Reducing the risk from spent power-reactor fuel

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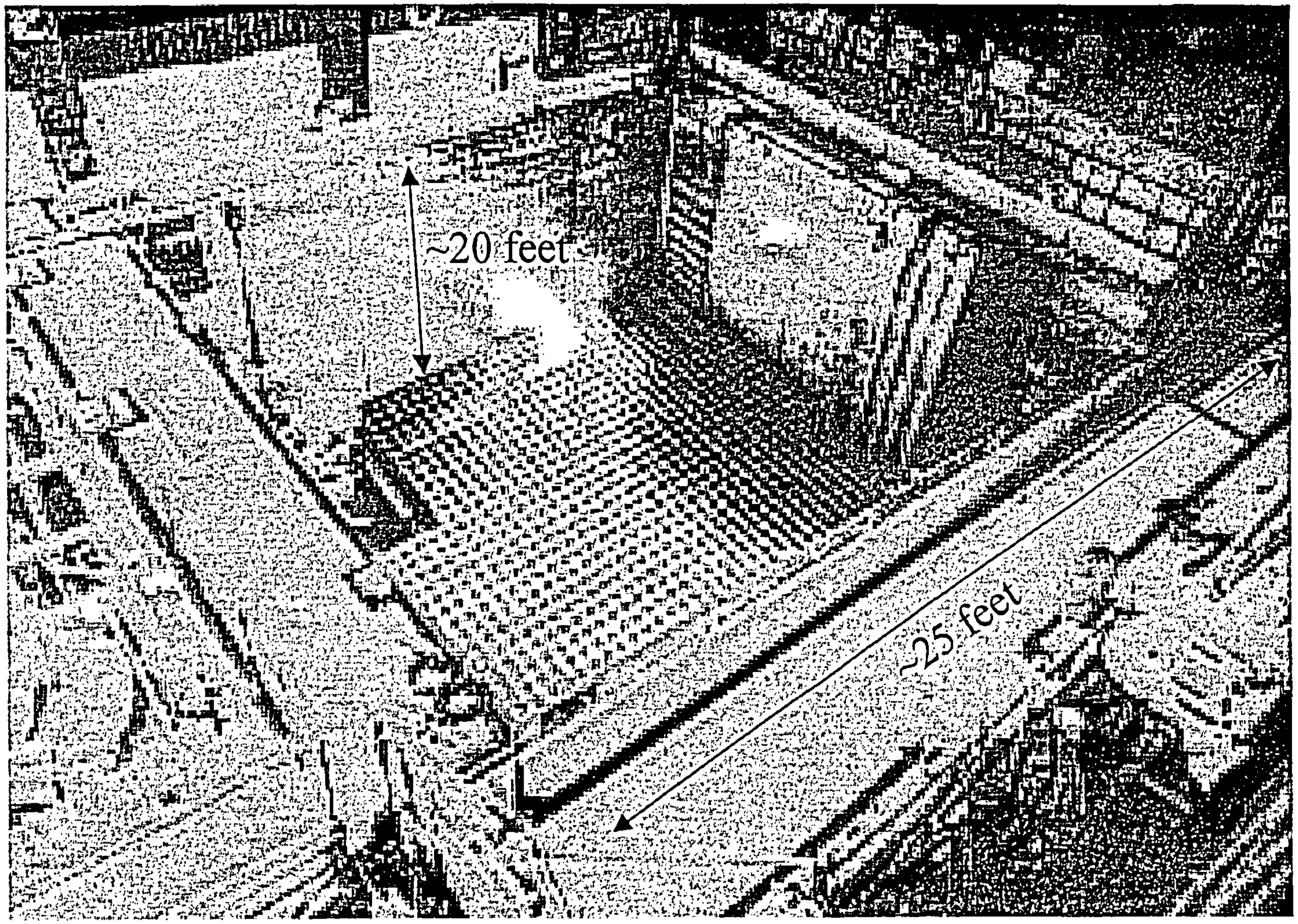
- In town because of a congressional briefing tomorrow
  - about an article on spent fuel
    - we are 3 of 8 co-authors
- We speak today as individuals
- Discussing only scenarios already in the public record
- Stress hazard reduction



An almost full spent-fuel storage pool

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

Red: radiation control area: > 4,000 sq. miles (1/2 of area of NJ)

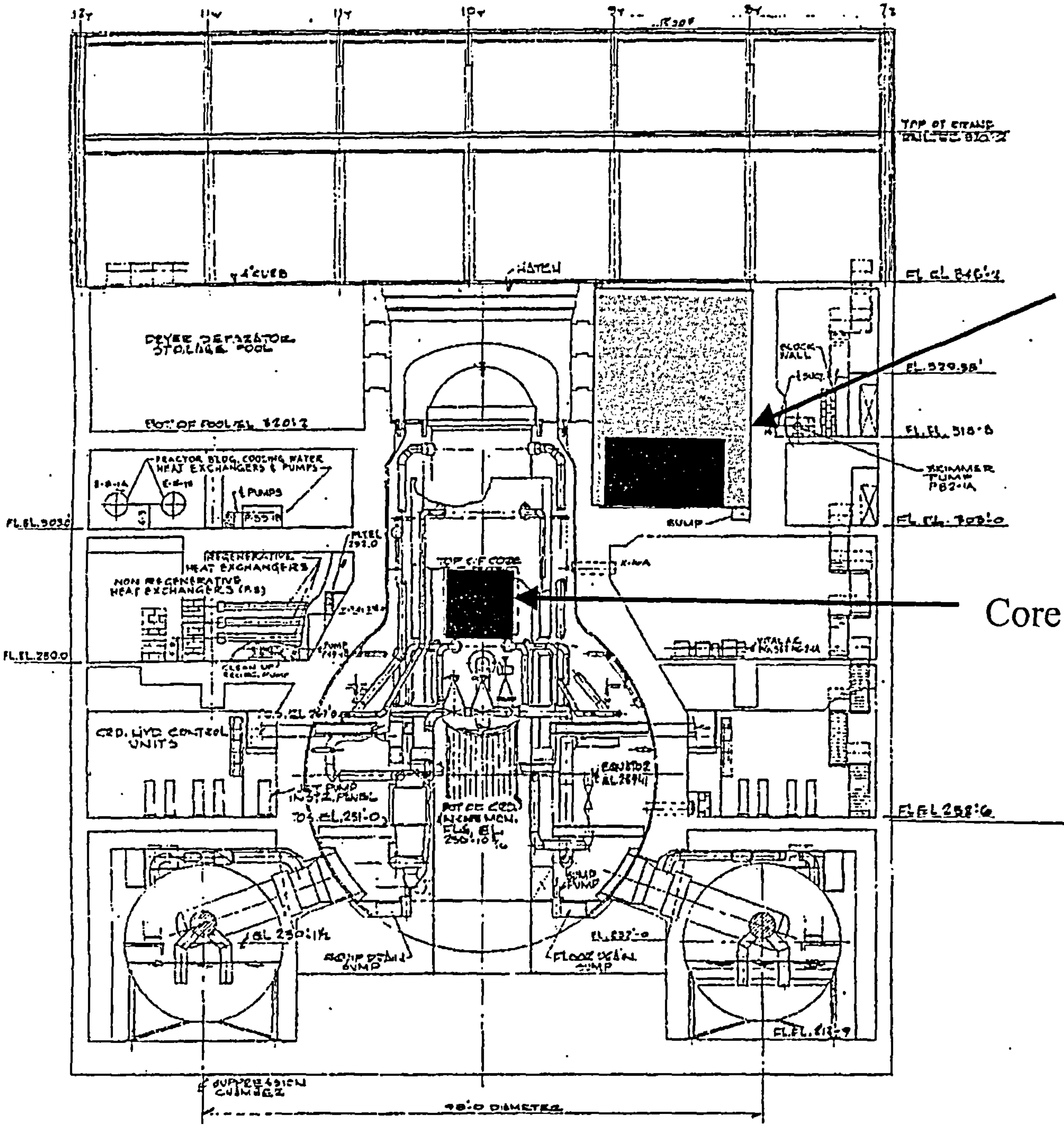
Darkest red:
> 1% chance of radiation-caused cancer death from external radiation ~ 250 sq. miles

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

18-mile radius

36-mile radius

Loss of water is possible (for example, BWR spent fuel storage pool is 50 feet up).



PWR spent fuel pool

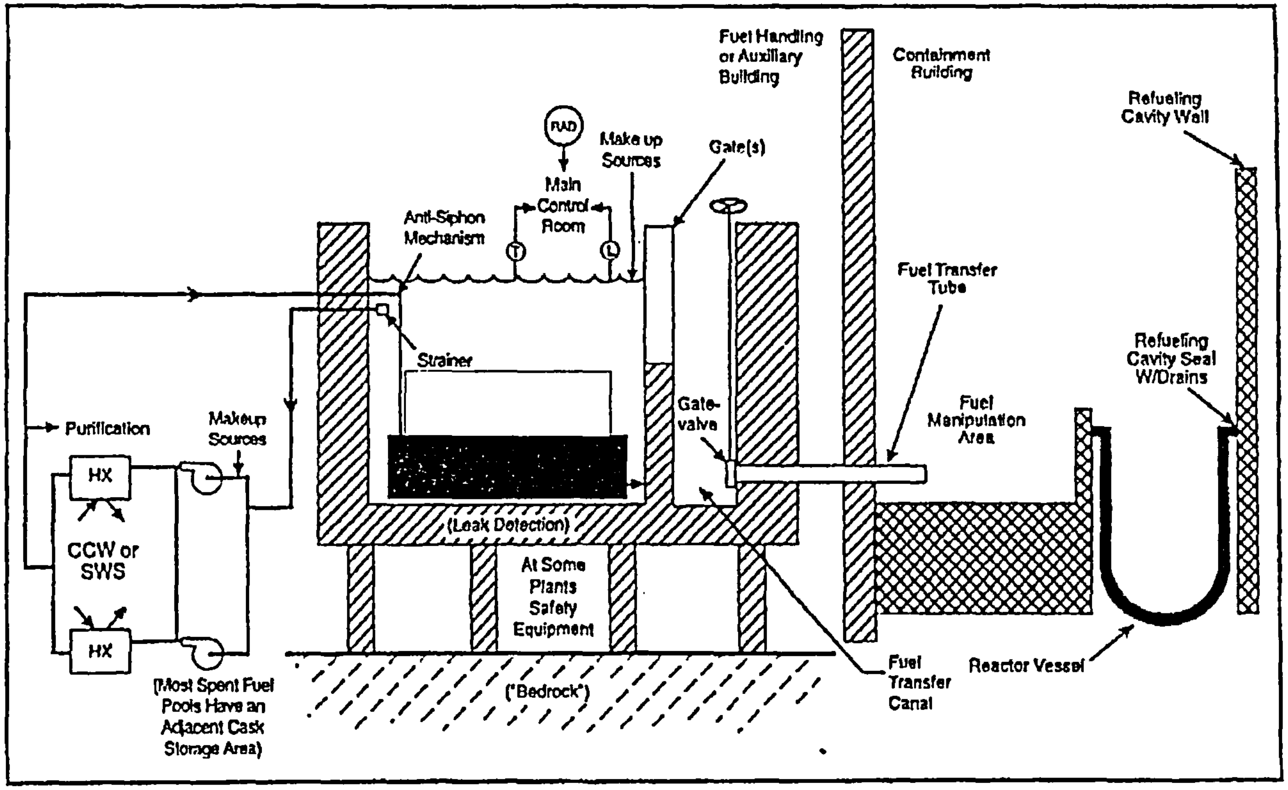
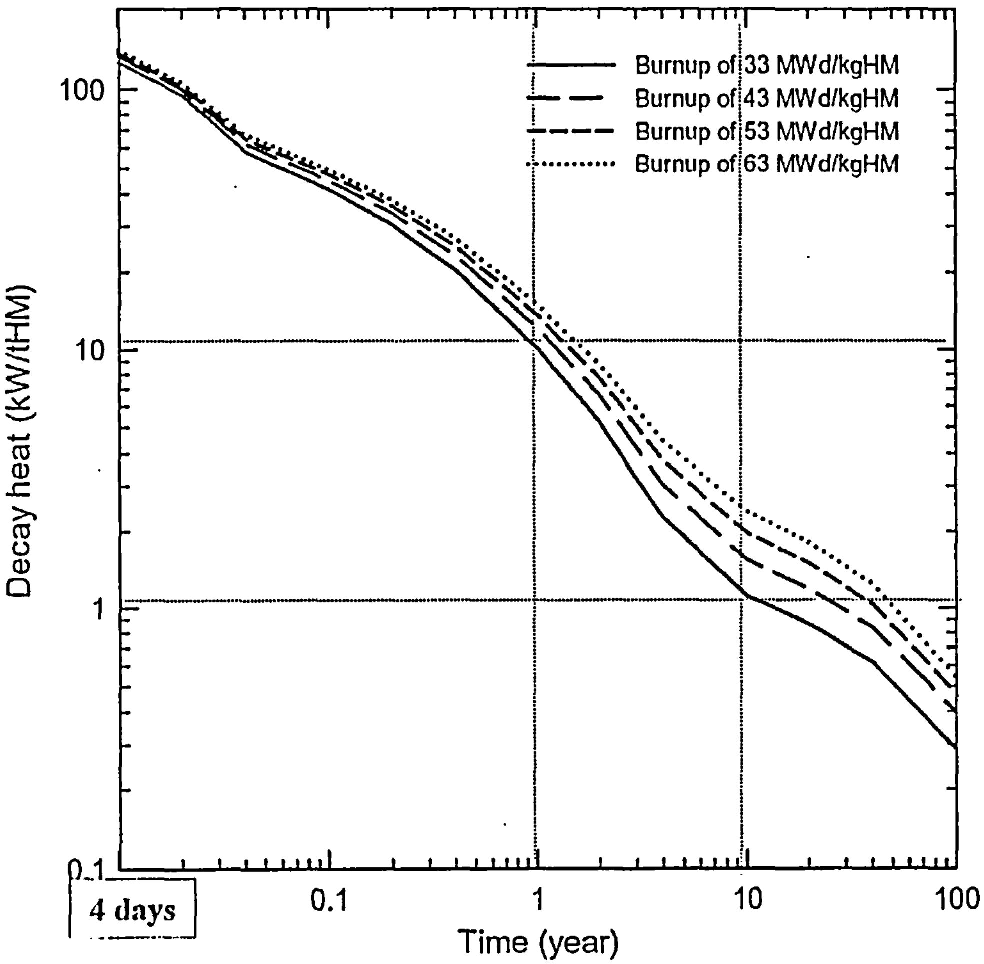


Figure 2.1 PWR Spent Fuel Cooling Systems (NUREG-1275)

Decay heat problem



Fresh core in pool:
Could dry pool out to top of spent fuel in a day.
Could heat up fuel to ignition in an hour.

Fresh core not in pool:
Dry out about 10 days.
Fuel could still ignite.

Fires following loss of coolant in a dense-racked pool

1979: Ignition of spent fuel less than 2 years post discharge

--NUREG/CR-0649

2001:"[I]t was not feasible, without numerous constraints, to establish a generic decay heat level (and therefore a decay time) beyond which a zirconium fire is physically impossible.."

--NUREG-1738

Probability of loss of coolant and fire

1/5000 per year in US from earthquake, cask drop, boil off due to loss of off-site power, fire, aircraft impact, tornado missile…"well within the Commission's Quantitative Health Objectives"

--NUREG-1738, 2001

What about the probability of terrorism?

"the possibility of a terrorist attack ... is speculative and simply too far removed from the natural or expected consequences of agency action..."

--NRC, Dec. 2002

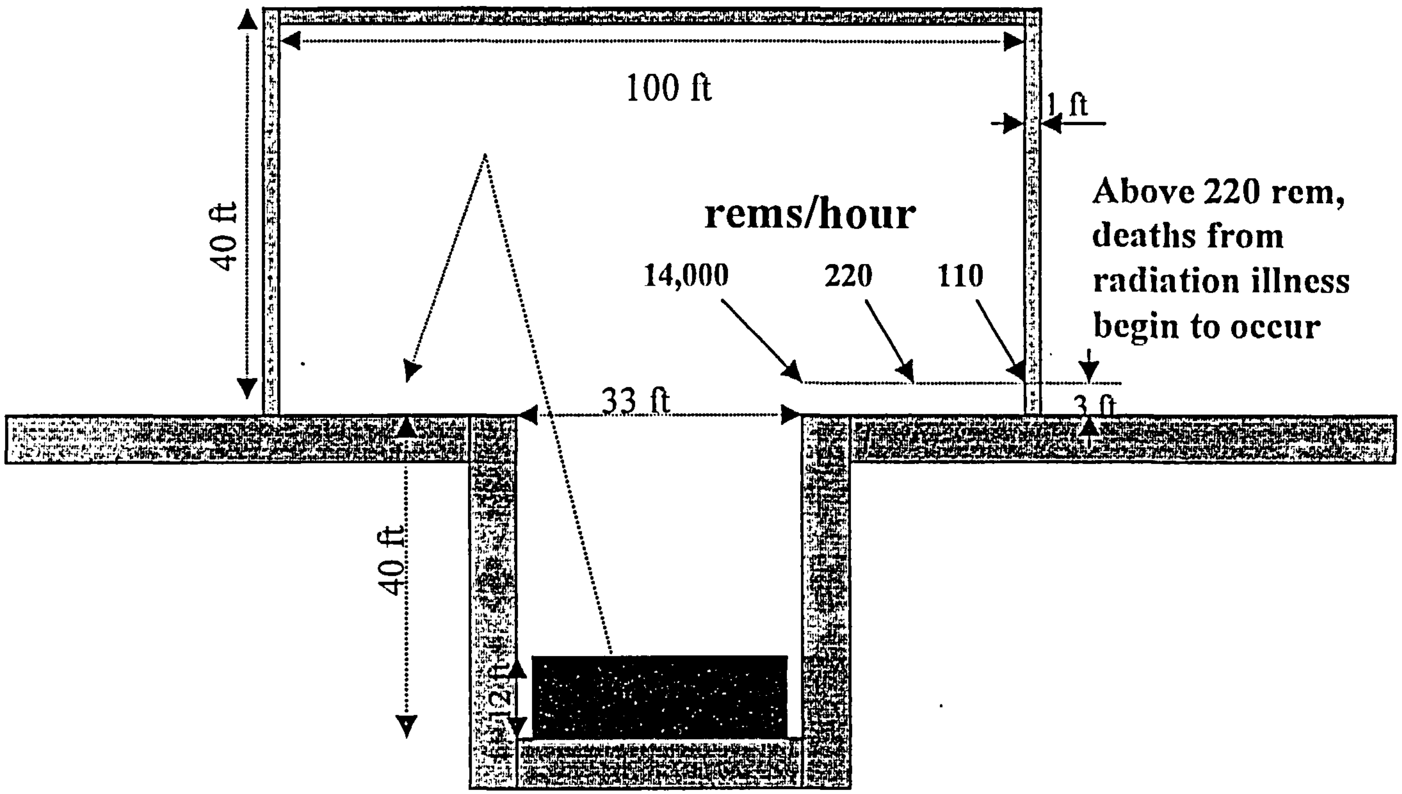
We think Congressional attention is required

e.g., to assign a probability to be used for planning purposes

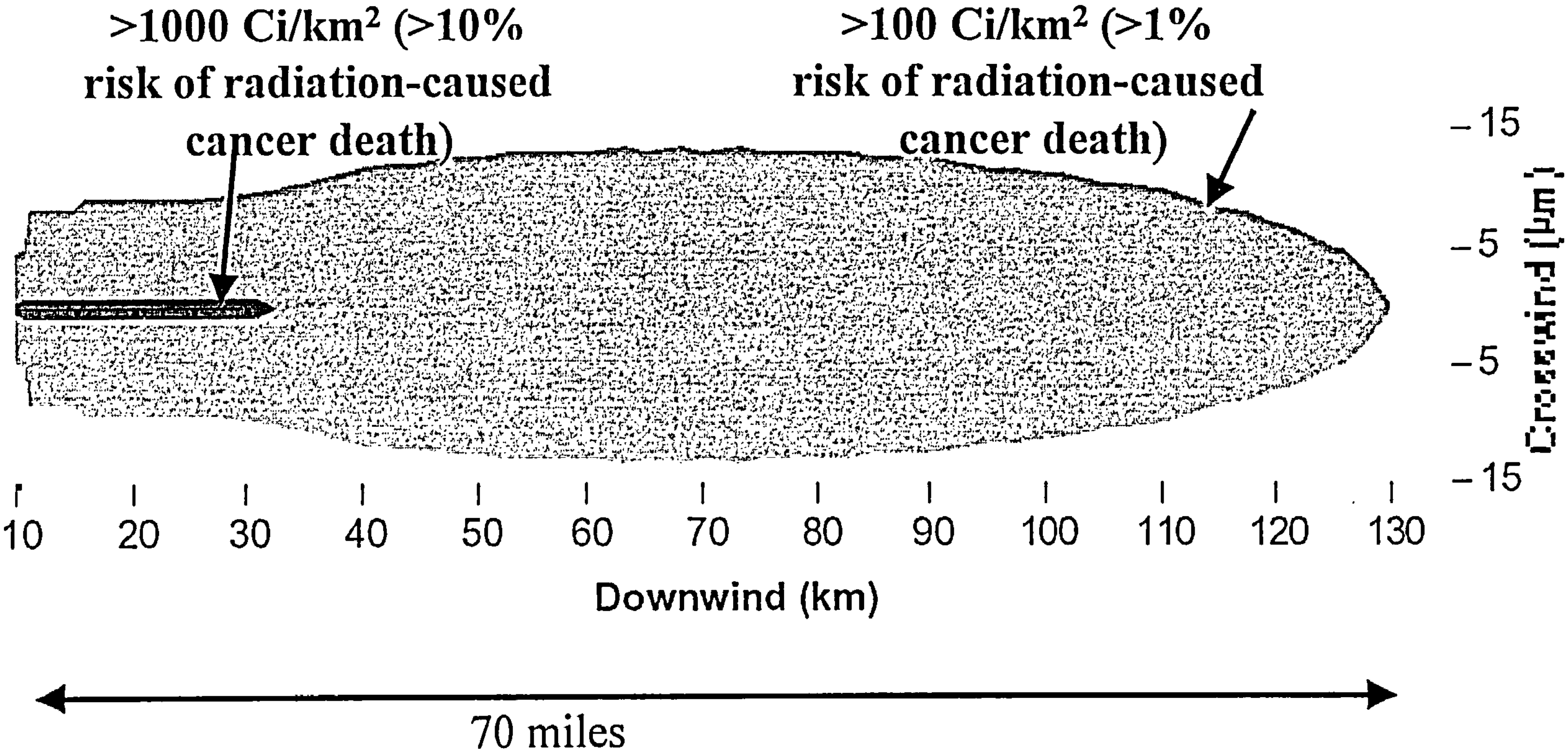
Our review of the technical issues

- Checked past calculations
- Focused on PWRs and only on scenarios already in the public record

Gamma radiation from dry spent-fuel pool: simplified circular pool layout, elevation view

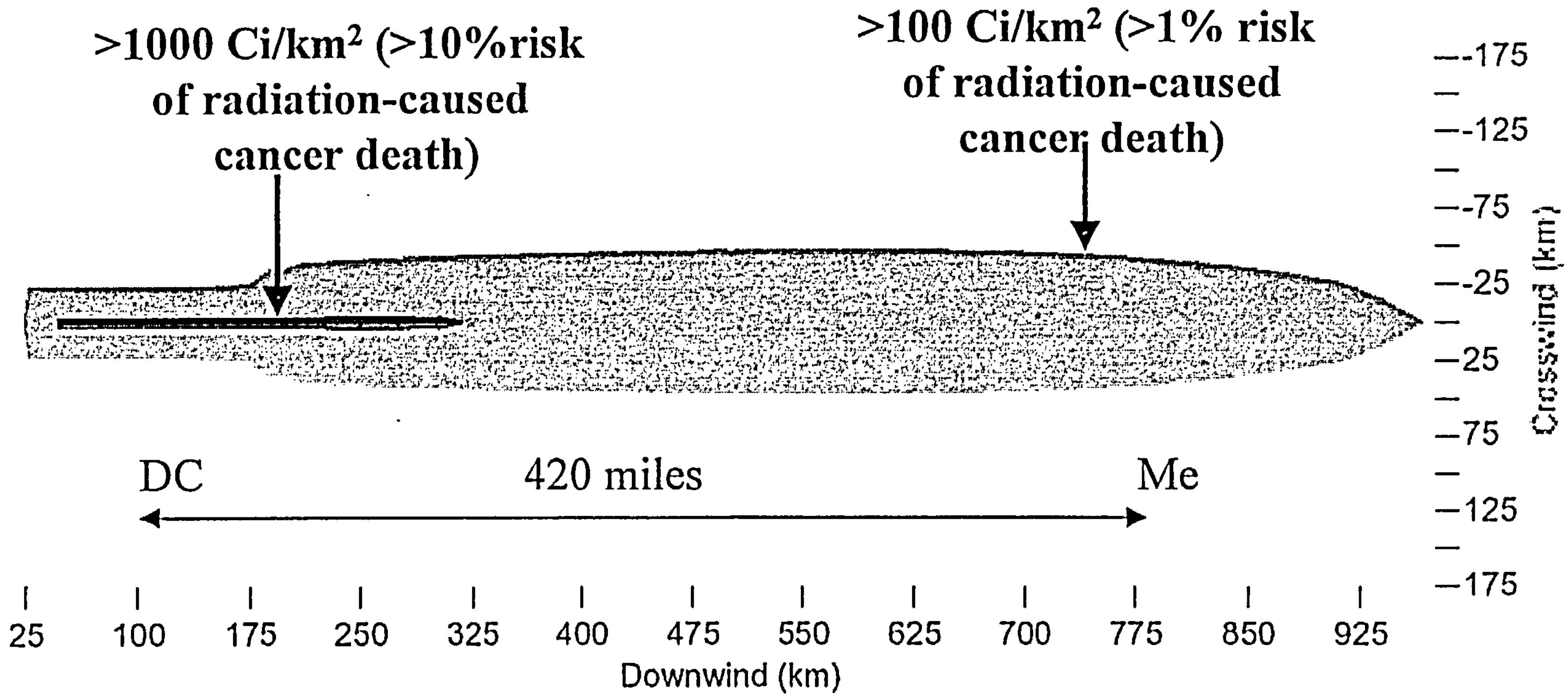


MACCS2 code prediction for smoldering pool fire that released 3.5 MCi of Cesium-137 into a 10 mph steady wind



Area about 1000 sq. miles (**Rhode Island**)

MACCS2 Code Prediction for hot pool fire that released 35 MCi of cesium-137 into a 10-mph steady wind



Area: 27,000 sq. miles (**Maryland + New Jersey + Massachusetts**)
Losses would be hundreds of billions of dollars.

Fuel rod

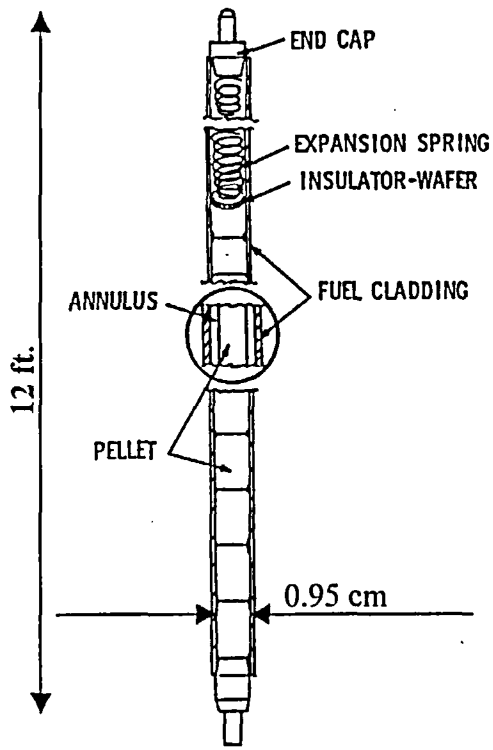


Figure 1-1.

CUTAWAY OF OXIDE FUEL FOR
COMMERCIAL LWR POWER PLANT

Fuel Assembly

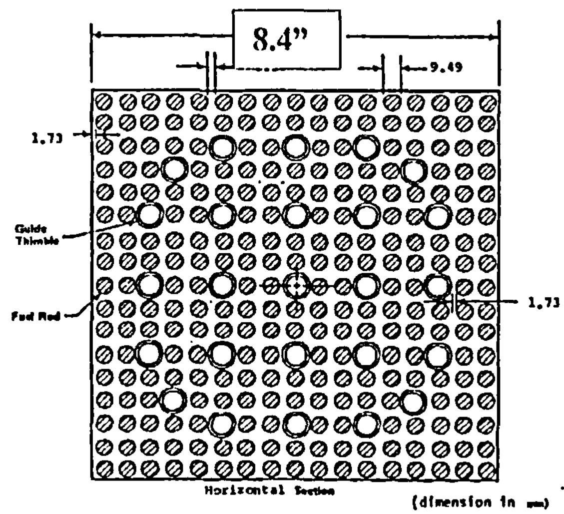


FIG. III.A.2. PWR 17×17 fuel bundle.

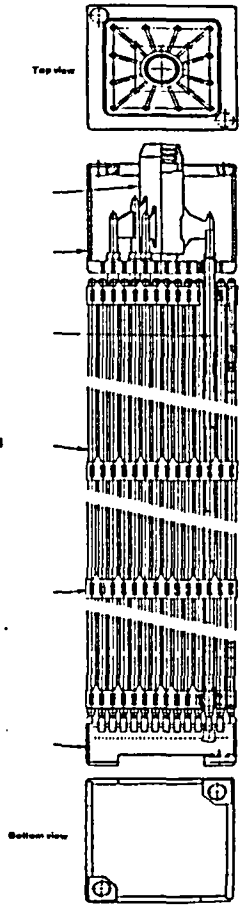
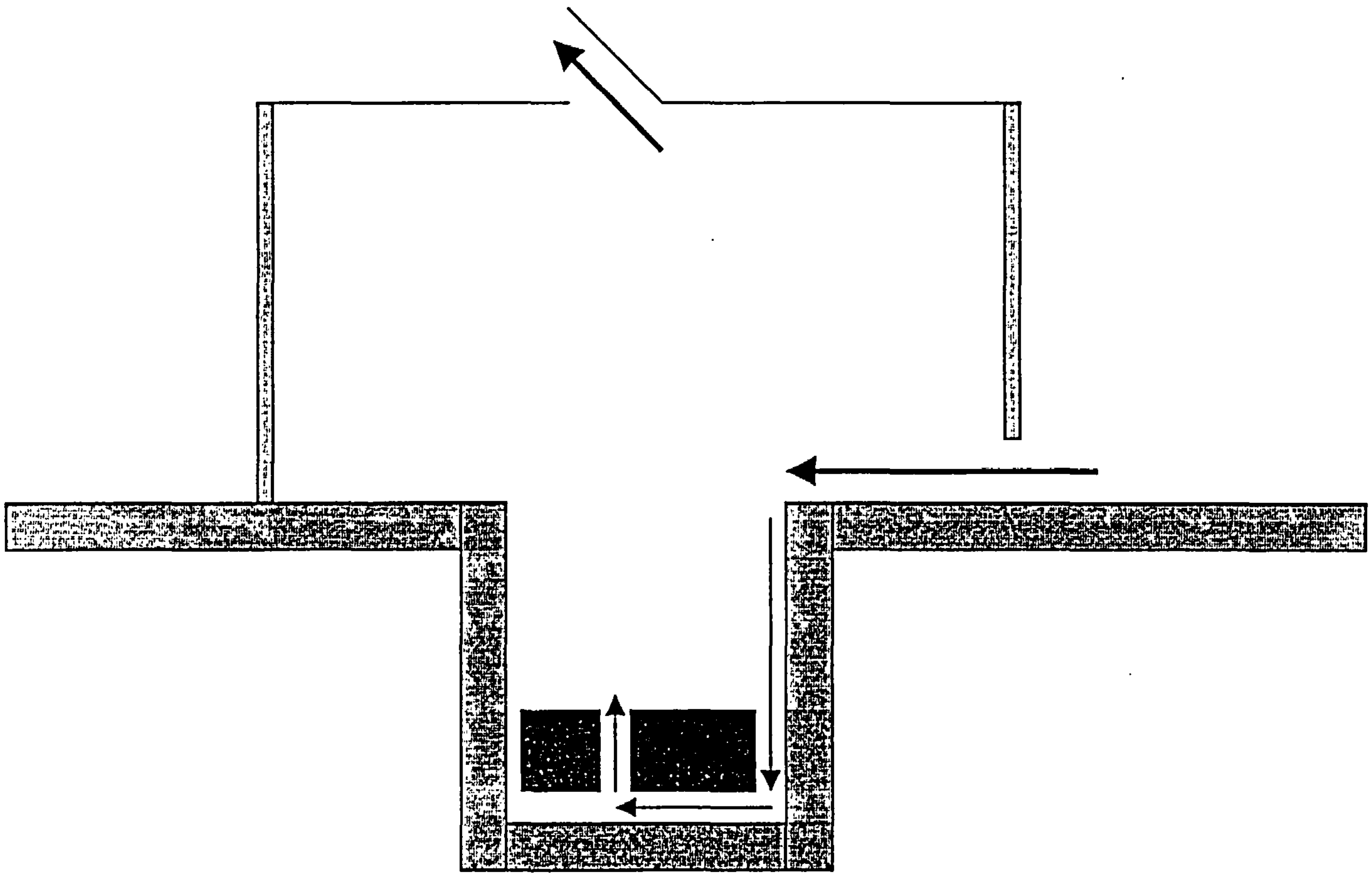


Figure 1-4

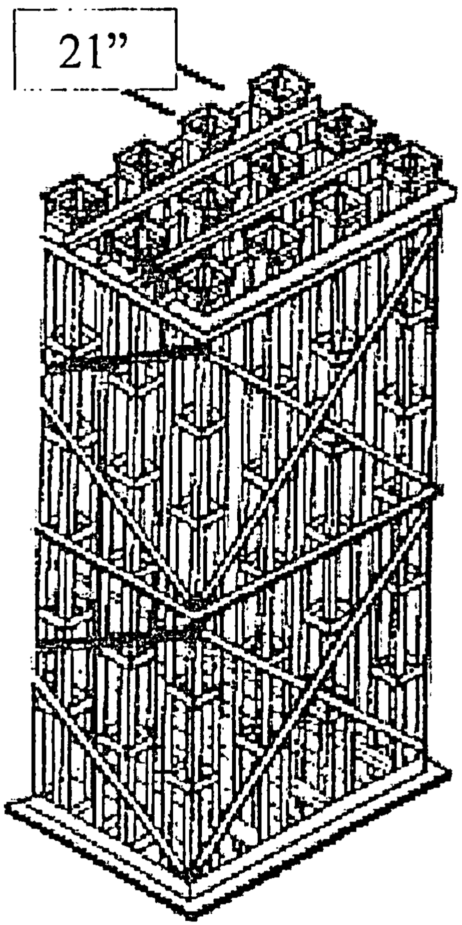
PWR Fuel Assembly

Convective air cooling



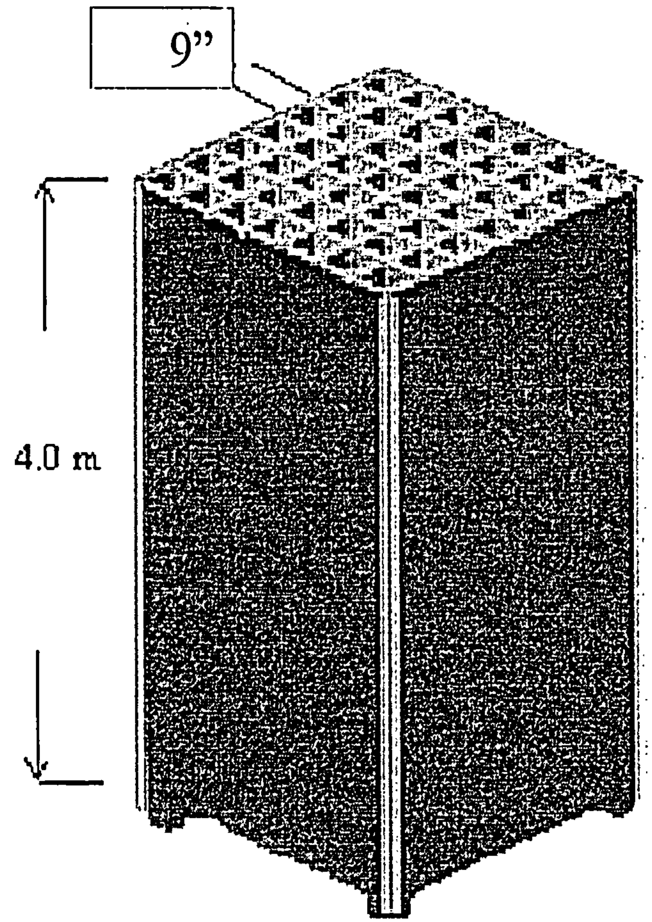
“Open Rack”

Natural convection air cooling possible 5 days after discharge



“Dense-pack”

Fuel less than a year old would heat up to ignition within a few hours.



Defense in Depth for Nuclear Power Plants and Spent Fuel

Line of Defense	Objective
1. Site safety and security	Safe operation and prevention of access by malicious parties
2. Facility robustness	Facilities to be capable of withstanding accident or attack
3. Accident management and damage control	Restore facilities to a safe state after accident or attack
4. Offsite emergency response	Reduce consequences of a radioactive release

The authors address aspects of 1, 2 and 3 for spent-fuel storage.

Operational options
(1st line of defense)

Minimize the movement of spent-fuel casks over spent-fuel pools.

Minimize occasions when the entire core is moved to the pool during refueling outages.

Transfer spent fuel to dry-cask storage 5 years after discharge from a power reactor.

Design options for facility robustness
(2nd line of defense)

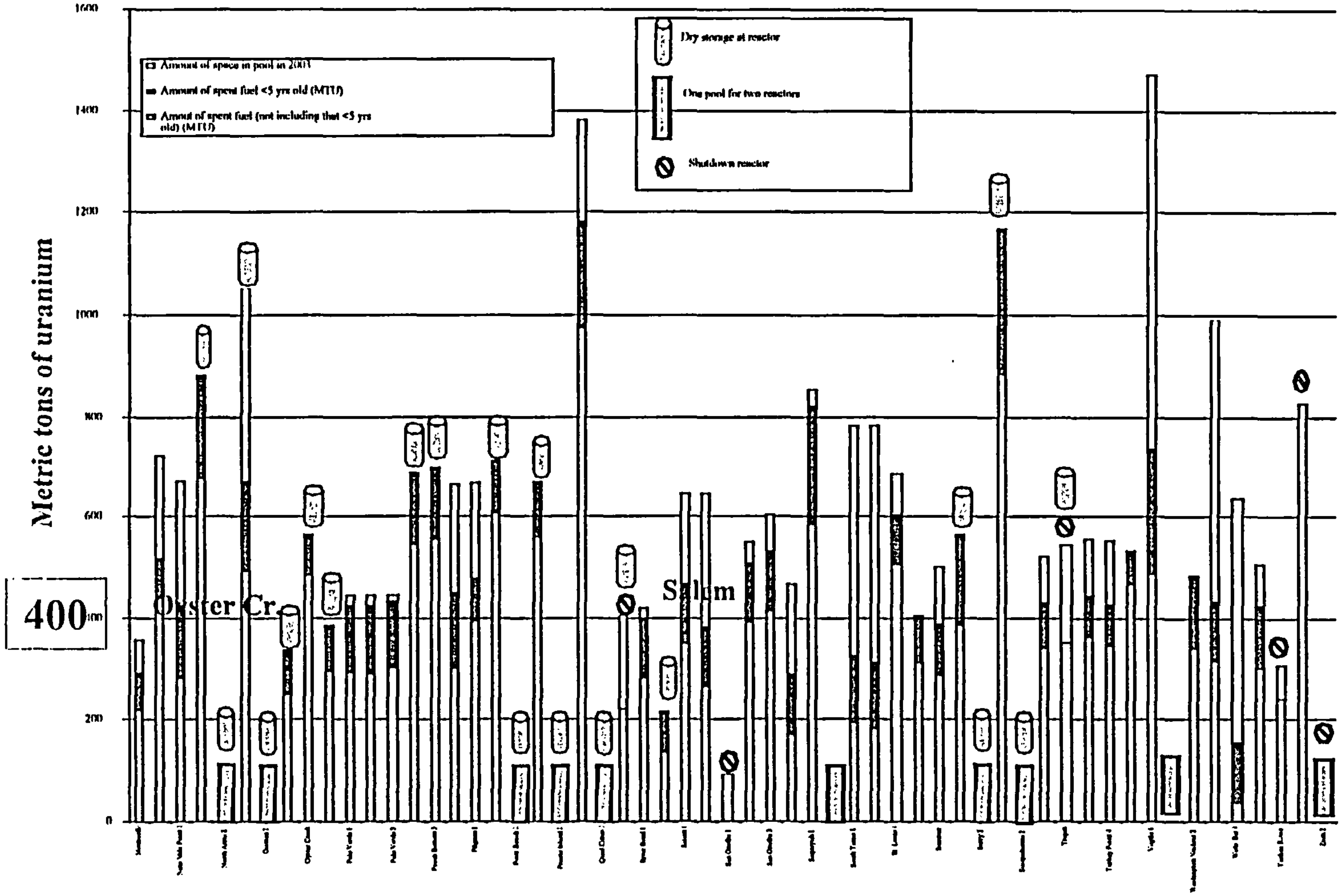
- **Return to open-frame storage -- perhaps with additional measures of criticality control.**
- Provide for emergency ventilation of spent-fuel buildings (Sandia)
- Install emergency water sprays (Sandia).
- Armor exposed outside walls and bottoms of pools against projectiles.

Damage-control options
(3rd line of defense)

Prepare to operate spent-fuel pools using normal equipment or emergency systems (e.g., ventilation, spays) **in conditions arising from accident or attack**

Make preparation for emergency repair of holes in pool walls and bottom

Inventory in some U.S. spent-fuel pools



400 tons of spent fuel contains ~ 35 MCi of cesium-137

Main Recommendations

Take spent fuel out of pools after five years

-- makes possible a return to open-rack storage

-- reduces inventory of fuel at risk of a pool fire

Transfer into hardened, dry storage

The Regulatory Challenge

Congress and NRC should judge the probability of a maliciously-caused spent-fuel-pool fire

--This could provide a basis for regulatory cost-benefit analysis.

NRC should require that nuclear-power-plant licensees have the capability to operate and repair spent-fuel pools after accident or attack.

Analysts (including us) and decision makers should be held accountable through open processes.

Dry storage exists or being installed in half of U.S. nuclear power plants

Used in U.S. since 1986

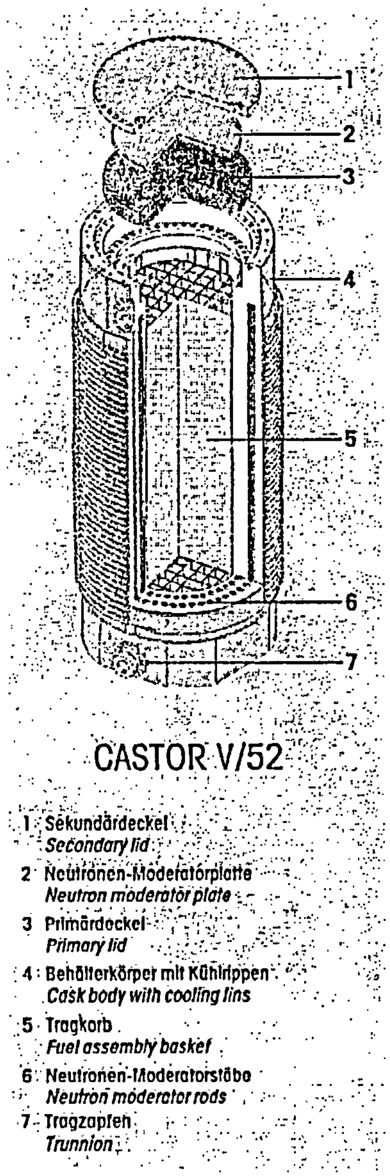
15 dry storage designs licensed by NRC

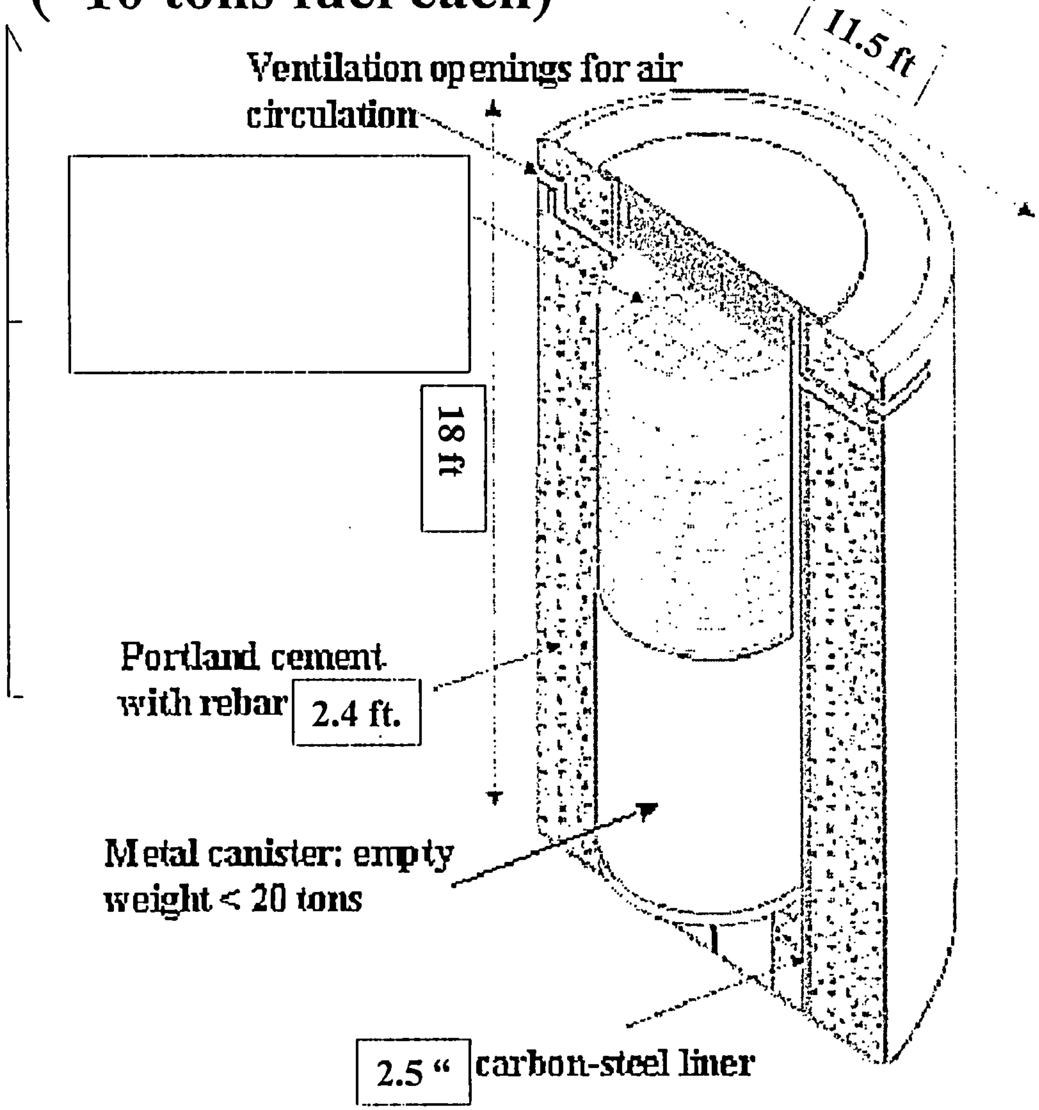
Currently at 33 nuclear reactors; 21 more in process

2,400 tons of spent fuel stored in 200 dry casks at U.S. reactors in 2000

Two types of dry storage casks

(~10 tons fuel each)





Magnitude of the task

45,000 tons of dense-packed fuel currently projected for 2010

35,000 tons with more than 5 years cooling could be stored in about 3500 casks

Process would take about 10 years

Cost of dry storage

$1-2 million per cask

$3.5-7 billion for 3500 casks

0.03-0.06 cents per kWh generated from the fuel (less than 1% of retail price of electricity in U.S.)

Most likely source of funding is the Nuclear Waste Fund (0.1 cent/kWh + interest)

THE END

BWR Spent-fuel pool

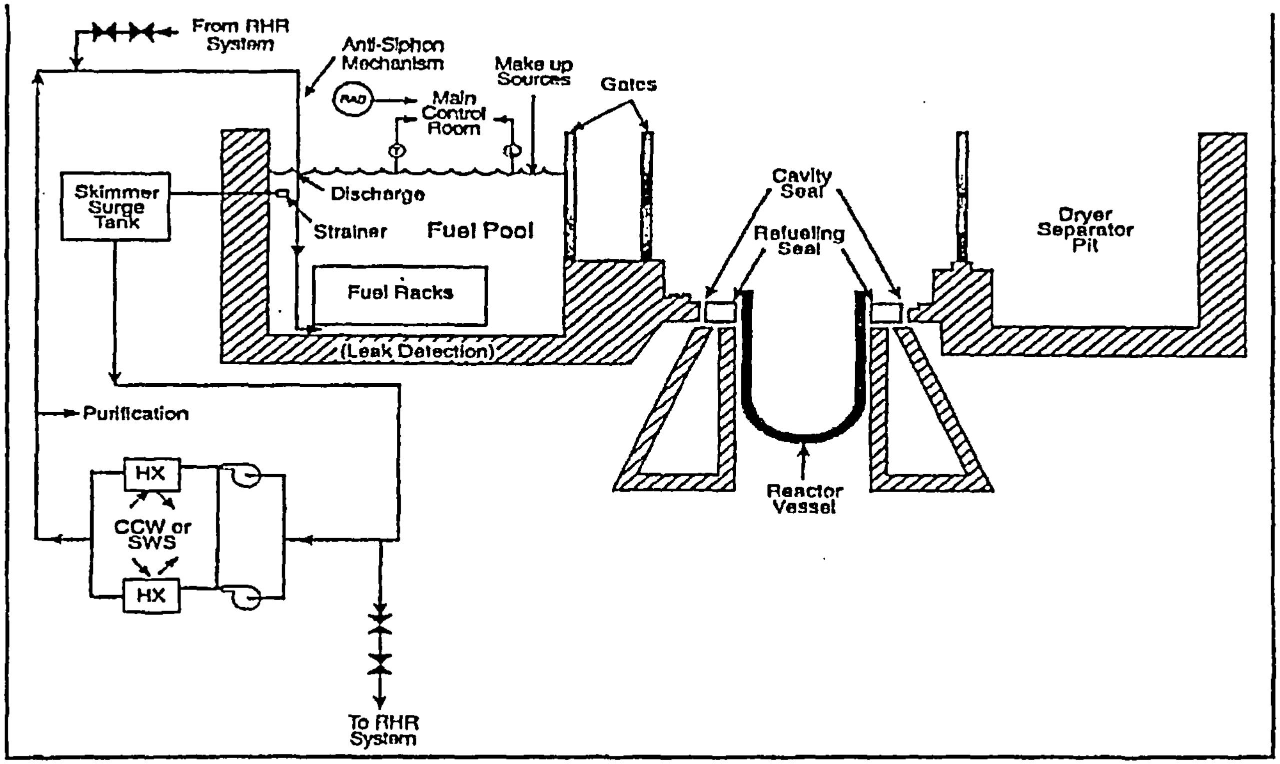


Figure 2.2 BWR Spent Fuel Cooling Systems

Numerical results (Sandia study)

One of two similar Figures proposed for removal from paper