



# **Dry cask storage issues**

## **Actions needed now**

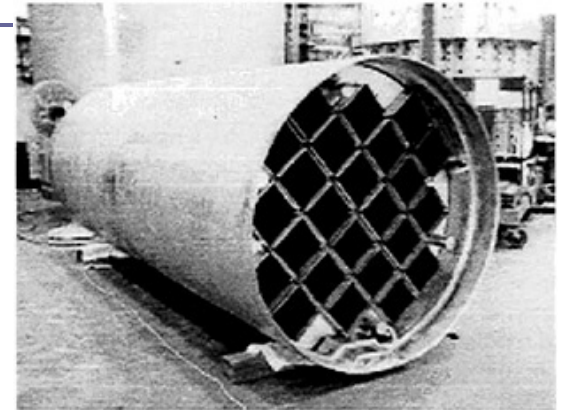
SOS

Donna Gilmore  
SanOnofreSafety.org  
November 2014

# Game changer

## Indefinite on-site storage

- August 26, 2014 NRC approved
  - 60 years (short term) on-site storage
  - 100 years (long term) on-site storage
  - Indefinite on-site storage
- No other storage sites on horizon
- Current U.S. thin steel canister designs inadequate
  - Cannot be inspected or repaired
  - May have stress corrosion cracks
  - No early warning monitoring
- Edison plans to spend \$400 million for a thin canister system (~100 canisters) for San Onofre spent fuel



# NRC proposed plan inadequate

---

- NRC revision to NUREG-1927 scheduled for 2015
- NRC plans to require first inspection after 25 years, allowing vendor 5 years to develop inspection technology
- Only requires inspection of one canister per plant
- That same canister to be inspected every 5 years
- NRC to allow up to 75% through-wall crack even though there is no seismic rating for cracked canisters

# Two-year old Diablo Canyon canister has conditions for cracking

- NRC assumed it would take over 30 years before temperatures low enough for cracks – proven wrong
- Canister inspected for temperature and salts; no technology exists to inspect for cracks or corrosion
  - Temperature low enough to initiate cracking in marine environment in only two years – under 85°C (185°F)
  - Salts found on canister can trigger corrosion and cracking



# Thin Canisters vs. Thick Casks

Safety Feature	Thin Canisters	Thick Casks
Thick walls	1/2" to 5/8"	Up to 20"
Won't crack		✓
Ability to repair		✓
Ability to inspect		✓
Early warning monitor		✓
ASME canister or cask certification		✓
Defense in depth		✓

# Thick casks designed for longer storage



CASTOR® - Type V19 cask

- Market leader internationally
- No stress corrosion cracking
- Can inspect casks
- Thick casks body -- forged steel or thicker ductile cast iron up to 20"
- Early warning before radiation leak (remote lid pressure monitoring)
- Double bolted thick steel lids allow reloading without damaging cask
- Cask protects from all radiation, unlike thin steel canisters. No concrete overpack required. Stored in concrete building for additional protection
- Both a storage and transport cask
- Parts (seals, lids) can be replaced, if needed
- ASME & international manufacturing cask certifications
- Defense in depth – damaged fuel sealed for radiation protection
- Not currently licensed in U.S. (18 to 30 month process)
- **Vendors won't request license unless they have customer**



# Sandia Labs: Ductile cast iron performs in an exemplary manner

- ...studies cited show DI [ductile iron] has sufficient fracture toughness to produce a containment boundary for radioactive material transport packagings that will be **safe from brittle fracture**.
- ...studies indicate that even with drop tests **exceeding the severity of those specified in 10 CFR 71** the DI packagings **perform in an exemplary manner**.
- Low temperature brittle fracture not an issue. The DCI casks were tested at **-29°C and -49°C exceeding NRC requirements**.
- Conclusions shared by **ASTM, ASME, and IAEA**.

*Fracture Mechanics Based Design for Radioactive Material Transport Packagings Historical Review*, Sandia Labs, SAND98-0764 UC-804, April 1998 <http://www.osti.gov/scitech/servlets/purl/654001>

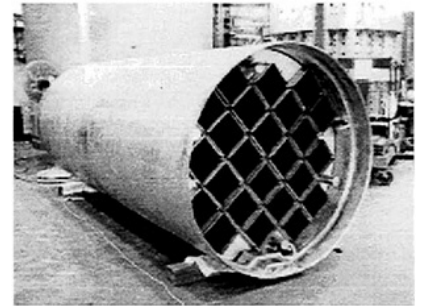
# Germany interim storage





# Problems with thin stainless steel canisters

- Cannot inspect exterior or interior for cracks
- Cannot repair cracks
- No warning BEFORE radiation leaks
- Canisters not ASME certified
- No defense in depth
- Unsealed damaged fuel cans
- Early stress corrosion cracking risk
- No adequate plan for failed canisters
- Inadequate aging management plan



# Thin canisters not what they're cracked up to be



- Condition of existing canisters unknown
  - No technology exists to inspect these canisters
  - Canisters in use less than 30 years (1986)
  - **Won't know until after leaks radiation**
- Other welded stainless steel items at nuclear plants failed in 11 to 33 years at ambient temperatures ~20°C (68°F)
- Crack initiation unpredictable
  - Cracks more likely to occur at higher end of temperature range up to 80°C (176°F) instead of ambient temperatures
  - Canister temperatures above 85°C will not crack from marine air – salts won't stay and dissolve on canister
- Crack growth about **four times faster** at 80°C (176°F) in “wicking” tests compared with 50°C (122°F)

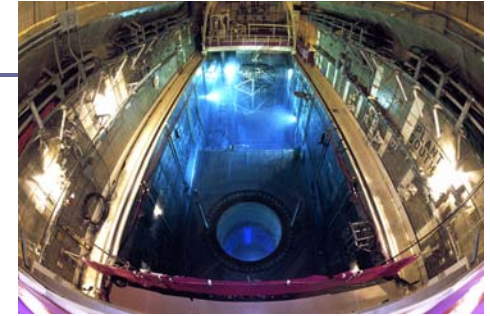
# Thin canisters cannot be inspected

- No technology to detect surface cracks, crevice and pitting corrosion in thin canisters filled with nuclear waste
  - Canister must stay inside concrete overpack/cask due to radiation risk, so future inspection technology may be limited
  - Thin canisters do not protect from gamma and neutrons
  - Microscopic crevices can result in cracks
- Thick casks can be inspected
  - Provide full radiation barrier without concrete
  - Surfaces can be inspected
  - Not subject to stress corrosion cracking



# Thin canisters not repairable

- No current technology to repair canisters filled with nuclear waste
  - Canisters must be repaired under water
  - Holtec Dr. Singh: should not attempt repair
    - Surface must be completely smooth to avoid imperfections that can initiate cracks
- **No seismic rating for a cracked canister**
- No plan for replacing canisters or casks
  - Funds not budgeted
  - NRC allows pools to be destroyed, removing only method for replacing canisters and casks
  - Vendor proposal to transport cracked canister in transport cask is unsafe and not NRC approved



# Thin canisters not designed to be replaced

---

- Welded lid not designed to be removed
- Lid must be unwelded under water
- Fuel transfer from damaged canister to new canister must be done under water
- No spent fuel has ever been reloaded into another thin canister
- Thick casks are designed to remove and reload fuel



# No warning before radiation leaks from thin canisters

---

- No pressure or helium monitoring
- Remote temperature monitoring not early warning
- No remote or continuous canister radiation monitoring
  - Workers “periodically” walk around canisters with portable radiation monitors
- Thick casks have continuous remote pressure monitoring – alerts to early helium leak
- Thick casks have continuous remote radiation monitoring

# Thin canisters not ASME certified

---

- Canisters do not have independent quality certification from American Society of Mechanical Engineers (ASME)
- NRC allows exemptions to some ASME standards
- No independent quality inspections
- ASME has not developed standards for spent fuel stainless steel canisters

# No defense in depth in thin canisters

- Thin stainless steel canisters do not protect from gamma or neutron radiation
  - Unsealed concrete overpacks/casks required for gamma and neutron protection
- Damaged fuel placed in vented cans provide no radiation protection
- High burnup fuel can damage protective Zirconium cladding in dry storage
- Technology to examine fuel assemblies for damage is limited
- We're only 1/2" to 5/8" away from a radiation disaster

# Recommendations

- NRC needs to act now
  - Freeze procurement of thin canisters
  - Set higher dry storage standards
  - Evaluate thick cask technology used internationally
    - Review Sandia Labs report to dispel myth of ductile cast iron embrittlement
  - Don't approve removal of empty pools until DOE takes waste
- Base standards on longer term storage needs
  - Not on limitations of thin canister technology
  - Not on vendor promises of future solutions
- Be proactive – take a leadership role
- Utilities need to evaluate thick cask technology



CASTOR® - Type V/19 cask

# References

---

- Diablo Canyon: conditions for stress corrosion cracking in two years, D. Gilmore, October 23, 2014  
<https://sanonofresafety.files.wordpress.com/2011/11/diablocanyonscc-2014-10-23.pdf>
- Top Ten Reasons to Buy Thick Casks, D. Gilmore, October 14, 2014  
<https://sanonofresafety.files.wordpress.com/2014/10/thincanistersvsthickcasks2014-10-14.pdf>
- Dry Cask Storage Issues, D. Gilmore, September 23, 2014  
<https://sanonofresafety.files.wordpress.com/2011/11/drycaskstorageissues2014-09-23.pdf>
- Additional references: [SanOnofreSafety.org](http://SanOnofreSafety.org)



The background of the slide is a photograph of a beach. In the upper portion, blue waves with white foam are breaking onto a sandy shore. The lower portion of the image shows the sand, where the letters 'SOS' are written in a large, dark, hand-drawn font. The text is centered horizontally and positioned between the waves and the 'SOS' in the sand.

**Donna Gilmore**  
**SanOnofreSafety.org**  
**dgilmore@cox.net**

**SOS**

# Additional Slides

---

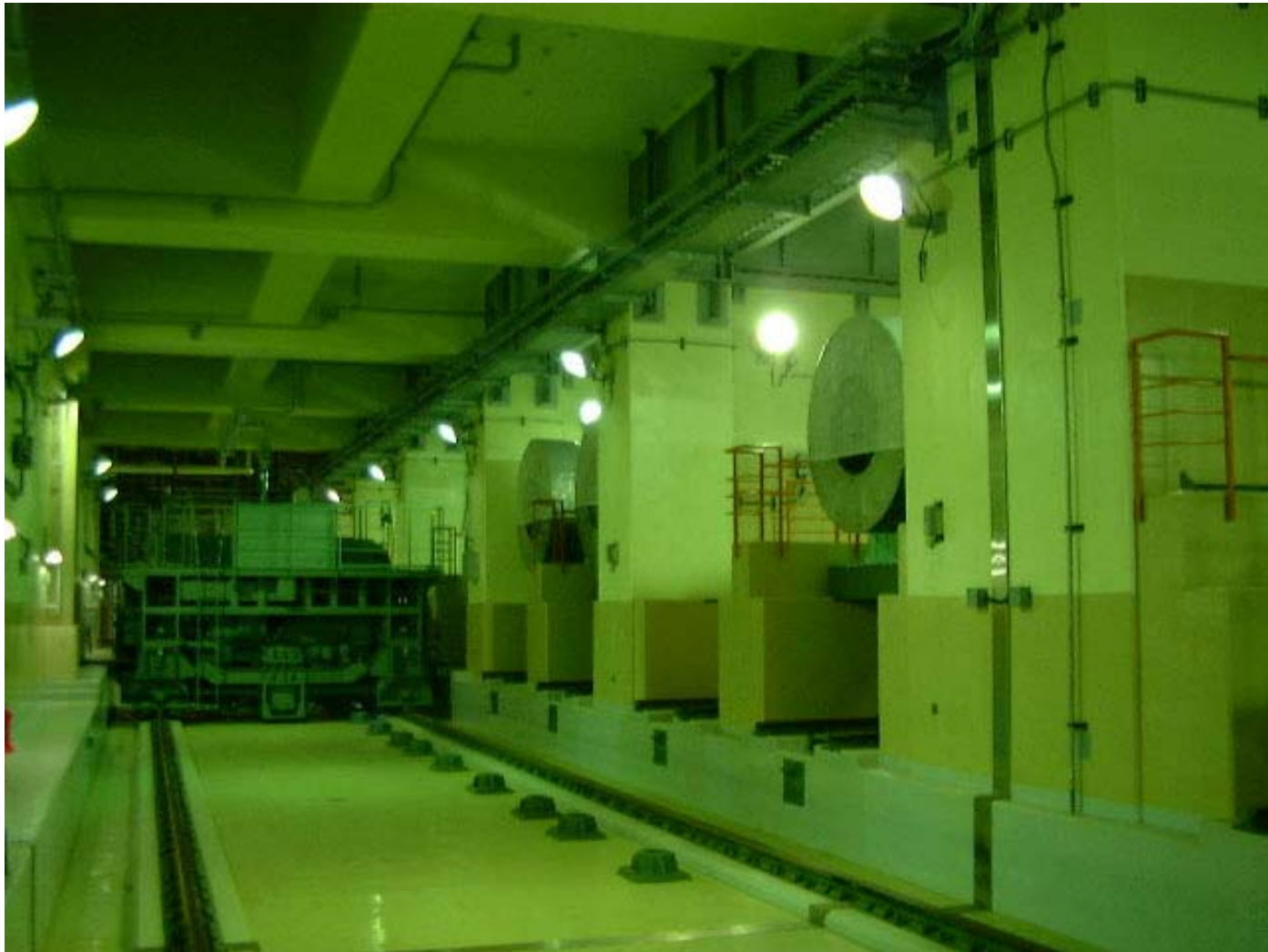
# Fukushima thick casks

## Specification of Dry Casks

	Large type	Medium type	
Weight (t)	115	96	
Length (m)	5.6	5.6	
Diameter (m)	2.4	2.2	
Assemblies in a cask	52	37	
Number of casks	5	2	2
Fuel type	8 x 8	8 x 8	New 8 x 8
Cooling-off period (years)	> 7	> 7	> 5
Average burn-up (MWD/T)	<24,000	<24,000	<29,000

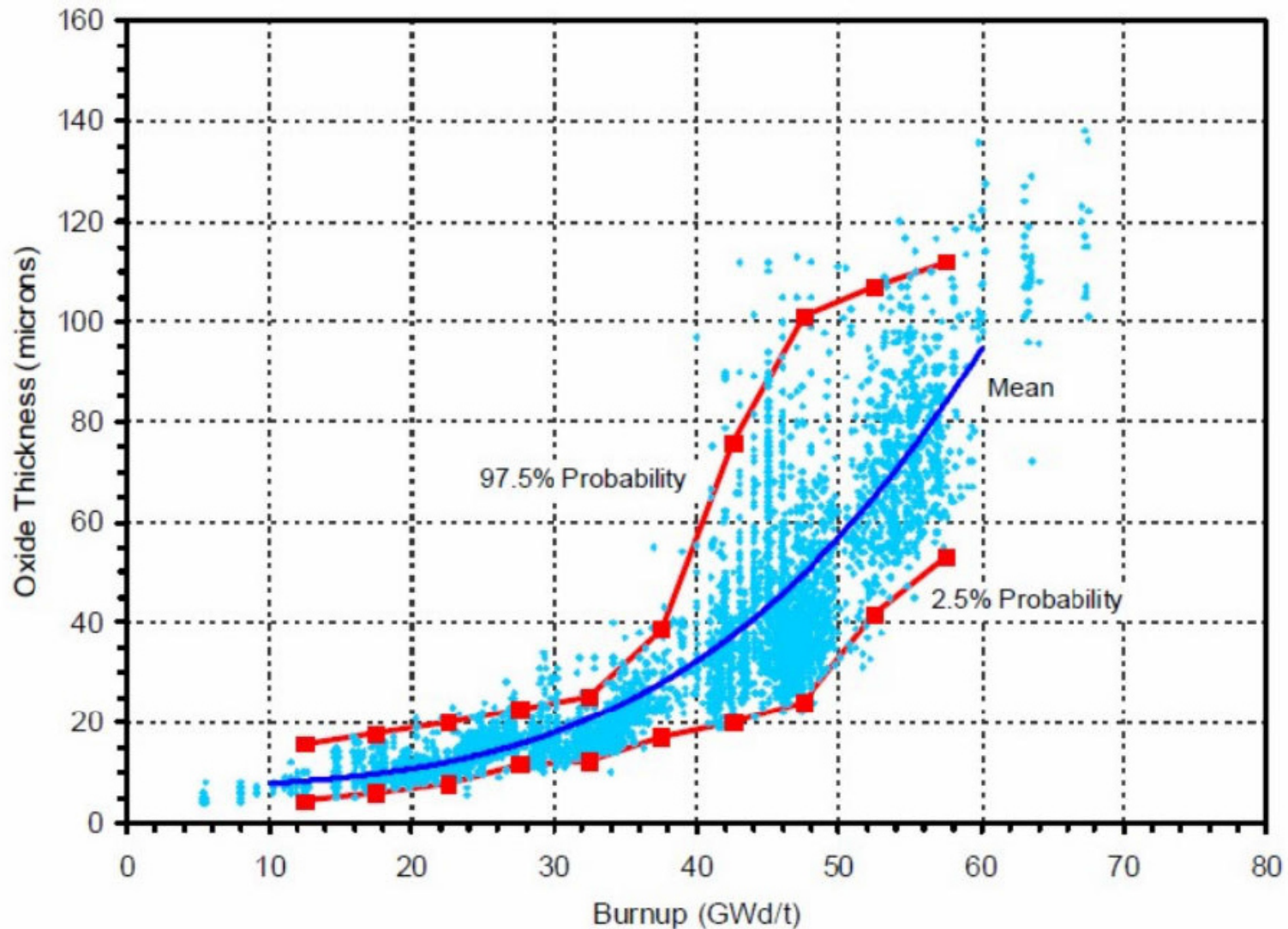
**Additional 11casks are being prepared for installation.**

# Fukushima cask building





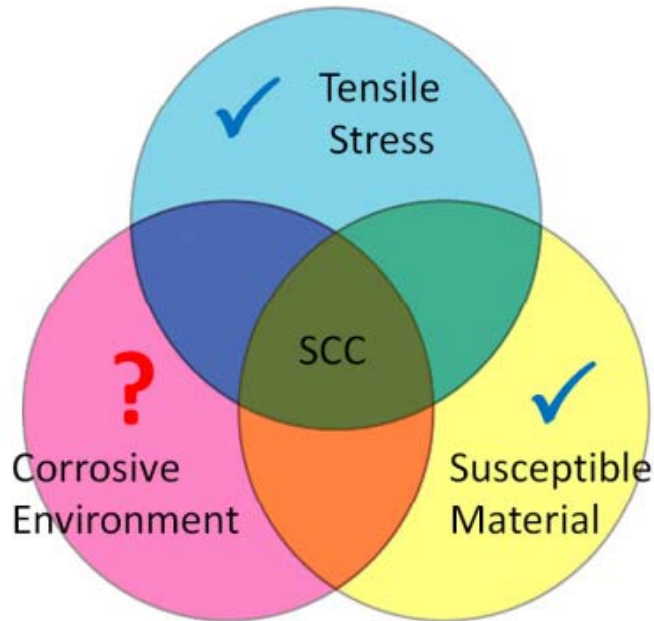
# Higher Burnup = Higher Cladding Failure



Higher oxide thickness results in higher cladding failure. Argonne scientists reported high burn-up fuels may result in fuel rods becoming more brittle over time. "... insufficient information is available on high burnup fuels to allow reliable predictions of degradation processes during extended dry storage." U.S. Nuclear Waste Technical Review Board *Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel*, December 2010, Burnup Chart Page 56



# Stress Corrosion Cracking Background Information



**2/3 of the requirements  
for SCC are present in  
welded stainless steel  
canisters**

- 304 and 316 Stainless steels are susceptible to chloride stress corrosion cracking (SCC)
  - Sensitization from welding increases susceptibility
  - Crevice and pitting corrosion can be precursors to SCC
  - SCC possible with low surface chloride concentrations
- Welded stainless steel canisters have sufficient through wall tensile residual stresses for SCC
- Atmospheric SCC of welded stainless steels has been observed
  - Component failures in 11-33 years
  - Estimated crack growth rates of 0.11 to 0.91 mm/yr

# Power Plant Operating Experience with SCC of Stainless Steels

Plant	Distance to water, m	Body of water	Material/ Component	Thickness, or crack depth, mm	Time in Service, years	Est. Crack growth rate, m/s	Est. Crack growth rate, mm/yr
Koeberg	100	South Atlantic	304L/RWST	5.0 to 15.5	17	$9.3 \times 10^{-12}$ to $2.9 \times 10^{-11}$	0.29 to 0.91
Ohi	200	Wakasa Bay, Sea of Japan	304L/RWST	1.5 to 7.5	30	$5.5 \times 10^{-12}$ to $7.9 \times 10^{-12}$	0.17 to 0.25
St Lucie	800	Atlantic	304/RWST pipe	6.2	16	$1.2 \times 10^{-11}$	0.39
Turkey Point	400	Biscayne Bay, Atlantic	304/pipe	3.7	33	$3.6 \times 10^{-12}$	0.11
San Onofre	150	Pacific Ocean	304/pipe	3.4 to 6.2	25	$4.3 \times 10^{-12}$ to $7.8 \times 10^{-12}$	0.14 to 0.25

- CISC growth rates of 0.11 to 0.91 mm/yr for components in service
  - Median rate of  $9.6 \times 10^{-12}$  m/s (0.30 mm/yr) reported by Kosaki (2008)
- Activation energy for CISC propagation needs to be considered
  - 5.6 to 9.4 kcal/mol (23 to 39 kJ/mol) reported by Hayashibara et al. (2008)



## Data Gap Summarization

Gap	Priority	Gap	Priority
Thermal Profiles	1	Neutron poisons – Thermal aging	7
Stress Profiles	1	Moderator Exclusion	8
Monitoring – External	2	Cladding – Delayed Hydride Cracking	9
Welded canister – Atmospheric corrosion	2	Examination of the fuel at the INL	10
Fuel Transfer Options	3	Cladding – Creep	11
Monitoring – Internal	4	Fuel Assembly Hardware – SCC	11
Welded canister – Aqueous corrosion	5	Neutron poisons – Embrittlement	11
Bolted casks – Fatigue of seals & bolts	5	Cladding – Annealing of radiation damage	12
Bolted casks – Atmospheric corrosion	5	Cladding – Oxidation	13
Bolted casks – Aqueous corrosion	5	Neutron poisons – Creep	13
Drying Issues	6	Neutron poisons – Corrosion	13
Burnup Credit	7	Overpack – Freeze-thaw	14
Cladding – Hydride reorientation	7	Overpack – Corrosion of embedded steel	14

*Imminent need*

*Immediate to facilitate demonstration early start*

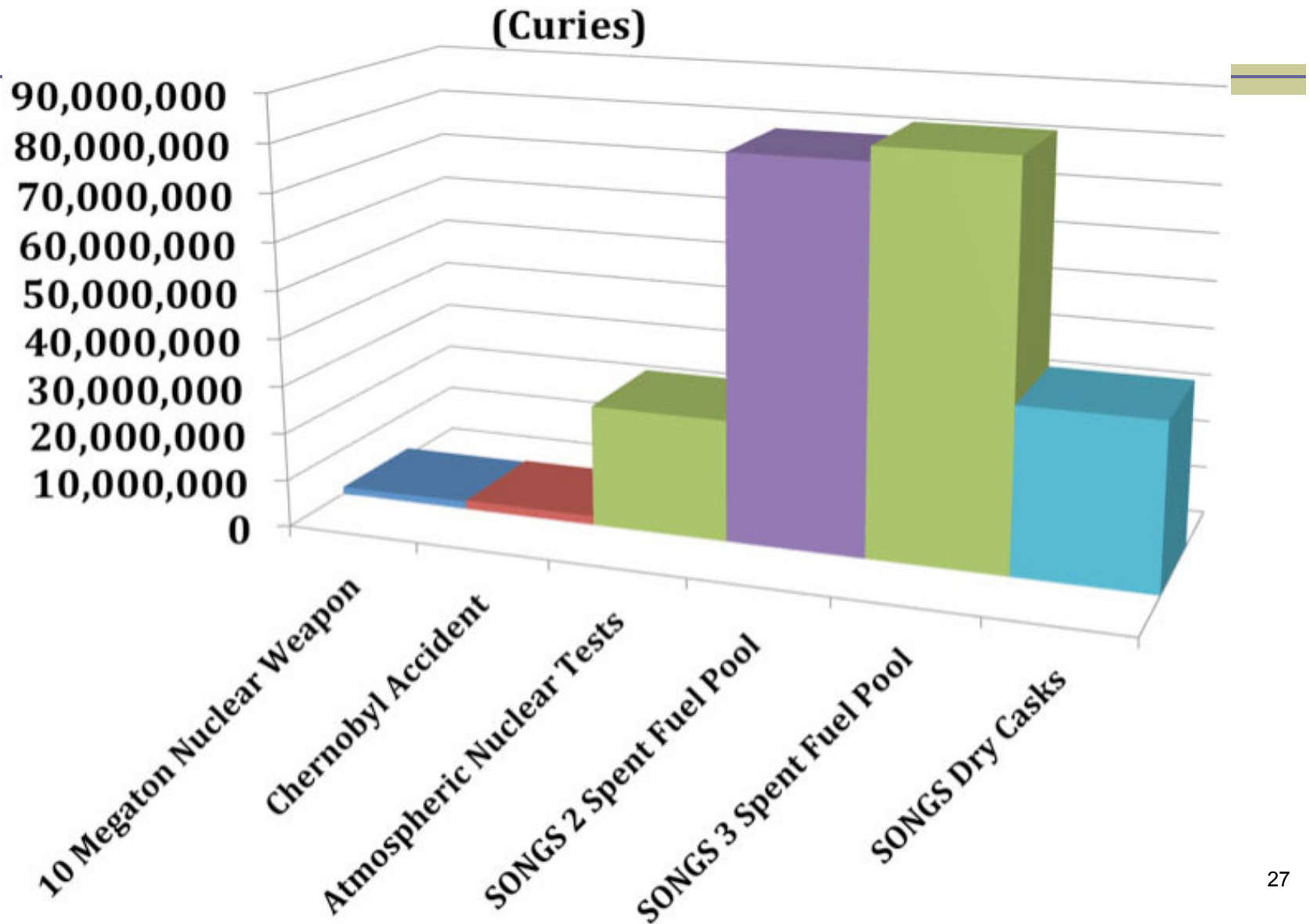
*Near-term High or Very High*

*Long-term High*

*Near-term Medium or Medium High*

*Long-term Medium*

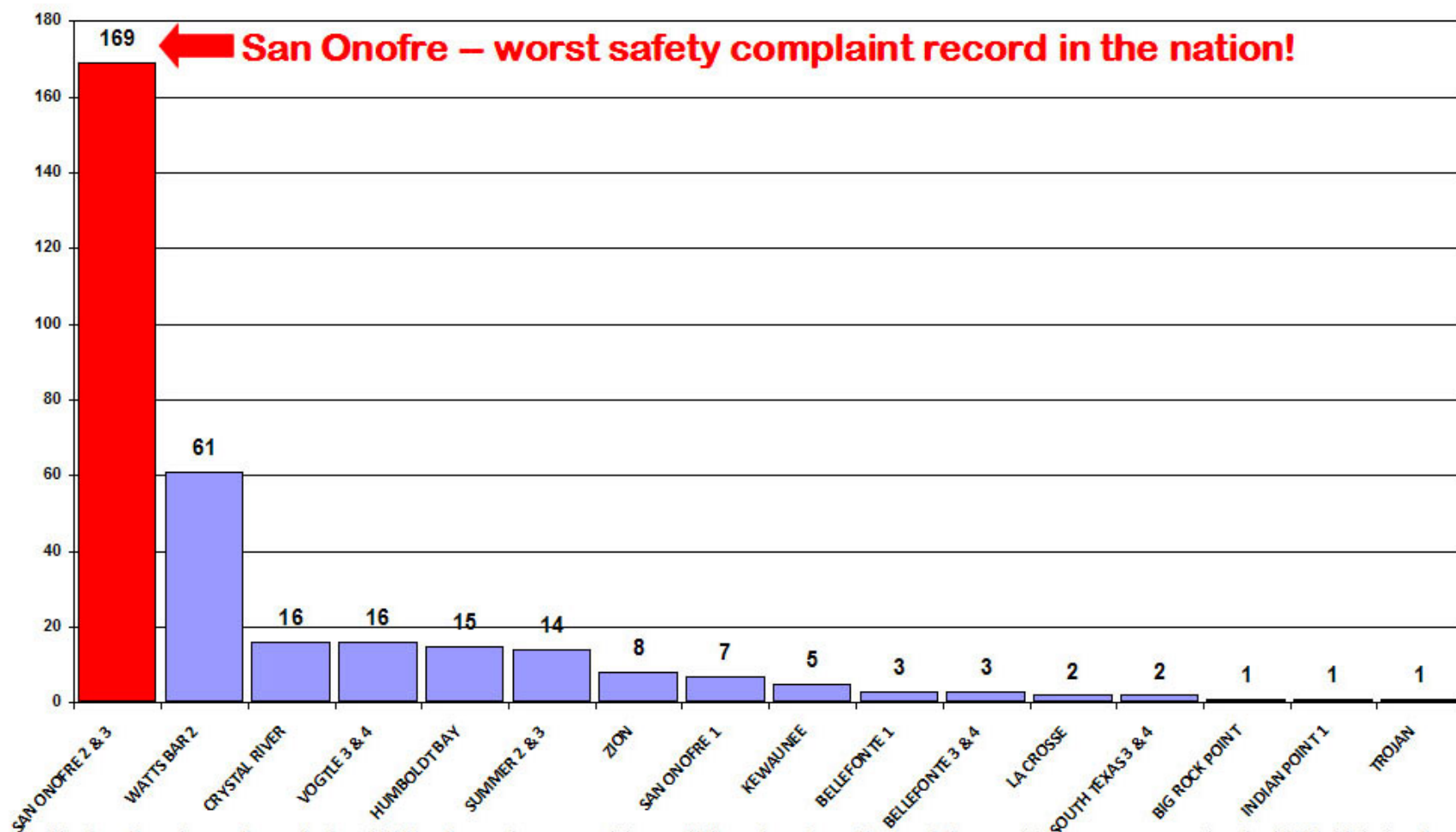
# San Onofre Cesium-137



# Safety Complaints to NRC from all External Sources\*

## Non-Operating U.S. Nuclear Power Reactors

### January 2009 to August 2013



\*Nuclear Regulatory Commission (NRC) refers to these complaints as "Allegations from External Sources" (all sources external to the NRC). Majority of complaints are from employees & other on-site sources. These are reports of impropriety or inadequacy of NRC-related safety or regulatory concerns. Includes all non-operating U.S. operating nuclear power plants & reactors. One allegation report may contain multiple allegations. However, the NRC counts it as one allegation in these statistics. A complaint about a safety-conscious work environment (SCWE) problem is important. However, a Notice of Violation cannot be issued, because there is no applicable NRC regulation. Source: [www.nrc.gov/about-nrc/regulatory/allegations/statistics.html](http://www.nrc.gov/about-nrc/regulatory/allegations/statistics.html)

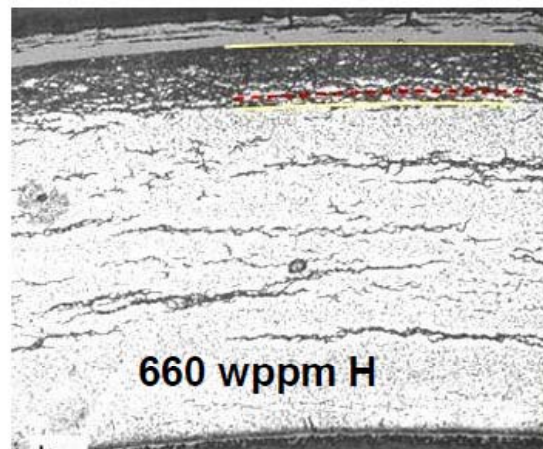


# Waste is not going anywhere

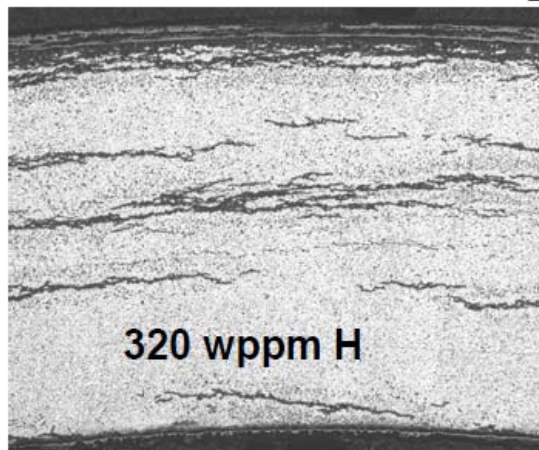
- **Yucca Mountain geological repository issues unresolved**
  - DOE plan: Solve water intrusion issue 100 years AFTER loading nuclear waste
  - Inadequate capacity for all waste
  - Not designed for high burnup fuel
- **Congress limited DOE to consider only Yucca Mountain**
  - Funding of storage sites unresolved
  - Communities do not want the waste
- **Poor track record for finding safe waste solutions**
  - New Mexico WIPP repository leaked within 15 years
  - Washington Hanford repository leaking containers
  - Other storage sites leaked
- **Inadequate transport infrastructure & potential for accidents**
- **High burnup fuel over twice as radioactive, hotter, and unstable**
  - Zirconium cladding more likely to become brittle and crack -- eliminates key defense in depth. Radiation protection limited to the thin stainless steel canister. Concrete overpack/cask only protects from gamma and neutrons.
- **Fuel assemblies damaged after storage may not be retrievable**
- **Inspection of damaged fuel assemblies is imperfect**



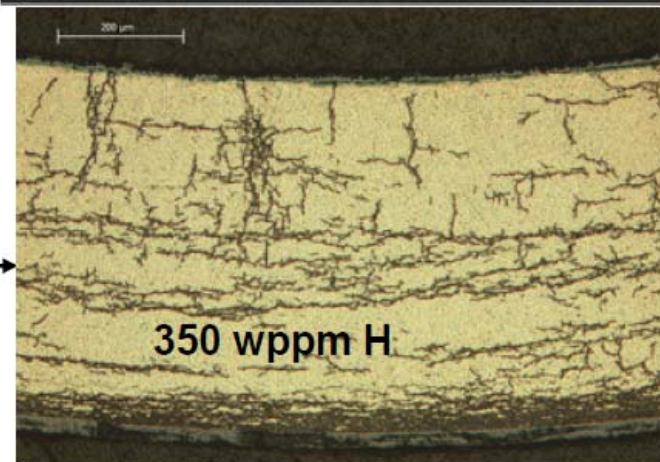
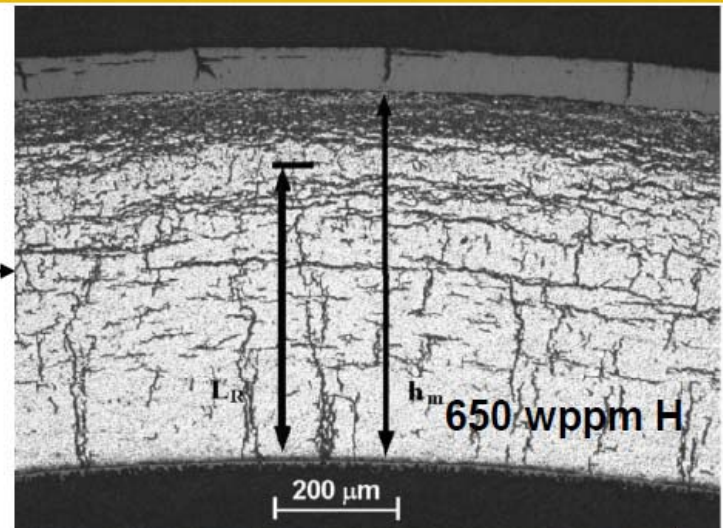
# Introduction: Circumferential and Radial Hydrides in HBU Cladding



As-Irradiated



Drying-Storage





## Summary of Results

### ■ Susceptibility to Radial-Hydride Precipitation

- Low for HBU Zry-4 cladding
- Moderate for **HBU ZIRLO™**
- High for **HBU M5®**

### ■ Susceptibility to Radial-Hydride-Induced Embrittlement

- Low for HBU Zry-4
- Moderate for **HBU M5®**
- High for **HBU ZIRLO™**

### ■ DBTT Values for HBU Cladding Alloys

- Peak drying-storage hoop stress at 400°C: 140 MPa → 110 MPa → 90 MPa → 0 MPa
- DBTT for **HBU M5®** after slow cooling: 80°C → 70°C → <20°C → <20°C
- DBTT for **HBU ZIRLO™** after slow cooling: 185°C → 125°C → 20°C → <20°C
- DBTT for **HBU Zry-4** after slow cooling: 55°C → <20°C → → >90°C
  - Embrittled by circumferential hydrides: 615±82 wppm 520±90 wppm 640±140 wppm
  - HBU Zry-4 with 300±15 wppm was highly ductile at 20°C



# Container Degradation Mechanisms

## Base Metal, Welds, Bolts, and Seals

Stressor	Degradation Mechanism	Influenced by VLTS or Higher Burnup	Additional Data Needed	Priority of R&D
Thermal and Mechanical	Embrittlement of elastomer seals	Yes	Yes	Low
	Thermomechanical fatigue of seals and bolts	Yes	Yes	Medium
Radiation	Embrittlement of elastomer seals	Yes	Yes	Low
Chemical	Atmospheric Corrosion (Including Marine Environment)	Yes	Yes	High
	Aqueous Corrosion: general, localized (pitting, crevice), SCC, galvanic	Yes	Yes	High

# Background information

- **CoCs/licenses for high burn-up fuel storage to be renewed over next few years**
  - **2012 Prairie Island-TN-40HT, Calvert Cliffs-NUHOMS<sup>1</sup>**
  - **2015 Transnuclear-NUHOMS 1004**
  - **2020 NAC-UMS; Holtec-Hi-STORM**
- **Storage of high burn-up fuel is relatively recent**
  - **9 years – Maine Yankee<sup>2</sup> (since 2003) up to 49.5 GWd/MTU**
  - **7 years – Robinson (since 2005) up to 56.9 GWd/MTU**
  - **6 years – Oconee (since 2006) up to 55 GWd/MTU**
  - **<4 years for most – up to 53.8 GWd/MTU**
- **~ 200 loaded-casks contain high burn-up fuel**
- **Most fuel in pools for future loading is high burn-up**



# High Burnup Fuel Approval

June 1992

Up to 60 GWd/MTU  
(60 MWD/kg)



UNITED STATES  
NUCLEAR REGULATORY COMMISSION  
WASHINGTON, D.C. 20555

June 22, 1992

Mr. A. E. Scherer, Director  
Nuclear Licensing  
Combustion Engineering, Inc.  
P. O. Box 500  
Windsor, Connecticut 06095

Dear Mr. Scherer:

SUBJECT: GENERIC APPROVAL OF C-E TOPICAL REPORT CEN-386-P, "VERIFICATION OF THE ACCEPTABILITY OF A 1-PIN BURNUP LIMIT OF 60 MWD/kg FOR COMBUSTION ENGINEERING 16X16 PWR FUEL (TAC NO. M82192)"

On November 14, 1991, you requested NRC review and generic approval of the C-E topical report CEN-386-P, entitled "Verification of The Acceptability of A 1-Pin Burnup Limit of 60 MWD/kg for Combustion Engineering 16X16 PWR Fuel." The methodology described in the topical report CEN-386-P was approved for licensing applications for ANO-2 and St. Lucie 2 in NRC safety evaluations dated November 27, 1990, and October 18, 1991, respectively. Based on your submittal and review of the previously approved SERs, we conclude that CEN-386-P is not necessarily plant-specific for ANO-2 or St. Lucie 2, and therefore CEN-386-P can be applied generically to other C-E 16x16 plants. The NRC staff was supported in this review by our consultant, the Pacific Northwest Laboratory, who previously provided input to the approval for applications to ANO-2 and St. Lucie 2. In summary, the NRC staff approves the generic applicability of CEN-386-P for licensing applications. Our evaluation applies only to matters described in the topical report.

In accordance with procedures established in NUREG-0390, "Topical Report Review Status," we request that C-E publish accepted versions of this topical report, proprietary and non-proprietary, within 3 months of receiving this letter. The accepted versions shall include an "A" (designating accepted) following the report identification symbol, and shall include this letter and the ANO-2 SER dated November 27, 1990.

If our criteria or regulations change such that we can no longer accept this report, applicants referencing this topical report will be expected to revise and resubmit their respective documentation, or submit justification that the topical report continues to apply without revision of their respective documentation.

Sincerely,

A handwritten signature in dark ink, appearing to read "Ashok C. Thadani".

Ashok C. Thadani, Director  
Division of Systems Technology  
Office of Nuclear Reactor Regulation

Enclosure:  
ANO-2 Safety Evaluation



# Used Nuclear Fuel in Storage

(Metric Tons, End of 2013)

