

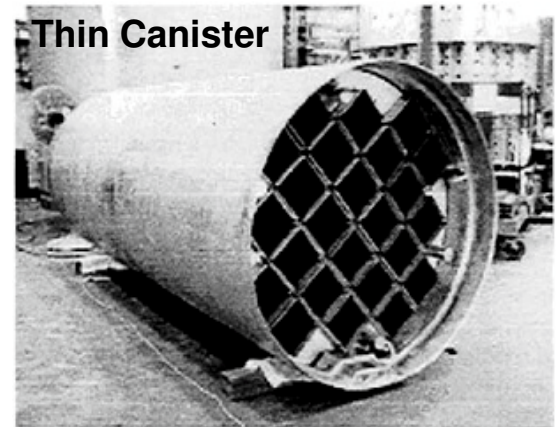
The background of the slide is a photograph of a beach. In the upper portion, blue waves with white foam are breaking onto a sandy shore. The lower portion of the image shows the sand, where the letters 'SOS' are written in a large, dark, hand-drawn font. The overall image conveys a message of emergency or distress, which is reinforced by the 'SOS' text and the title about nuclear safety requirements.

# **Nuclear Fuel Dry Storage Minimum Safety Requirements**

**Donna Gilmore, [SanOnofreSafety.org](http://SanOnofreSafety.org)  
August 19, 2020**

# Only thick-wall casks meet safety requirements

Safety Features	Thin canisters	Thick casks
Thick walls	1/2"- 5/8"	10"- 19.75"
Won't crack		✓
Ability to repair, replace seals		✓
Ability to inspect (inside & out)		✓
Monitored to <b>prevent</b> failure		✓
ASME N3 storage & transport		✓
Defense in depth (redundancy)		✓
Store in concrete building		✓
Gamma/neutron protection	With concrete vented overpack	✓
Transportable	unknown w/o inspection	✓
Market leader	<b>U.S.</b>	<b>World</b>



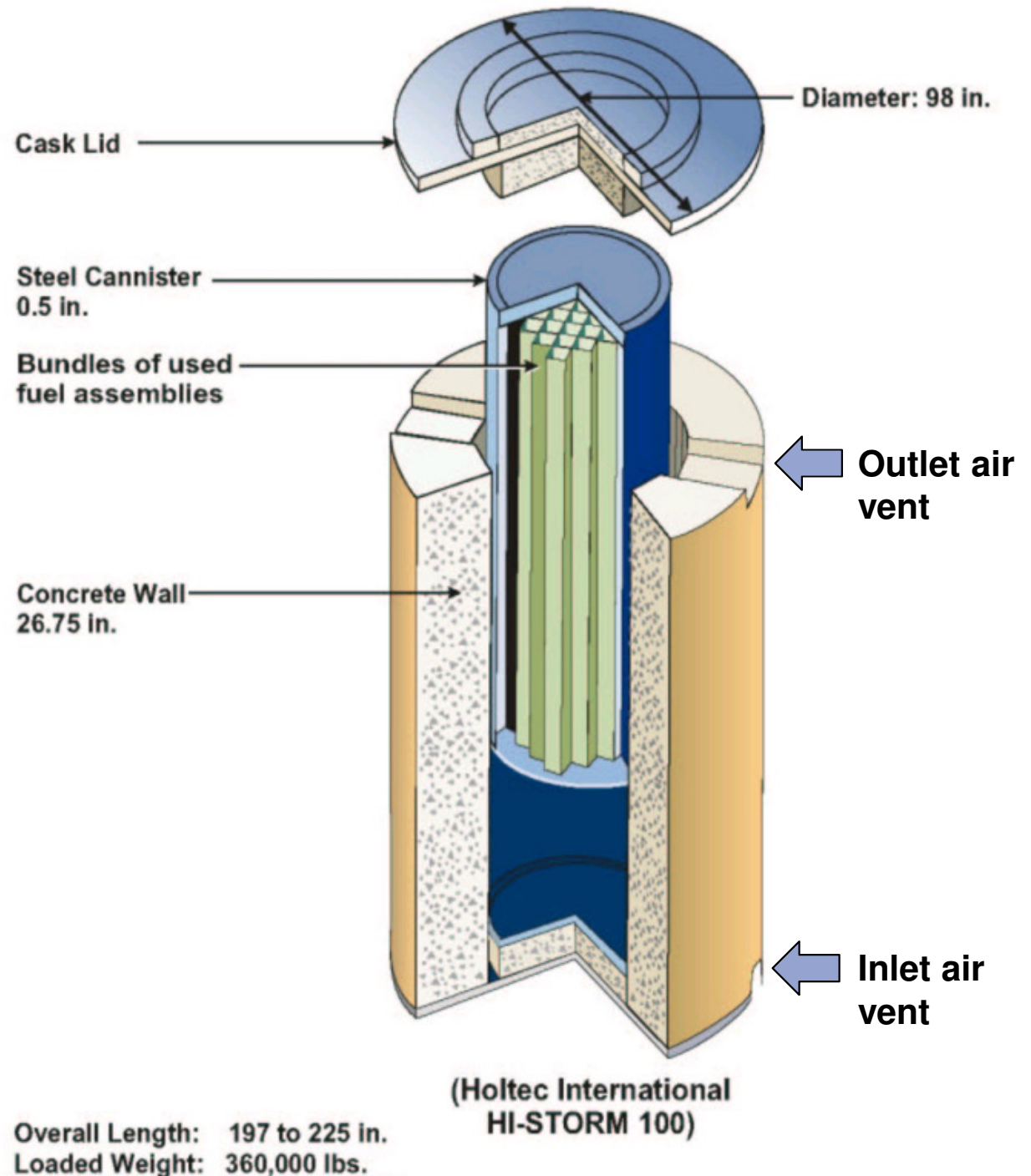
CASTOR® - Type V/19 cask

# Nuclear Waste Technical Review Board recommendations ignored for short-term and long-term storage

- **Spent nuclear fuel and its containment must be maintained, monitored, and retrievable in a manner to prevent radioactive leaks and hydrogen gas explosions.**
  - Need pressure monitoring and pressure relief valves.
  - NRC allows exemptions to these and other ASME requirements for thin-wall canister pressure vessels.
  - Need to determine amount of water in canisters. Concerned about explosion risks for storage and transport.
  - Dec. 2017 NWTRB Spent Nuclear Fuel Report to Congress and DOE
- **No technology to make geological repositories work short-term or long-term, even for 20 years.**
  - No idea how they will ever have the technology.
  - May 2018 NWTRB Geological Repository meeting ([nwtrb.gov](http://nwtrb.gov))

## Would you buy a car without these safety features?

- Cannot inspect (inside or out)
- Cannot repair
- No monitoring system to **prevent** failure
- Transport safety unknown
- Earthquake safety unknown





## Holtec President Kris Singh admits problems

---

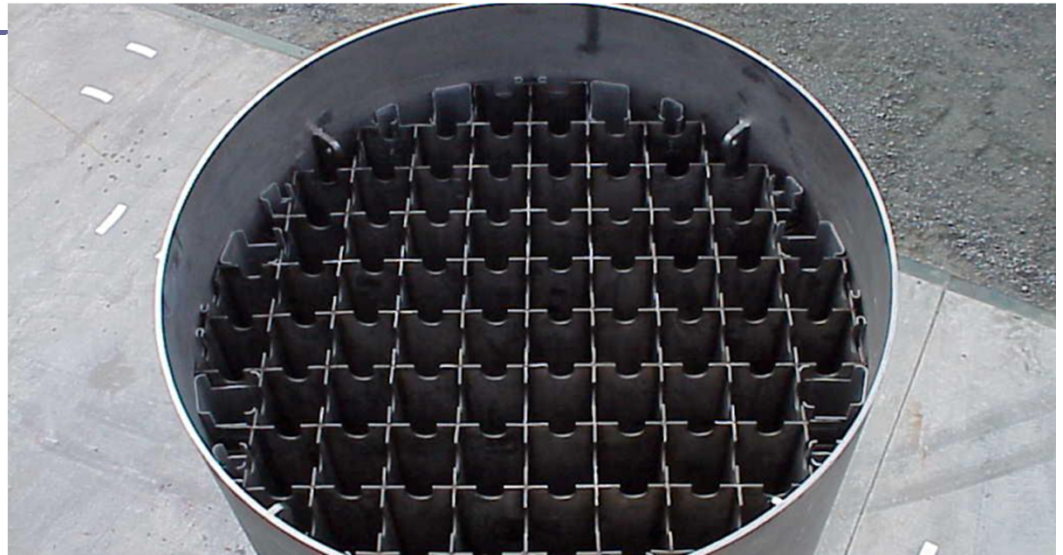


- “It is **not practical to repair** a canister if it were damaged...
- You will have, in the face of **millions of curies of radioactivity coming out of canister**; we think it’s not a path forward.”

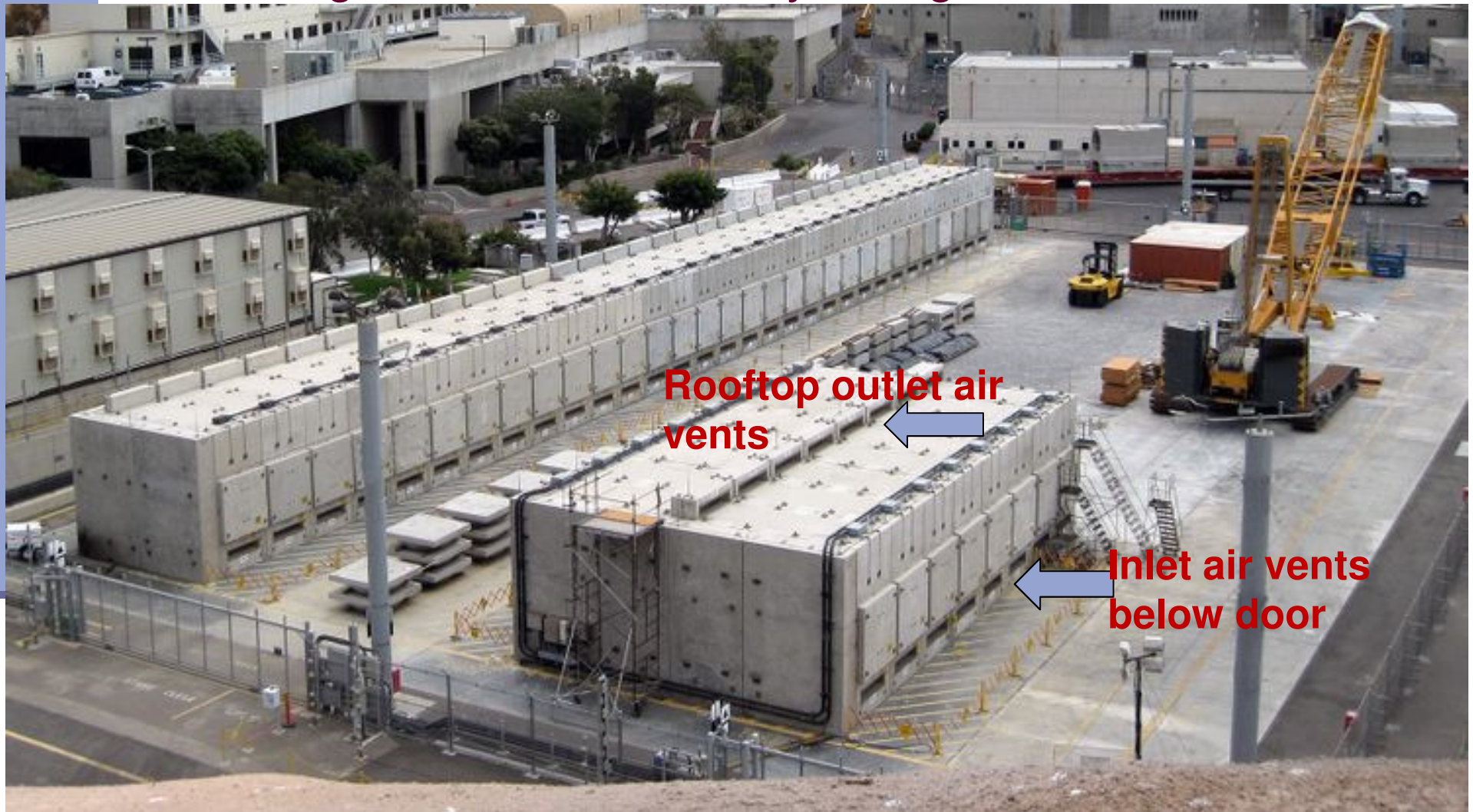
– Dr. Kris Singh, Holtec CEO & President  
<http://youtu.be/euaFZt0YPi4>

# Over 3200 US uninspectable thin-wall stainless steel welded canisters

- Thin-wall (1/2" to 5/8" thick) stainless steel canister vendors: Holtec, NAC and Transnuclear
- VSC-24 1" thick carbon steel canisters were discontinued, but in use at Arkansas, Palisades and Point Beach
- Japan required stainless steel fuel baskets after finding degradation with aluminum alloy baskets in Fukushima casks
- US has older stainless steel baskets, but now standardizes on aluminum baskets. **No US fuel baskets have been inspected.** Baskets are critical to maintaining fuel assemblies.
- Holtec BWR basket shown here holds up to 68 smaller fuel assemblies. PWR basket normally hold 24 to 37 larger fuel assemblies.



NUHOMS Horizontal Thin-Wall Canister System  
NRC hiding outlet air vent radiation levels. No longer requires  
measuring them. What are they hiding?





# New Holtec UMAX system lids corroding





# Holtec HI-STORM UMAX System

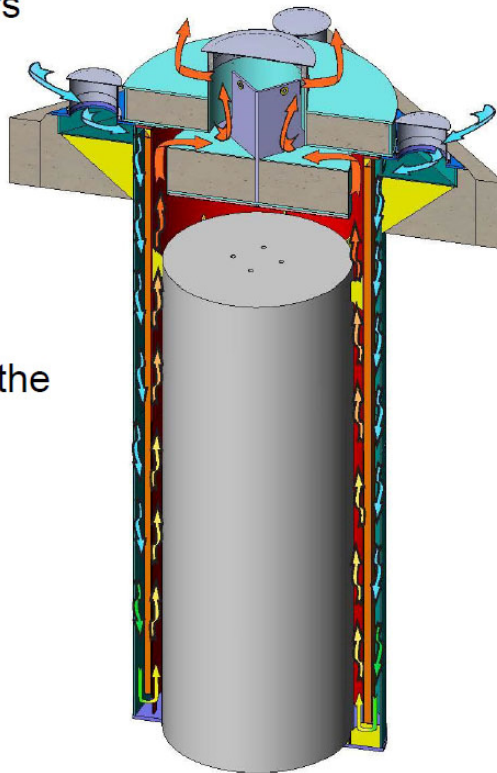
## No drains: 5" at bottom stops cooling

**HI-STORM UMAX Operates in a Completely Passive Mode Using Natural Convection to Cool the Spent Fuel**

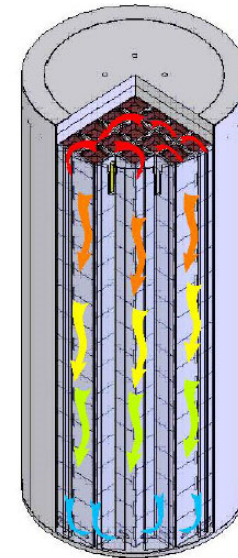


a generation ahead by design

- Cooling air enters lid.
- Air flows down through a downcomer.
- Air flows up adjacent to canister cooling the outside canister wall.
- Air is ejected through the lid.



- Within the canister internal convective flows cool the fuel and transfers the heat to the inside of the canister wall.



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

- Temperature low enough to initiate cracks in 2 years <85 °C (185 °F)
- Moisture dissolves sea salt – one of **many** triggers for corrosion and cracking





# Diablo Canyon: corrosive coastal environment





# San Onofre between Ocean & I-5 freeway 73 Holtec UMAX & 51 Areva NUHOMS canisters



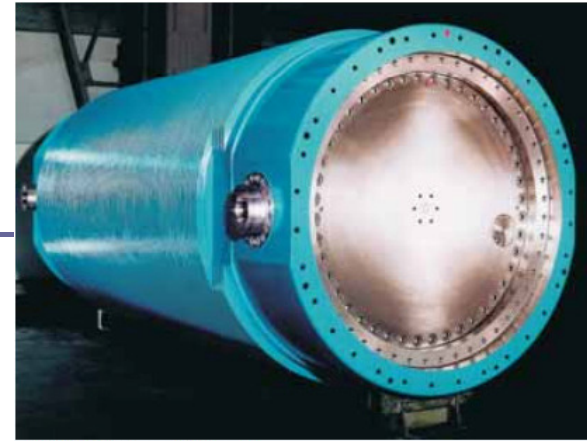


NRC claims not enough humidity at San Onofre for corrosion. Ignores frequent fog, surf, on-shore winds



# Thick casks designed for longer storage

- **Market leader internationally**
- **No stress corrosion cracking**
- **Maintainable**
  - Inspectable
  - Replaceable parts (metal seals, lids, bolts)
  - Double bolted thick steel lids allow reloading without destroying cask
  - Over 40 years in service with insignificant material aging.
- **Some currently licensed and used in U.S.** (18 to 30 month process for new or amended license). US modifications to design lowered maintainability.
- **Vendors won't request NRC license unless they have customer**
- **Thick cask body** – forged steel or thick ductile cast iron (10" to 19.75")
- **Early warning before radiation leak** (remote lid pressure monitoring)
- **Cask protects from all radiation, unlike thin steel canisters.**
  - No concrete overpack required (reduced cost and handling)
  - No transfer or transport overpack required (reduced cost and handling)
  - Stored in concrete building for additional protection
  - Used for both storage and transportation (with transport shock absorbers)
- **ASME N3 & international cask certifications** for storage and transport
- **Damage fuel rods sealed** (in ductile cast iron casks)



CASTOR® - Type V/19 cask

# Swiss Solution for Thick Cask Storage





# Swiss Zwilag Hot Cell

## Inspect or transfer fuel to new cask





# How many cracks in thin-wall canisters?

## No one knows

---

- No one knows how many cracks or size of cracks in any of the over 3200 canisters
- Diablo Canyon canister has all conditions for cracking in **2-year old** canister (salt & moisture) (EPRI)
- Cracks can grow through wall **16 years** after crack starts (NRC)
- Koeberg tank leaked in **17 years. Cracks over 0.61"** (NRC). Thin-wall canisters only **0.50"** or **0.625" thick** (NRC)
- **Cannot inspect canister for cracks** after fuel loaded. Requires dye penetrant per ASME codes

# Holtec HI-STORM UMAX System Visual Assessment – Not an Inspection



# Every Holtec thin-wall canister is damaged

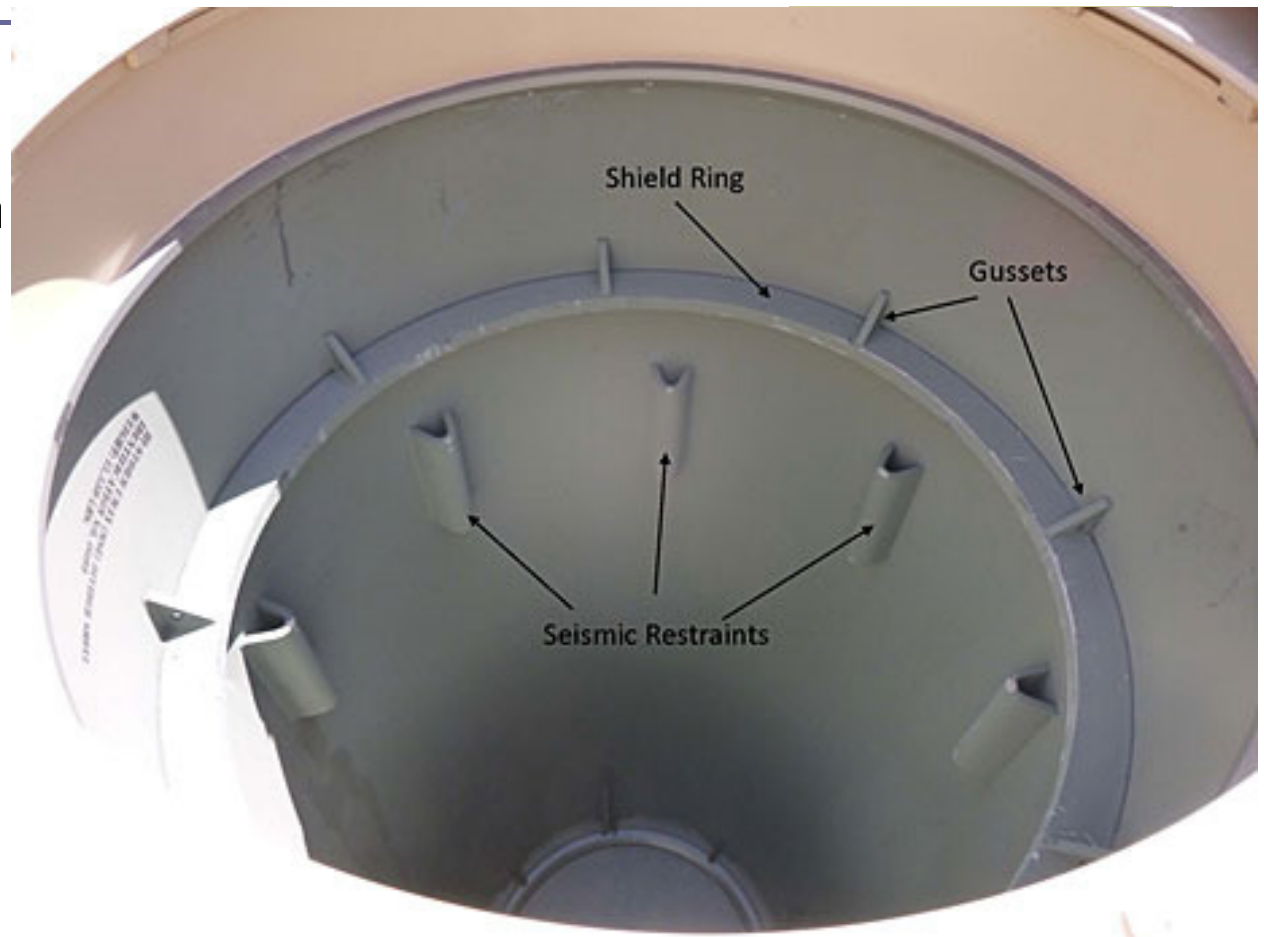
---

Both above ground and subterranean Holtec storage canisters are damaged when loaded into the carbon steel lined concrete storage casks/overpacks.

- Results in scraping, scratching and gouging canister walls the entire length of the canisters.
- Results in pit corrosion cracking from carbon particles embedded on the stainless steel walls.
- Results in shortened lifespan
- Caused by poorly engineered lack of precision downloading system with small margin between canister walls and interior canister guides.
- Above ground system scrapes against vertical canister guides
- Subterranean (UMAX) system is scraped and gouged against shield rings and canister guides

# Holtec HI-STORM UMAX subterranean system damages canisters

During canister downloading into subterranean carbon steel lined concrete vented cavities, canister walls are scraped the entire length against shield ring and other protrusions. (NRC)





# Holtec HI-STORM above ground system damages canister walls

During canister downloading into above ground carbon steel lined concrete vented casks, canister walls are scraped the entire length against vertical channels inside the concrete cask.

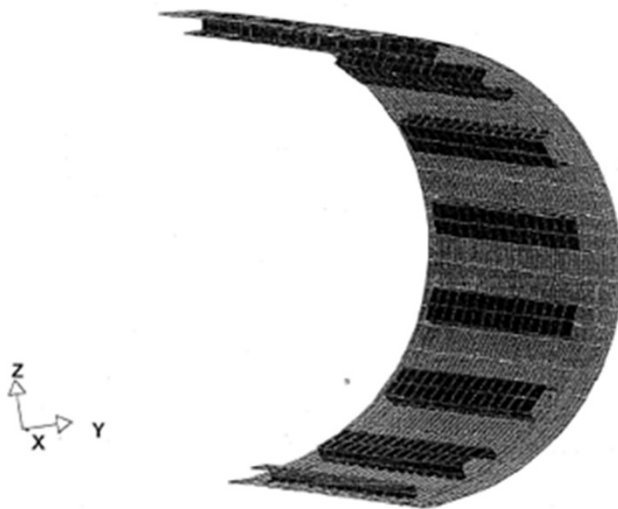
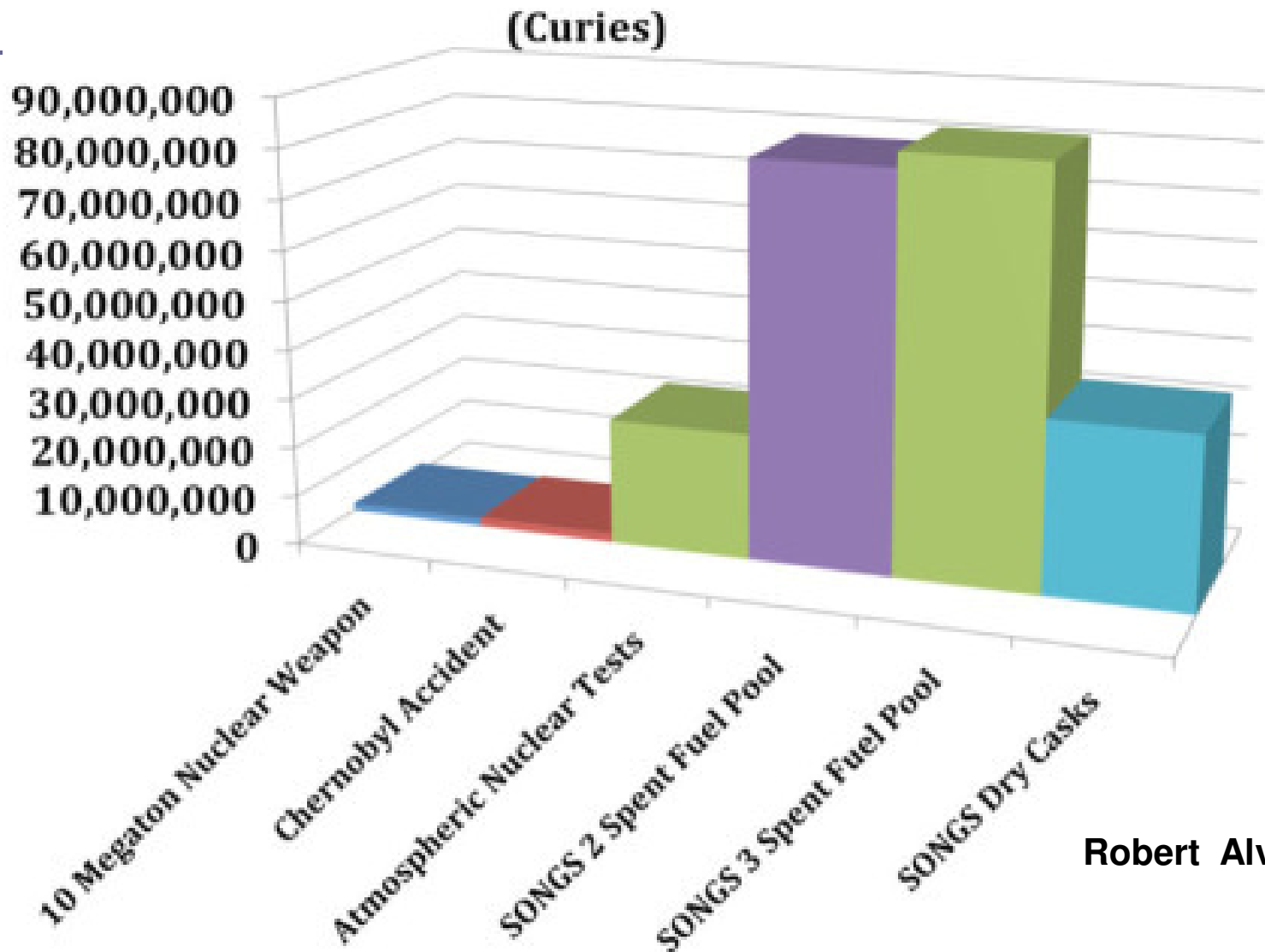


FIGURE 3.A.12 INNER SHELL AND CHANNELS FINITE-ELEMENT MODEL (3-D VIEW)



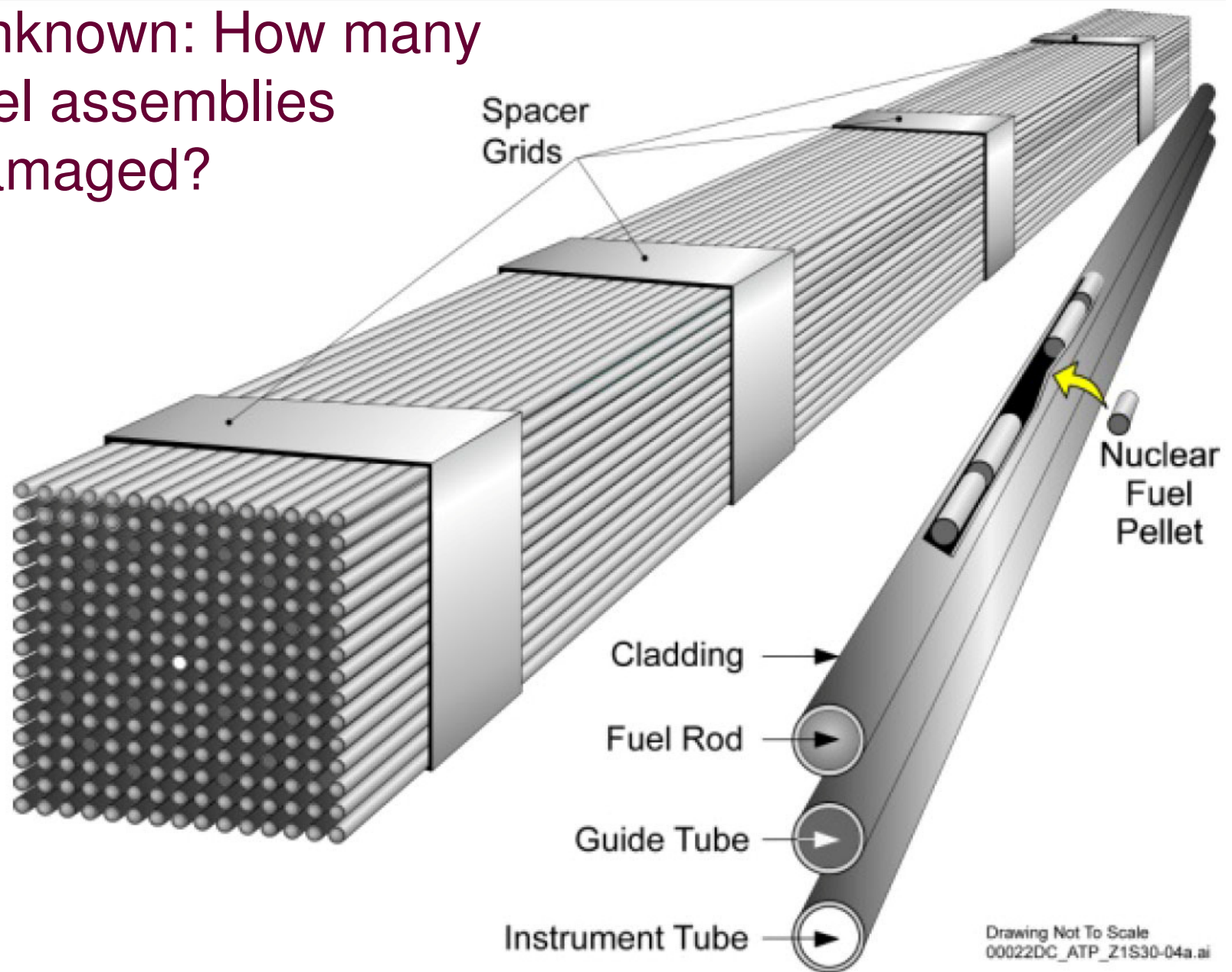
Cutaway of spent fuel storage cask shows spent fuel assemblies surrounded by steel and thick concrete shielding.

One canister holds roughly the Cesium-137 released from 1986 Chernobyl disaster



Robert Alvarez

Unknown: How many  
fuel assemblies  
damaged?



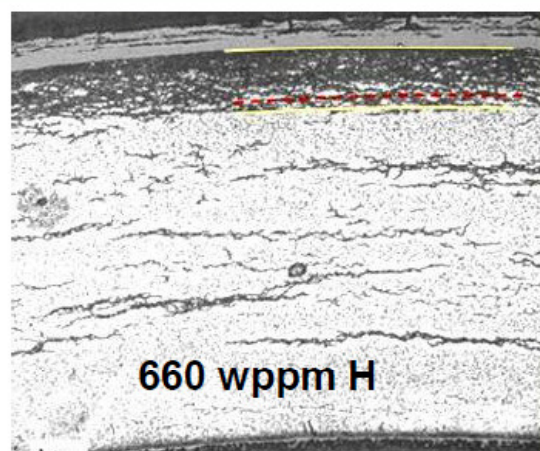




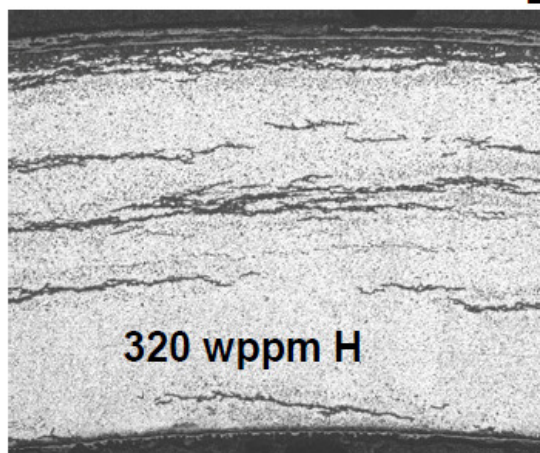
U.S. DEPARTMENT OF  
**ENERGY**

Nuclear Energy

## Introduction: Circumferential and Radial Hydrides in HBU Cladding

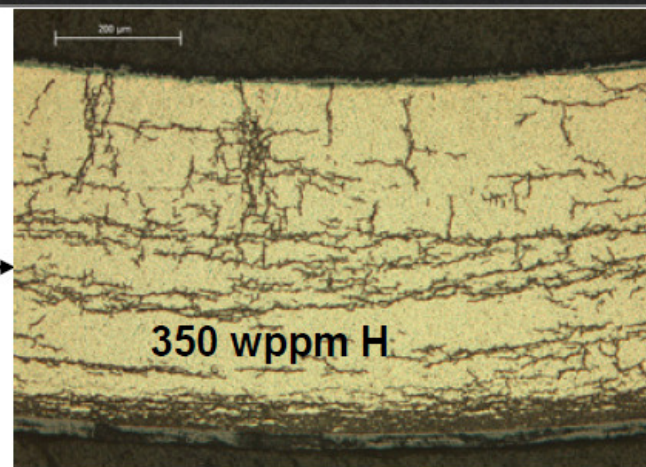
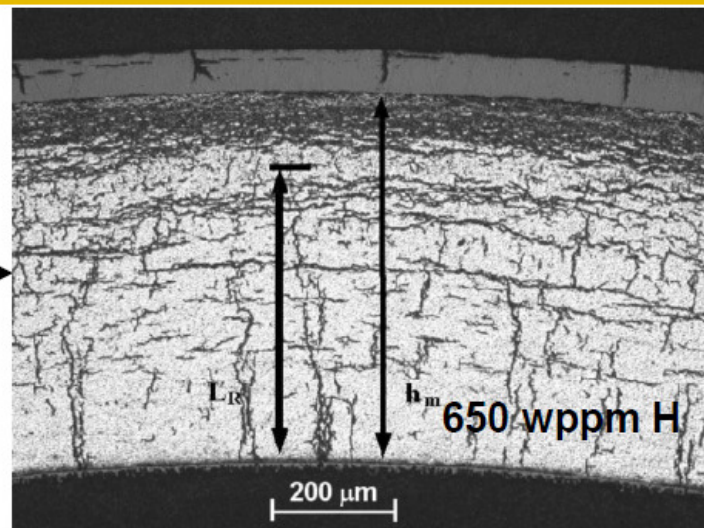


As-Irradiated

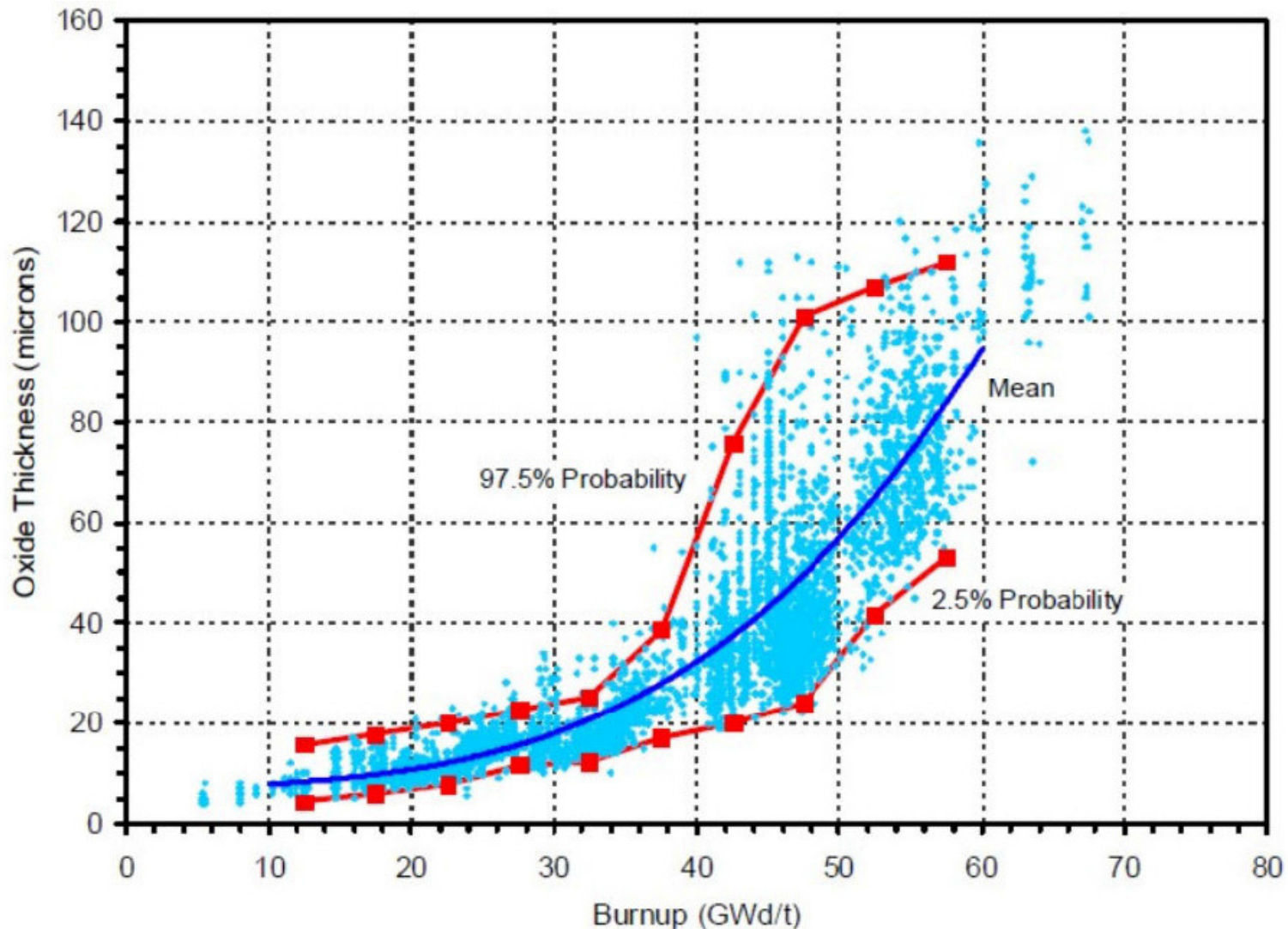


After

Drying-Storage



# Hydrogen gas explosion risk increases with burnup

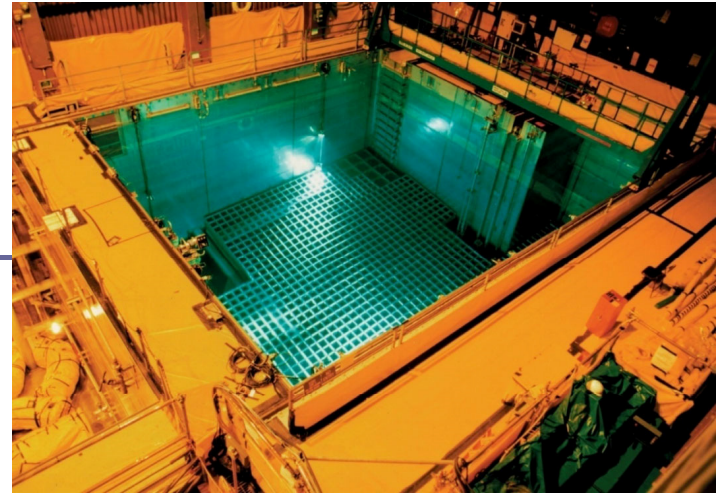


Higher oxide thickness results in higher cladding failure. Argonne scientists reported high burn-up fuels may result in fuel rods becoming more brittle over time. "... insufficient information is available on high burnup fuels to allow reliable predictions of degradation processes during extended dry 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



# No plan for cracking or leaking canisters

- License requires returning fuel to pool, but never been done with thin-wall canisters
- Hotter fuel cannot be unloaded back into pool
  - Results in “reflooding” problem, yet NRC ignoring this
- Plan to destroy empty spent fuel pools
  - NRC false assumption nothing can go wrong in dry storage
  - Pool is only on-site current option to replace defective canisters
- Hot cell (dry fuel handling facility) is only other option





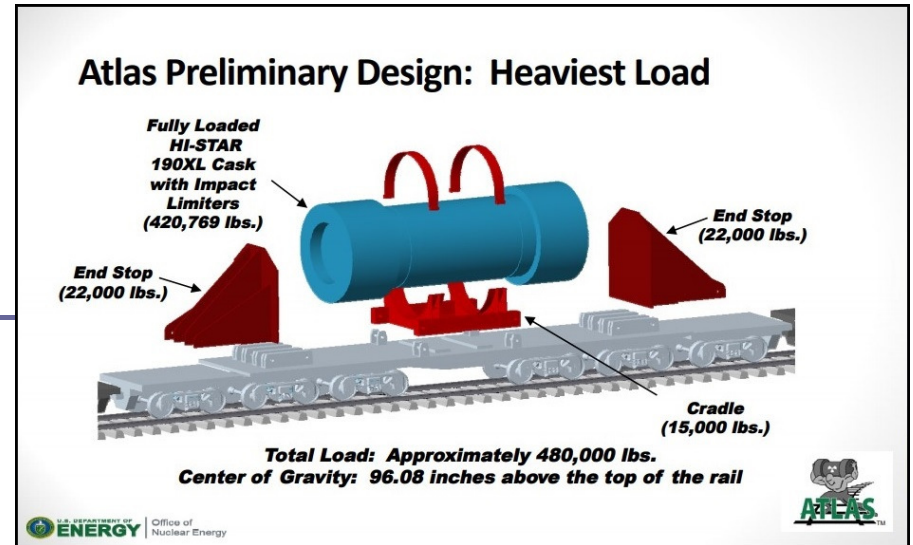
# Hot Cell is only other option

- Idaho Test Area North (TAN) hot cell destroyed in 2007
- No other U.S. hot cell large enough to replace canisters
- No plans to build hot cell
- Assumes nothing will go wrong



# Unsafe for transport

- Cracking or leaking canisters and casks unsafe for transport
- ***NRC Regulation 10 CFR § 71.85 Packaging and Transportation of Radioactive Materials. Preliminary determinations.***
  - ***Before the first use of any packaging for the shipment of licensed material — (a) The certificate holder shall ascertain that there are **no cracks**, pinholes, uncontrolled voids, or other defects that could significantly reduce the effectiveness of the packaging.***
- **Holtec and WCS Centralized Interim Storage Plan: Return cracking/leaking canisters to sender**



# No warning before major radiation releases from thin-wall canisters



**Microscopic cracks**

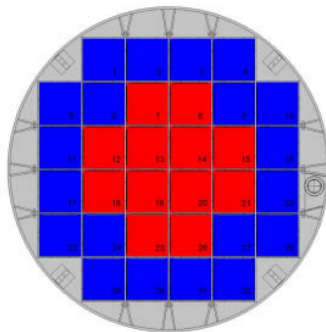
- **No early warning monitoring**
  - Remote temperature monitoring not early warning
  - No pressure or helium monitoring
  - Thick casks have continuous remote pressure monitoring – alerts to early helium leak.
- **No remote or continuous canister radiation monitoring**
  - Workers walk around canisters with a “radiation monitor on a stick” once every 3 months.
  - Thick casks have continuous remote radiation monitoring
  - **NRC refuses to share or require outlet air vent radiation monitoring**
- **After pools emptied, NRC allows**
  - **Removal of all radiation monitors**
  - **Elimination of emergency planning to communities** – no radiation alerts
  - **Removal of fuel pools** (assumes nothing will go wrong with canisters)



# Fuel needs to cool for over a decade before safe to move to dry storage

- NRC approving amendments for unsafe heat loads in dry storage – double the previous heat loads
- High heat can damage fuel rods – unknown condition
- Fuel too hot to return to pools

The heat from the fuel stored in the core region of the basket is removed by the thermosiphon (circulatory) action. As a result, high heat rate fuel (gamma radiation emitted is proportional to the heat emission rate from the fuel) can be placed in the core region of the basket, surrounded by the cooler (and older) fuel in the periphery. This approach, known as “regionalized” storage, is extremely effective in promoting the thermosiphon effect as well as mitigating the dose emitted from a basket in the lateral direction. The benefits to the user: high heat loads and low dose to the loading crew.



**Regionalized Storage in the MPC 32**

- Region 1 “Hot/Young” Fuel
- Region 2 “Old/Cold” Fuel

# Some aging canisters at risk for cracks and leaks

	<b>Loaded</b>	<b>Age (2020)</b>
■ Calvert Cliffs	1993	27 years
■ Rancho Seco	2001	19 years
■ Oyster Creek	2002	18 years
■ San Onofre	2003	17 years
■ Indian Point	2008	12 years
■ Diablo Canyon	2009	11 years
■ Most U.S. thin canisters in use less than 15 years		

<https://sanonofresafety.files.wordpress.com/2018/07/d32-caskinventorybystate2018-07-14a.pdf>

# Explosion Risks

## ■ Hydrogen Gas explosion risks

- Spent fuel exposed to air in pool or dry storage can result in hydrogen gas explosions
- “Evidence” claiming no explosion risk, ignore hydrides
- Hydrides in both zirconium cladding and uranium fuel increases at moderate burnup levels
- Zirconium hydride gas ignites at 270 degrees Celsius
- Water remaining after drying develops hydrogen from irradiation. Canisters may over pressurize, but have no pressure monitors or pressure relief valves. (NWTRB).

## ■ Fuel can go critical if exposed to unborated water.

- Boron in canisters only for loading from pool to dry storage. Not credited to prevent criticality if exposed to water. (NRC, Holtec).



# Fukushima thick casks survived 2011 earthquake and tsunami



# German interim storage over 40 years



# Thick casks used worldwide The TN<sup>®</sup>24 Cask Family

Packaging	Number of fuels	Burn-up (MWd/tU)	Cooling time (years)	Enrichment (%)	Country
TN 24 D	28 PWR	36 000	8	3.4	B
TN 24 DH	28 PWR	55 000	7	4.1	B
TN 24 XL	24 PWR	40 000	8	3.4	B
TN 24 XLH	24 PWR	55 000	7	4.3	B
TN 24 SH	37 PWR	55 000	5	4.25	B
<b>TN 24 G</b>	<b>37 PWR</b>	<b>42 000</b>	<b>10</b>	<b>3.81</b>	<b>CH</b>
TN 24 (F1*)	37 BWR	33 000	4	3.2	J
TN 24 E	21 PWR	65 000	5	4.65	G
TN 32	32 PWR	45 000	7	4.05	US
TN 40	40 PWR	45 000	10	3.85	US
TN 24 P	24 PWR	33 000	5	3.5	US
<b>TN 52 L</b>	<b>52 BWR</b>	<b>55 000</b>	<b>mini 2.5</b>	<b>4.95</b>	<b>CH</b>
<b>TN 24 SWR</b>	<b>61 BWR</b>	<b>70 000</b>	<b>mini 5.5</b>	<b>5.0</b>	<b>G</b>
TN 68	68 BWR	45 000	7	4.4	US
<b>TN 97 L</b>	<b>97 BWR</b>	<b>35 000</b>	<b>10</b>	<b>4.0</b>	<b>CH</b>
<b>TN 24 BH</b>	<b>69 BWR</b>	<b>50 000</b>	<b>6</b>	<b>5.0</b>	<b>CH</b>
TN 24 (F1*)	52 BWR	33 000	4	3.2	J
TK 69	69 BWR	40 000	10	3.2	J
TN 24 ER	32 BWR (Th)	13 700	40	5.2	I

TN INTERNATIONAL



# NRC license excludes aging issues

- **Ignores issues that may occur after initial 20 year license, such as cracking and other aging issues**
- **Refuses to evaluate thick casks unless vendor applies**
- **Requires first canister inspection after 25 years**
  - Allowing **5 years** to develop inspection technology
- **Requires inspection of only one canister per plant**
  - That same canister to be inspected **once every 5 years**
- **Allows up to a 75% through-wall crack**
  - **No seismic rating** for cracked canisters
- **No replacement plan for cracked canisters**
  - Approves destroying fuel pools after emptied
  - No money allocated for replacement canisters
- **NRC aging management (NUREG-1927 rev. 1) not enforced**

# Consolidated Interim Storage (CIS)?

- Legal challenges likely will delay or stop new sites indefinitely
- Shimkus 2018 H.R. 3053 NWPA Amendments make problem worse
  1. Allows license transfer to DOE at current site
  2. Removes safety requirements needed to **prevent** major leaks
  3. Removes site specific environmental requirements
  4. Removes oversight of DOE (*existing DOE waste sites leak!*)
  5. Removes state, local, public rights to oversight, input, transparency
  6. Removes other federal, state and local rights (land, utilities, etc.)
  7. Ignores current storage and transport safety issues
  8. Removes cost analysis requirements for waste transport & storage
  9. Ignores transport infrastructure safety issues
  10. Inadequate funding for storage and transport

***None of these issues discussed in House hearings!***

## NRC ignores and weakens regulations

- Ignores aging issues
- Allows destruction of pools in spite of knowing it is the only approved on-site option for replacing failing canisters
- Allows canisters vulnerable to short-term cracking in spite of knowing they cannot be transported, inspected, maintained or monitored to prevent major radioactive releases.
- Allows high burnup fuel in spite of knowing it can be damaged -- not safe for transport or storage





# Recommendations

## ■ STEP ONE: Swiss Solution

- Require thick-wall metal maintainable, transportable storage casks **before** thin-wall canisters fail.
- Require ASME N3 Nuclear Pressure Vessel certification
- Keep pools until on-site hot cell implemented
- Freeze decommissioning funds until funding issues resolved

## ■ STEP TWO

- Store in hardened buildings
  - Store away from coastal and flood risks
- These are the only technical and financially sound options





**Donna Gilmore**  
**SanOnofreSafety.org**  
**donnagilmore@gmail.com**

**SOS**



# Background Slides

---





# Roadblocks to moving waste

- **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
  - Numerous technical, legal and political issues unresolved
  - Congress limited DOE to consider only Yucca Mountain
  - Funding of storage sites unresolved
  - Communities do not want the waste
- **NWTRB says no technology to make any geological repository work**
- **False promises & leaking DOE waste sites**
  - WIPP repository leaked within 15 years – broken promises to New Mexico
  - Hanford, WA, Savannah River and other sites leaking
- **States have no legal authority over radiation safety – only cost and permits**
- **Transport infrastructure issues, accident risks, cracking canisters**
- **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**

# Condition of existing canisters unknown



- **No technology exists to inspect canisters for cracks**
  - Most thin canisters in use less than 20 years
- **Won't know until AFTER leaks radiation**
- Similar steel components at nuclear plants **failed in 11 to 33 years** at ambient temperatures ~20 °C (68 °F)
- **Crack growth rate about four times faster** at higher temperatures
  - 80 °C (176 °F) in “wicking” tests compared with 50 °C (122 °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 – chloride salts won't stay and dissolve on canister
- **Many corrosion factors not addressed.** NRC focus is chloride-induced stress corrosion cracking (CISCC).

# Koeberg steel tank failed in 17 years

- **CA coastal environment similar to Koeberg plant in South Africa**
  - Salt and high moisture from on shore winds, surf and fog
  - EPRI excluded these factors in their crack analysis
- **Koeberg refueling water storage tank failed with 0.6" deep crack**
  - EPRI excluded this fact in their crack analysis (cherry picked data)
- **CA thin canisters only 0.5" to 0.625" thick**
  - **Diablo Canyon 0.5"** steel canister, inside vented concrete cask
  - **Humboldt Bay 0.5"** steel canister inside thick bolted lid steel cask, inside experimental underground concrete system
  - **Rancho Seco 0.5"** steel canister inside vented concrete overpack
    - Also at risk from salt air and fog
  - **San Onofre 0.625"** steel canister inside vented concrete overpack
  - **San Onofre proposed Holtec vented underground HI-STORM UMAX system not used anywhere in the world & not approved**
- **Koeberg cracks could only be found with dye penetrant test**
  - Test cannot be used with canisters filled with spent nuclear fuel



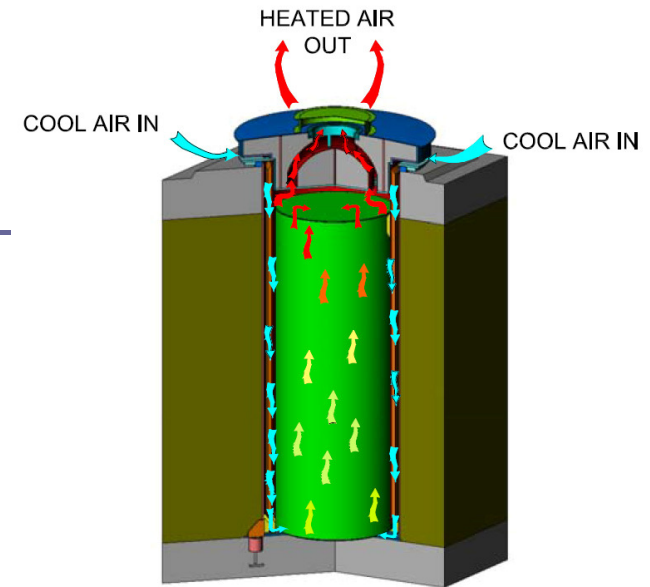
# Can't repair canisters and No plan to replace them

- **“It is not practical to repair a canister if it were damaged...** if that canister were to develop a leak, let's be realistic; you have to find it, that crack, where it might be, and then find the means to repair it. You will have, in the face of **millions of curies of radioactivity coming out of canister**; we think it's not a path forward.”
  - Dr. Kris Singh, Holtec CEO & President <http://youtu.be/euaFZt0YPi4>
- **No plan to replace casks or cracked canisters**
  - **NRC allows pools to be destroyed**, removing the only available method to replace canisters and casks
  - **No plans or funds to replace pools or spent fuel dry storage systems**
  - **Dry transfer systems don't exist** for this and are too expensive
  - **Transporting cracked canisters is unsafe** & not NRC approved
  - **Storing failed canister in a thick transport cask is no path forward**, expensive & not NRC approved
  - **No seismic rating for a cracked canisters**

# Game Changer

## Indefinite on-site storage

- **2014 NRC continued storage decision\***
  - **100+ years on-site storage**
  - **Reload** canisters every 100 years
- **No other storage sites on horizon**
- **Canisters may fail in 20 to 30 years**
  - Some may already have cracks
- **Cannot inspect for or repair corrosion and cracks**
  - No warning until after radiation leaks into the environment
- **Diablo Canyon Holtec thin canister has *conditions* for cracking after only 2 years!**
- **No replacement plan for failure**



\*GEIS analyzed the environmental impact of storing spent fuel beyond the licensed operating life of reactors over three timeframes: 60 years (short-term), 100 years after the short-term scenario and indefinitely, August 26, 2014. [assuming 40 year license: 60+40 = 100 (short term)]

# Enforce Public Resources Code Regulation §30253



CASTOR® - Type V/19 cask

**New development shall do all of the following:**

- (a) Minimize risks to life and property in areas of high geologic, flood, and fire hazard.**
- (b) Assure stability and structural integrity, and neither create nor contribute significantly to erosion, geologic instability, or destruction of the site or surrounding area or in any way require the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs.**
- (c) Be consistent with requirements imposed by an air pollution control district or the State Air Resources Board as to each particular development.**
- (d) Minimize energy consumption and vehicle miles traveled.**
- (e) Where appropriate, protect special communities and neighborhoods** that, because of their unique characteristics, are popular visitor destination points for recreational uses.

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

## ■ Safe from brittle fracture in transport

- ...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.

## ■ Exceeds drop test standards

- ...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.

## ■ Exceeds low temperature requirements

- 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>



# 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
- Quality control has been an issue with thin canisters

# 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.**

# 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
- Potential problem unloading fuel from a dry storage canister or cask into a pool with existing fuel

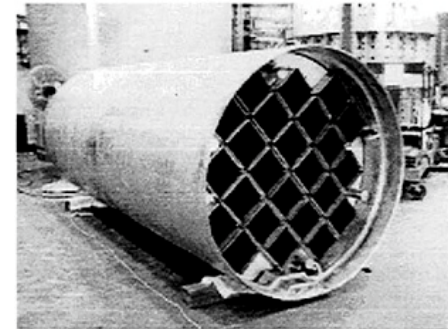
# No defense in depth in thin canisters

- **No protection** from gamma or neutron radiation in thin canister
  - **Unsealed** concrete overpack/cask required for gamma & neutrons
  - **No other type of radiation protection if thin canister leaks**
  - Thick steel overpack transfer cask required to transfer from pool
  - Thick steel overpack transport cask required for transport
- **High burnup fuel (HBF)** (>45 GWd/MTU)
  - Burns longer in the reactor, making utilities more money
  - Over twice as radioactive and over twice as hot
  - Damages protective Zirconium fuel cladding even after dry storage
  - Unstable and unpredictable in storage and transport
- **Limited technology** to examine fuel assemblies for damage
- **Damaged fuel cans** vented so no radiation protection
  - Allows retrievability of fuel assembly into another container

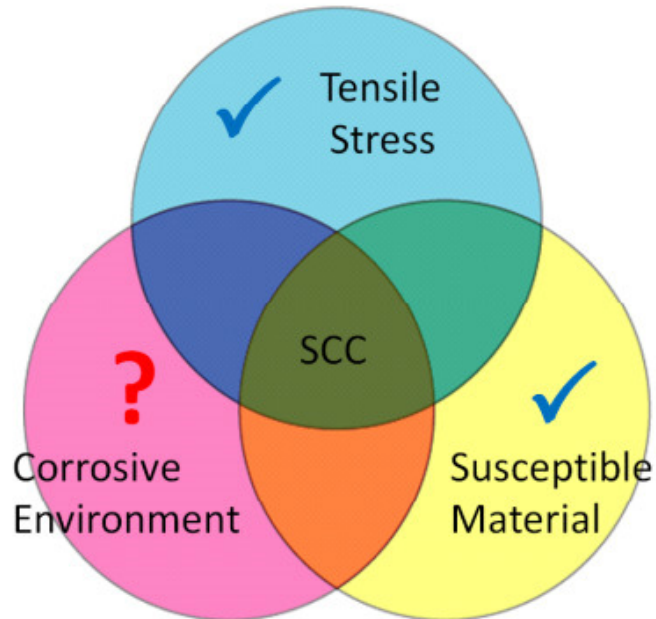


# Problems with thin stainless steel canisters

- **Not maintainable**
  - Cannot inspect exterior or interior for cracks
  - Cannot repair cracks
  - Not reusable (welded lid)
- **No warning BEFORE radiation leaks**
- **Canisters not ASME certified**
- **NRC allows exemptions from ASME standards**
- **No defense in depth**
  - Concrete overpack vented
  - Unsealed damaged fuel cans
  - No adequate plan for failed canisters
- **Early stress corrosion cracking risk**
- **Inadequate aging management plan**



# 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)



# Used Fuel Disposition

## 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*

January 14, 2013

Separate Effects and Small-Scale Testing in Support  
of Extended Dry Storage

3





## 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

## 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**



1) Since 1992, allowable burn-up to 47 GWd/MTU, since 2010, up to 52 GWd/MTU

2) All high burn-up fuel is in damaged fuel cans



# 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 "A. Thadani".

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

Enclosure:  
ANO-2 Safety Evaluation

# 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





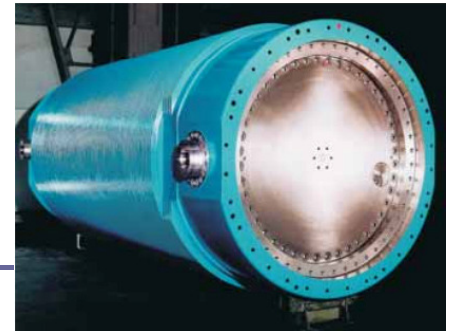
# Recommendations to NRC



- **Require best technology used internationally**
- **Base standards on longer term storage needs**
  - Not on limitations of thin canister technology
  - Not on vendor promises of future solutions
- **Store in hardened concrete buildings**
- **Don't destroy defueled pools until waste stored off-site**
- **Install continuous radiation monitors with on-line public access**
- **Continue emergency plans until waste is off-site**
- **Certify safety of dry storage systems for 100 years, but require 20-year license renewals**

# Recommendations

We cannot kick this can down the road



CASTOR® - Type V/19 cask

- **STOP thin canister procurement**
- **Develop minimum dry storage requirements to ensure adequate funding for new 100+ year storage requirements**
  - **Maintainable** – We don't want to buy these more than once
  - **Early warning** prior to failure and prior to radiation leaks
  - **Inspectable, repairable** and **doesn't crack**
  - **Cost-effective for 100 year storage, transportable**
  - **Ability to reload fuel without destroying container**
- **Don't allow purchase of vendor promises – it's not state policy to purchase non-existent features (e.g., vaporware)**
- **Require bids from leading international vendors**
- **Replace existing thin canisters before they fail**
- **Store in hardened concrete buildings**
- **Require mitigation plan**
  - **Don't destroy empty pools until waste removed from site**
  - **Install continuous radiation monitors with on-line public access**
  - **Continue emergency planning until waste is off-site**



**Donna Gilmore**  
**SanOnofreSafety.org**  
**donnagilmore@gmail.com**

**SOS**