Spent fuel Management
The case for Hardened On-Site Storage (HOSS)

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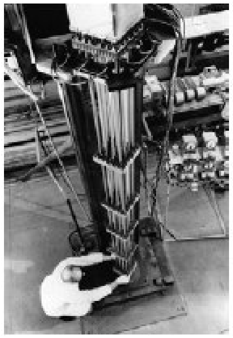
San Onofre – aerial view

Elements of fuel assemblies

Pre-irradiated Fuel Pellets.[4]

Pre-irradiated Fuel Pellets ready for assembly.

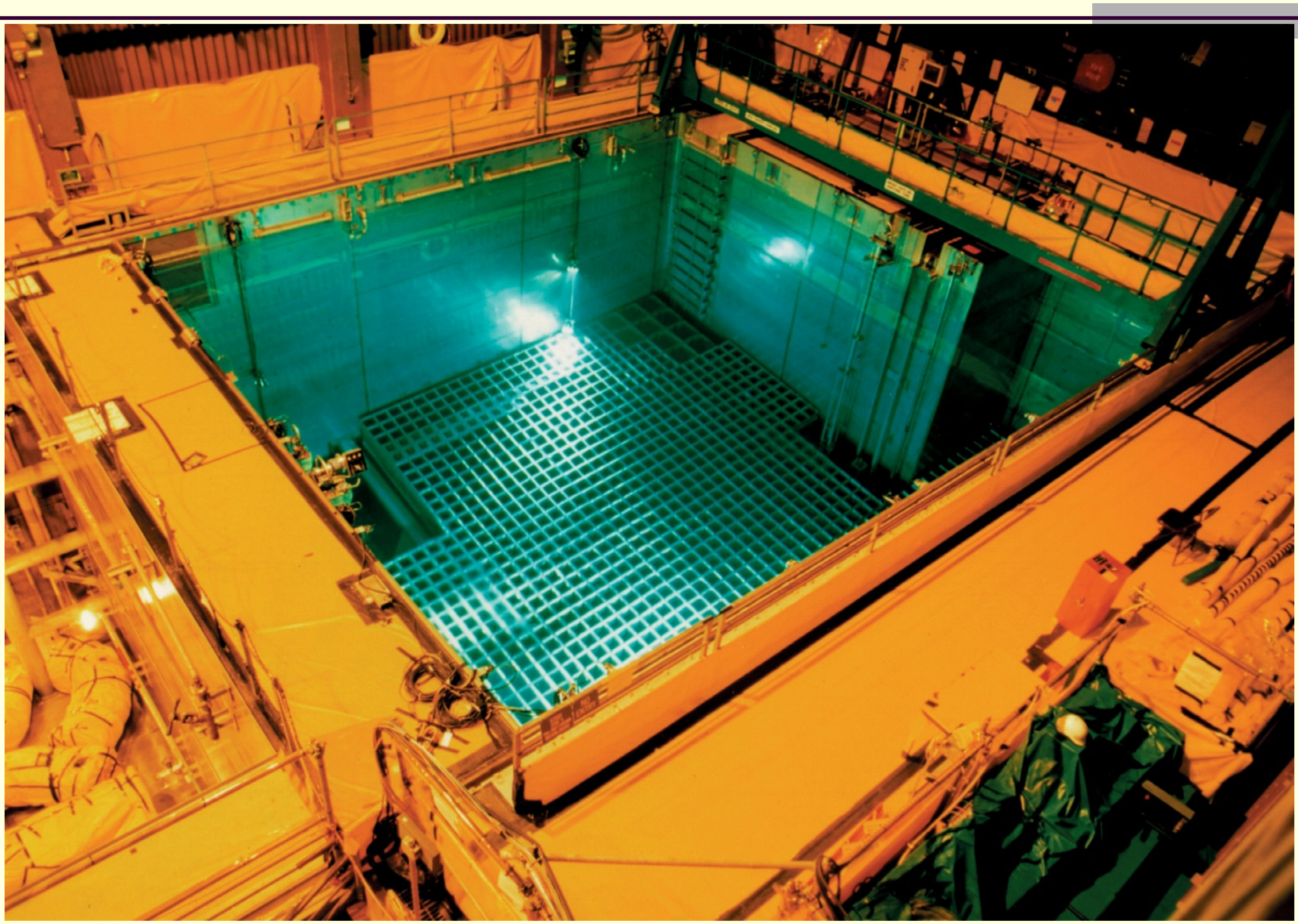
Zirconium Fuel Tubes.[5]



A Fuel Assembly.[5]

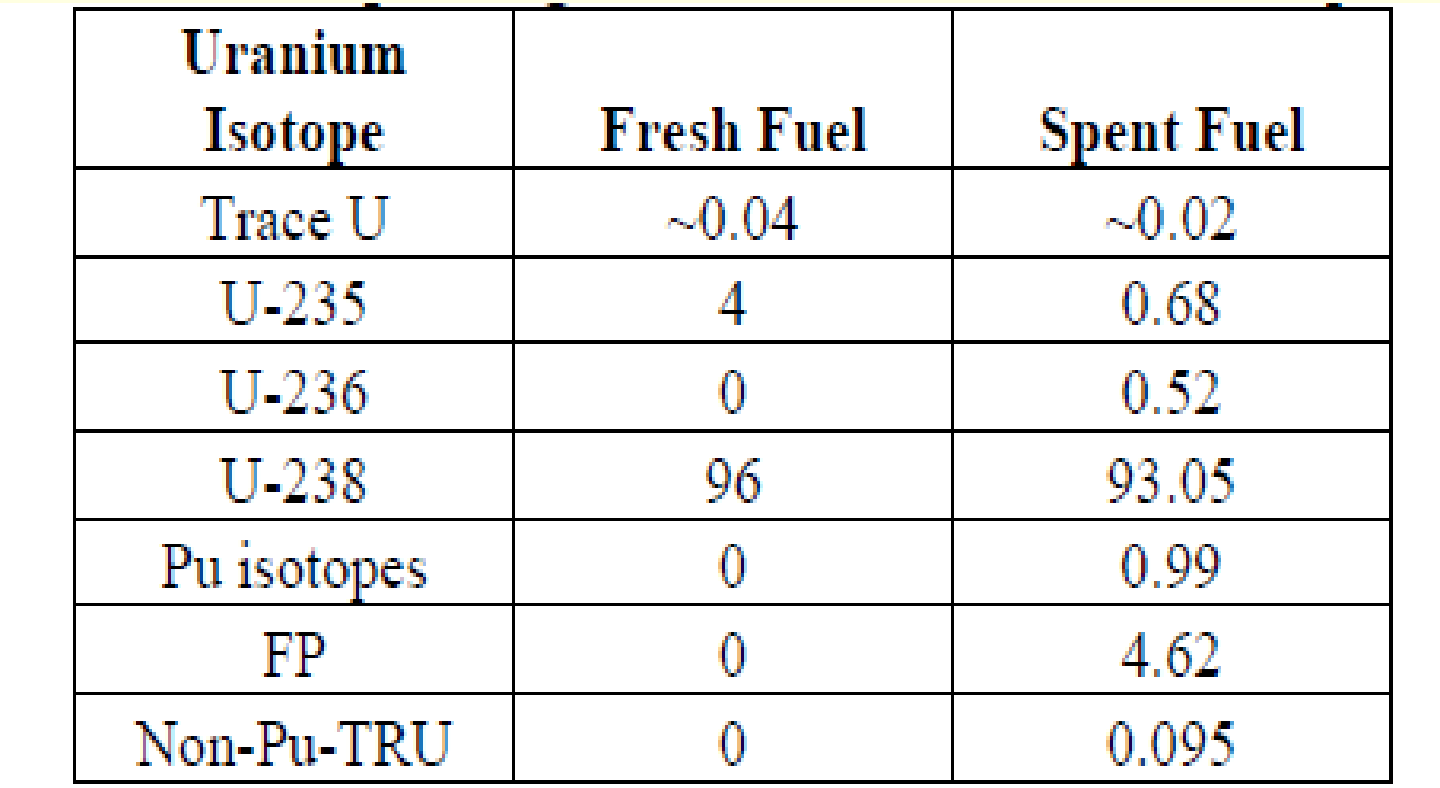
New (pre-irradiated) U.S. fuel being inspected.[4]

Spent fuel pool



NRC File Photo: number 20071115-009

Typical Fresh and Spent Fuel Composition -- PWR



Uranium Isotope	Fresh Fuel	Spent Fuel
Trace U	~0.04	~0.02
U-235	4	0.68
U-236	0	0.52
U-238	96	93.05
Pu isotopes	0	0.99
FP	0	4.62
Non-Pu-TRU	0	0.095

San Onofre spent fuel numbers

- Unit 1: about 400 assemblies in dry casks (SONGS number). Sandia March 2011 report: 665 assemblies, 245 MT.
- Units 2 and 3: SONGS estimate: 2,776 assemblies in pools. Sandia estimate for end of 2011 in March 2011 report: 1,581 for Unit 2 and 1,578 for Unit 3, total = 3,169 assemblies (666 + 664 MT = 1,330 MT) total assemblies. Number for pools may not be current. Alvarez compilation = 3406 assemblies.
- Total assemblies in casks as of 2011 = 1,091
- Burn up range Unit 2:: 11,053 to 67,525 MWdth/MTHM Average enrichment: = 4.08%).
- San Onofre-3: 14,290 to 67,676 MWdth/MTHM; average enrichment: 4.08%.
- Note: Upper limit of burnup needs to be verified. Maximum in NRC waste confidence GEIS is 62,500 MWdth/MT Q

San Onofre radioactivity:

- Cs- 137 source term at an average of 40,000 MWdth/MT for SONGS 2 and 3: ~120 million curies.
- Actual amount may be considerably higher since higher burnup fuel (>45,000 MWdth/MT) is less old than 15 years. Need burnup and discharge dates of assemblies over time to estimate the inventory.
- Strontium-90 inventory about the same as Cs-137 (U-235 fission yield: 5.75% compared to 6.09%).
- 63,000 MWdth/MT ~double the thermal load of 33,000 MWdth/MT at 10 years

Risks

- Main long-lived volatile radionuclide: cesium-137. Current inventory will also have cesium-134 (half-life 2.1 years) of the same order of magnitude as Cs-137 but this will decay to a few million curies in ten years while Cs-137 will still be a hundred million curies or more (both pools).
- A fire releasing 10 percent of the Cs-137 inventory in one pool to the atmosphere in the next year or two years could contaminate thousands of square kilometers of land at levels equal to or greater than the Chernobyl control zone (15 curies per square kilometer), assuming wind from the southwest. Highly weather dependent.
- Cigar shaped trace of >15 Ci/km2 (Chernobyl control limit) could be hundreds of miles long.
- Since San Onofre is on the Pacific Ocean, spent fuel severely damaged by fire could leave Sr-90 vulnerable to mobilization by rain and runoff, as is occurring at Fukushima, leaving the Pacific Ocean with a double-barrel East-West radioactive source term. Sr-90 bioaccumulates strongly.
- SCE plans to move the spent fuel to dry casks over 20 years.

Interim management policy

- Direct disposal of spent fuel decision should be maintained. Reprocessing existing spent fuel plus repository development would increase waste management costs and risks considerably.
- Low-density, open-frame, spent fuel pool storage
- Move as much spent fuel as possible to hardened dry storage.
- Store spent fuel on-site or as close to the site as possible (if safety considerations preclude on-site storage for extended periods)
- Moving spent fuel to centralized storage while reactors are operating needlessly increases risks.

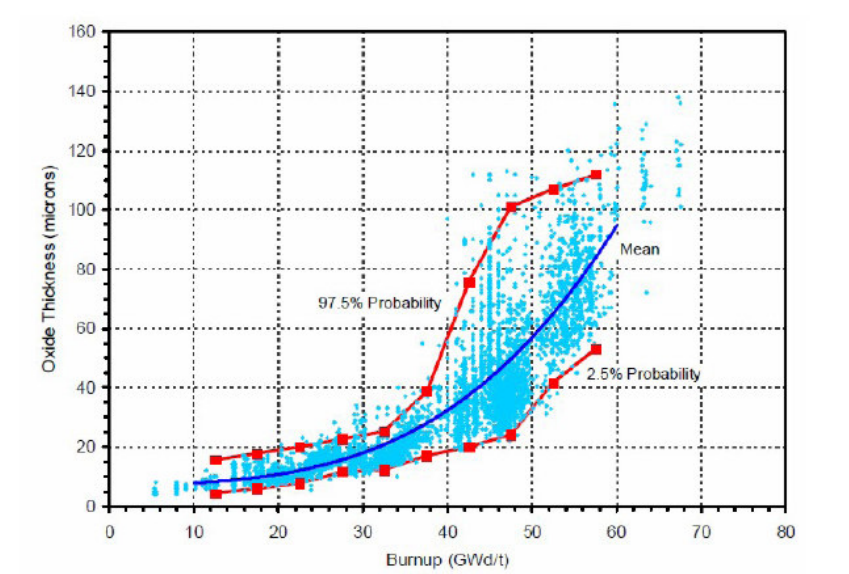
Dry vs. wet storage

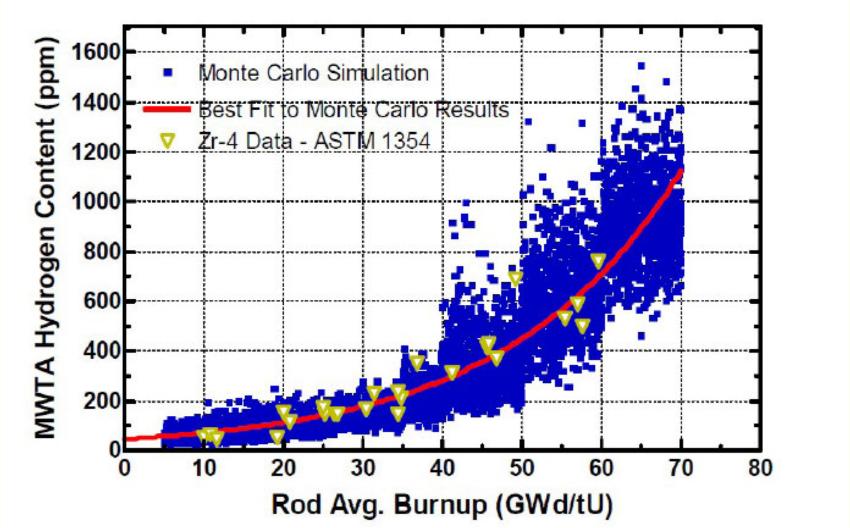
- Fire in a dense wet storage pool can cause vastly more damage and probability is higher that there will be a fire than in dry storage.
- Open rack, low density pool has a much lower risk of fire. Can be prevented with adequate air cooling.
- At ~10 metric tons per cask, 10% release fire in one cask would cause ~1.5% percent of damage of a 10% release from one pool.
- Risks can be lowered with Hardened On-Site Storage (HOSS).
- Unclear how the present track for dry storage can be made compatible with HOS criteria

High burn up oxide layer and hydrogen content data

Oxide layer thickness

Hydrogen content





High burnup fuel damage

- Data indicate higher probability of damage.
- Higher temperature leads to higher likelihood of damage.
- NRC admits it does not have the data.
- High burnup allowed without EIS.
- Waste confidence Draft GEIS assumes essential no damage for ever even if casks changed every 100 years.
- There are about 95 failed fuel assemblies at San Onofre loaded in dry casks. How many, if any, are high burnup?
- Not clear if long term storage of high burnup fuel is a good idea. There are no data.

Dry storage NUHOMS casks, San Onofre

Figure V.1-1: NUHOMS® horizontal dry storage systems at San Onofre.

Hardened On-Site Storage – elements

- Robust casks with leak detection, like German Castor V casks.
- Low Visual signature offsite
- Low infrared signature
- Difficult to target from offsite
- Protected from direct attack by berms or other robust structures
- And of course at San Onofre, conservative earthquake-resistant design.
- But how about high burnup spent fuel?

Big picture considerations

- Storage will be needed for decades.
- Onsite or offsite at an operating plant not in a high seismicity zone? Trade off between time needed for finding and prolonged pool storage.
- Possible middle road: Onsite in robust dual purpose storage/transportation casks like Castor V and secure offsite location.
- Worst-case outcome of a deep geologic repository is orders of magnitude lower than several possible severe surface storage outcomes (fires, terrorist attacks, eventual plutonium separation).
- Need to work for limiting spent fuel stream – i.e., phasing out nuclear power – HOSS, and a science-based, consent-based repository program.

Basic principles

- Repository program cannot be consent-based if it is not informed consent.
- Informed consent requires sound science to come first.
- Basis for a scientifically-based site selection does not exist now.

Yucca Mountain: a bad choice
Pomegranates: 20 miles away

Photo courtesy of the U.S. Department of Energy.
(http://ocrwm.doe.gov/info_library/newsroom/photos/images/ym_1883_72dpi.jpg)

Fir0002 (www.commons.wikimedia.org/wiki/Image:Pomegranate_fruit.jpg)

Basic geologic isolation system

Three elements of an isolation system:

- Spent fuel, containers, engineered barriers
- Repository backfill and sealing system (including shaft and drift sealing)
- Host rock and geologic setting

Each element must be evaluated. Natural analogs for materials have been studied and need more attention. All elements must work together for containment and to provide redundancy. For instance, metal containers in an oxidizing environment, as in Yucca Mountain, invite problems. Metal containers in a reducing environment, as in Sweden, provide a sounder approach.

Recommend: About ten years of research on various possible combinations of the three elements BEFORE the start of site selection.