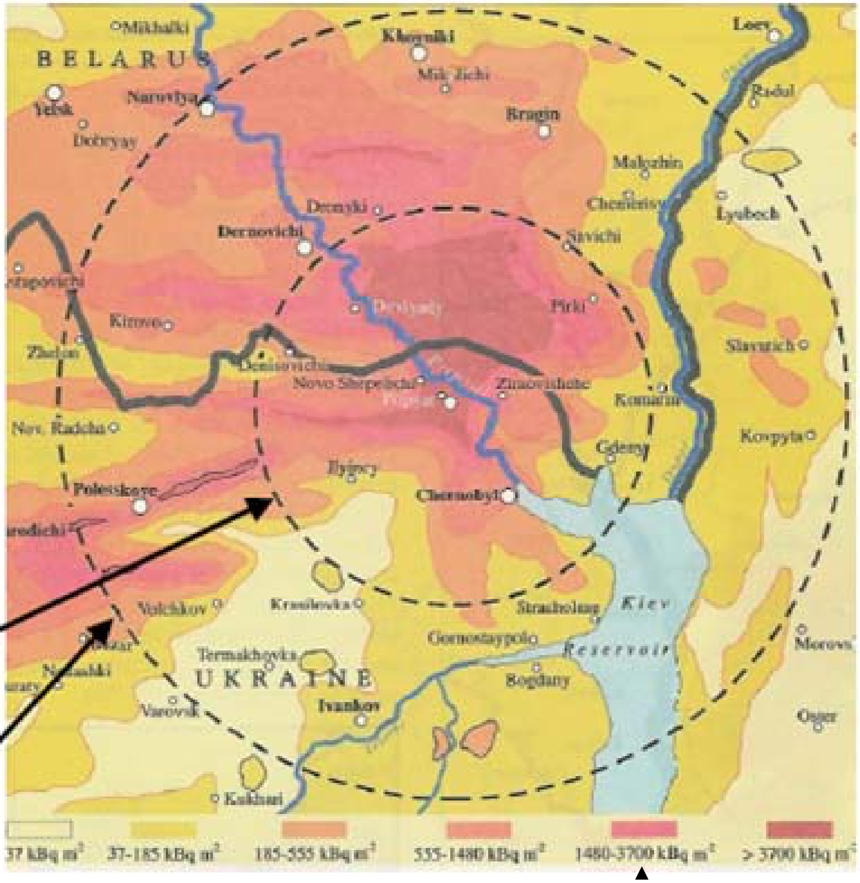
Source: DOE/EIS-0250 Appendix A.

- About 4.5 billion curies, roughly 40 percent of the U.S. spent fuel inventory, is cesium-137.
- With a half-life of 30 years, Cs-137 gives off potentially dangerous external penetrating radiation.
- Cs-137 mimics potassium as it accumulates in the food chain.
- There is about four to five times the amount of cesium-137 than in reactor cores.
- Spent fuel at U.S. nuclear reactors contains roughly 20 times more cesium-137 than was released by more than 650 atmospheric nuclear weapons tests throughout the world.

2 MCi of Cs^{137} (30-year halflife) released by Chernobyl

>15 Ci/km²: radiation control area: > 10,000 km² (1/2 of area of NJ)

>50 Ci/km²): >0.7% chance of radiation-caused cancer death from lifetime external radiation ~ 3100 km²



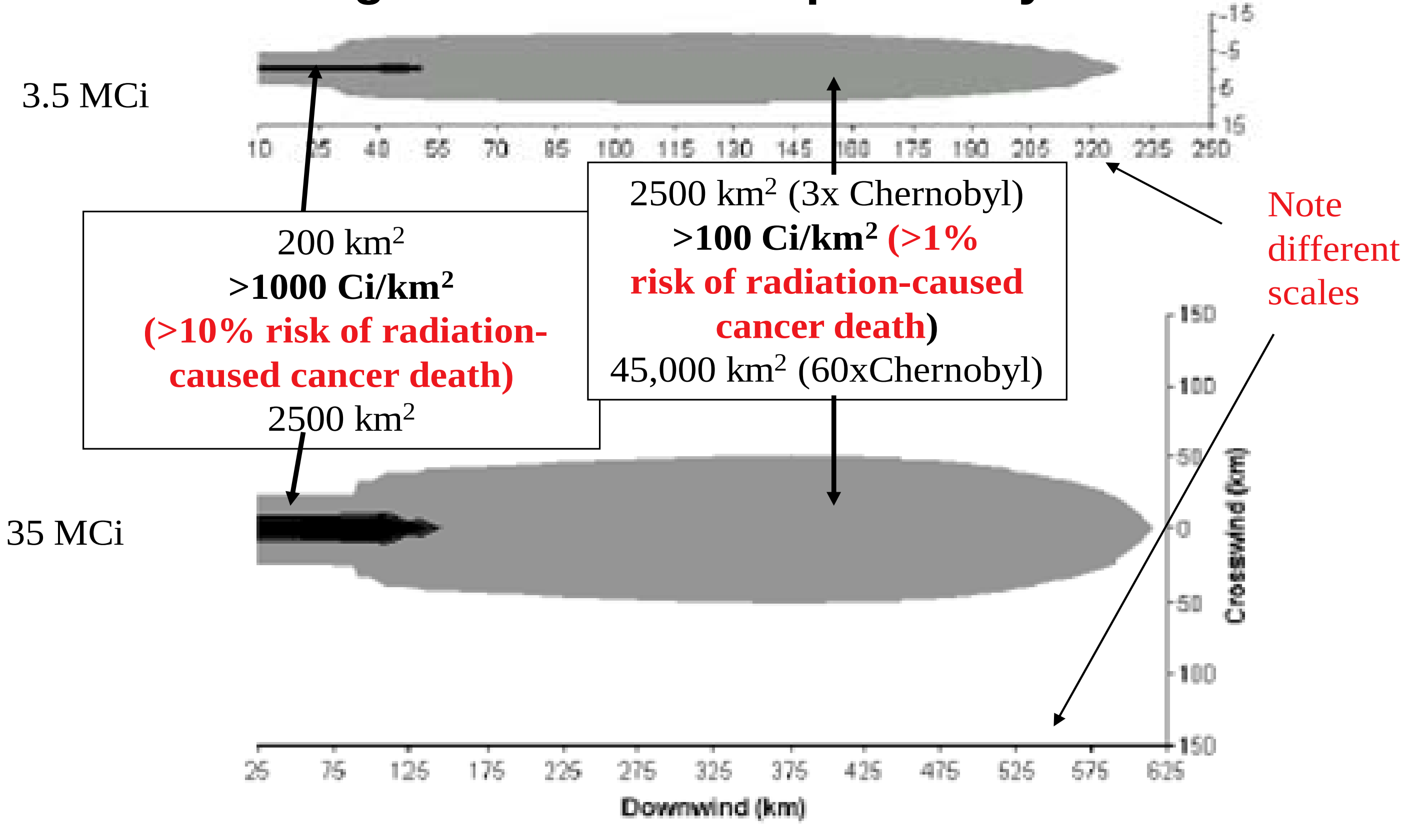
18-mile radius (permanently evacuated)

36-mile radius

(UNSCEAR-2000)

50 MCi/km²

MACCS2 code prediction for smoldering pool fire releasing ^{137}Cs into a 10 mph steady wind



Source: F. von Hippel, presentation to NAS, February 12, 2004

National Research Council Findings Regarding Vulnerabilities of Reactor Spent Fuel Pools

"A loss-of-pool-coolant event resulting from damage or collapse of the pool could have severe consequences…

It is not prudent to dismiss nuclear plants, including spent fuel storage facilities as undesirable targets for terrorists…

under some conditions, a terrorist attack that partially or completely drained a spent fuel pool could lead to a propagating zirconium cladding fire and release large quantities of radioactive materials to the environment…

Such fires would create thermal plumes that could potentially transport radioactive aerosols hundreds of miles downwind under appropriate atmospheric conditions."

National Research Council, Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, "Board on Radioactive Waste Management," (2006)

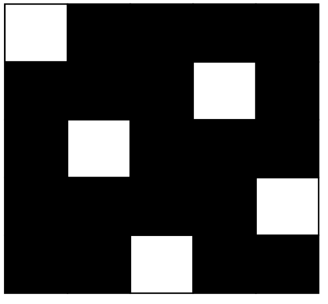
Damage estimates for 3.5-35 MCi Cs-137 release

Site	Damages ($B)	Cancer Deaths
Catawba	76-547	3100-7700
Indian Point	145-461	1500-5600
LaSalle	54-80	2100-6400
Palo Verde	11-80	600-2000
Three-Mile Is.	171-568	2300-7000
Average	**91-347**	**1900-5700**

Source: F. von Hippel, presentation to NAS, February 12, 2004

Why reduce storage density?

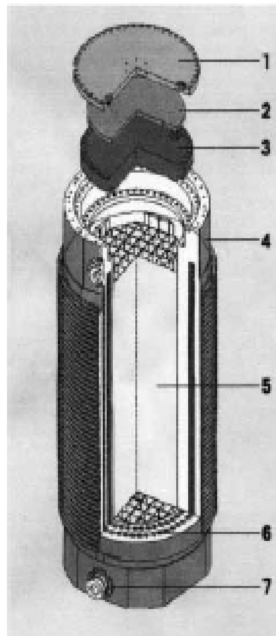
- Reduces the risk of ignition.
- Would allow open-rack storage of hottest fuel or
- Removal of one fifth of fuel assemblies could expose at least one side of each to an open channel



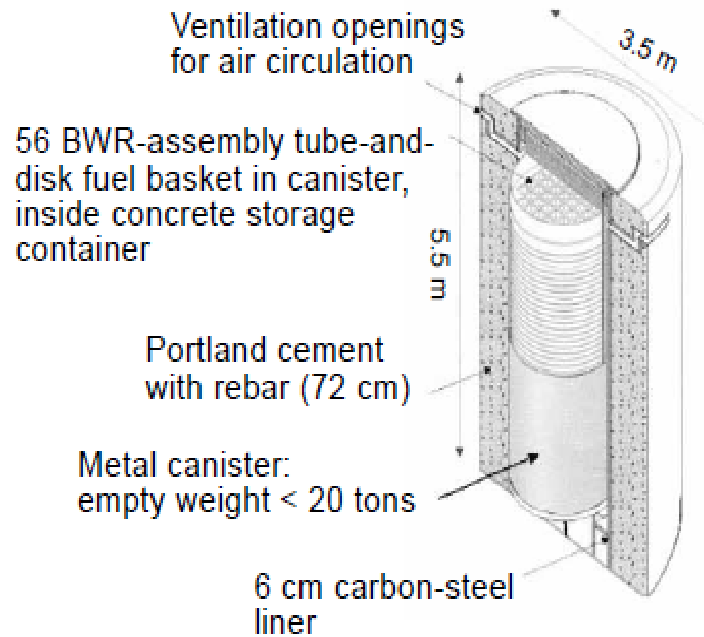
Two Types of Dry Storage Casks

Castor V/52

1. Secondary Lid
2. Neutron Moderator Plate
3. Primary Lid
4. Cask Body with Cooling Fins
5. Fuel Assembly Basket
6. Neutron Moderator Rods
7. Trunnion



Holtec



Solid cast iron steel shell shielded by concrete

Magnitude of Task

- ~50,000 metric tons of dense-packed fuel currently in pools.

- 10,000 tons with more than five years cooling could be stored in about 10,000 casks.

- 15,573 metric tons in dry storage.

- Two major U.S. manufacturers have said they could ramp up their combined production to 500 casks/yr.

Recommendations of the U.S. Blue Ribbon Commission on America's Nuclear Future

In January 2010 The Obama administration has canceled long-contested plans to develop a permanent, deep disposal site at Yucca Mountain in Nevada.

In its place, a Blue Ribbon Commission on America's Nuclear Future was tasked with coming to terms with the country's five-decade-plus quest to store and dispose of its high-level radioactive waste. In January 2012, the Panel recommended, among other things:

> *** development of a "new consent-based process.. for selecting and evaluating sites and licensing consolidated storage and disposal facilities in the future:"**
> *** establishment of "a new waste management organization" to replace the role of the Energy Department with "a new independent, government-chartered corporation…;"**

THE BOTTOM LINE IS THAT, OPTIMALLY, THESE RECOMMENDATIONS WILL TAKE SEVERAL DECADES BEFORE CONSOLIDATED STORAGE AND DISPOSAL OF WASTES CAN OCCUR.

The risk of densely-packed fuel pools in the U.S. can be significantly reduced by placing spent fuel older than five years into dry, hardened storage containers –something Germany did 25 years ago.

$1-2 million per cask =>$1-2 billion for 1000 casks

Cost of dry storage

0.04- 0.7 cents per kWh generated from the fuel (less than 1% of retail price of electricity in U.S.)

Money could also be allocated from $18.1 billion in unexpended funds already collected from consumers of nuclear-generated electricity under the Nuclear Waste Policy Act to establish a disposal site for high-level radioactive wastes.

Conclusion

After more than 50 years, the quest for permanent nuclear waste disposal remains illusory.

One thing, however, is clear: the largest concentrations of radioactivity on the planet will remain in storage at U.S. reactor sites for the indefinite future.

In protecting America from nuclear catastrophe, safely securing the spent fuel by eliminating highly radioactive, crowded pools should be a public safety priority of the highest degree.

With a price tag of as much as $7 billion, the cost of fixing America's nuclear vulnerabilities may sound high, especially given the heated budget debate occurring in Washington. But the price of doing too little is incalculable.