U.S. nuclear waste dry storage canisters at high risk for leaks

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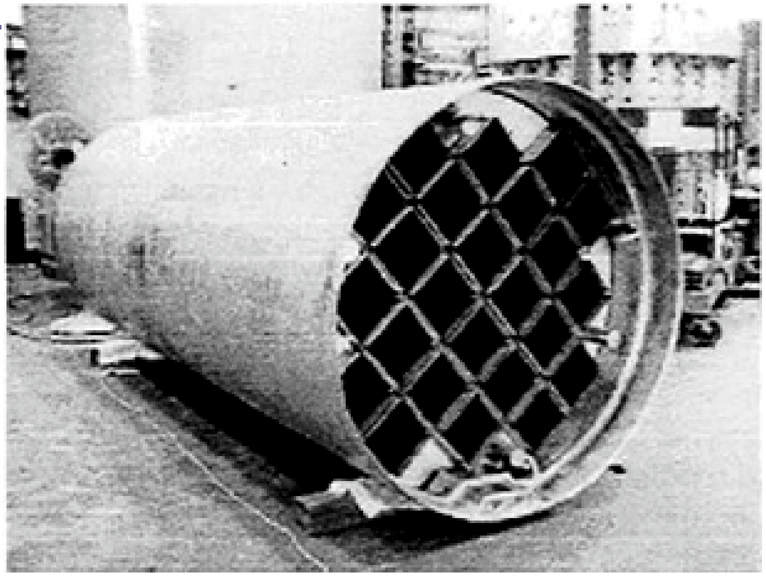
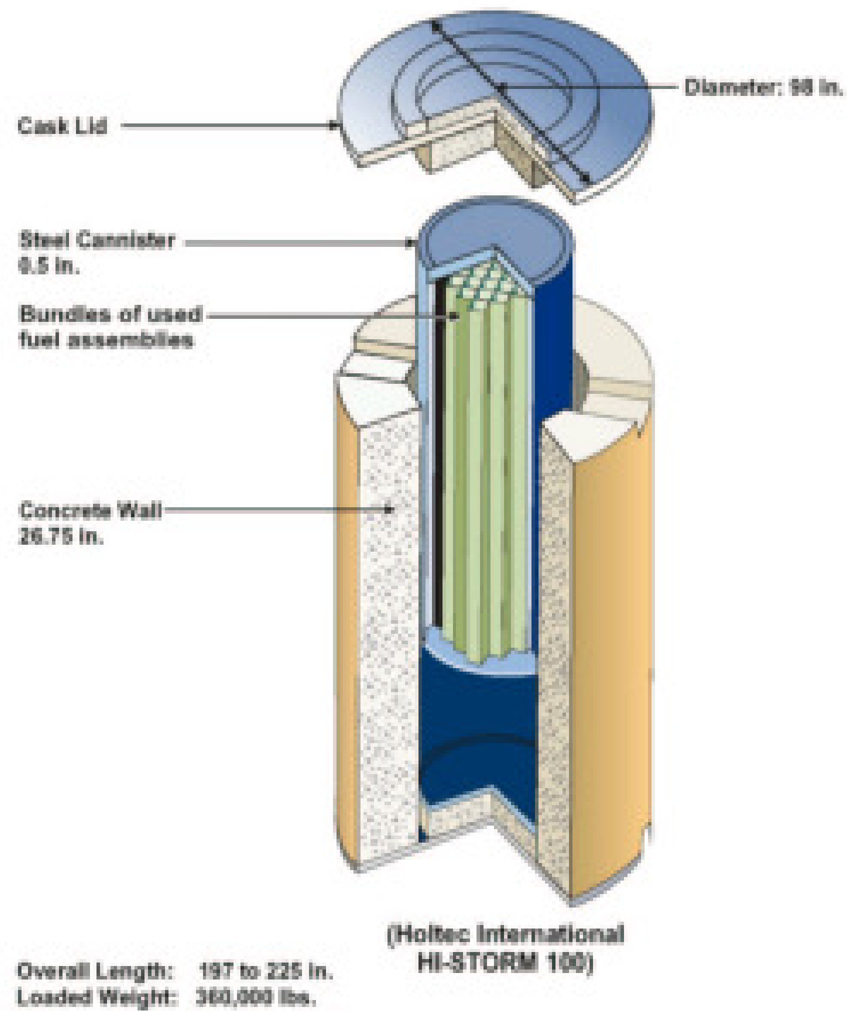
Risks of short-term cracks and leaks from thin-wall nuclear waste "Chernobyl" canisters



- Over 2000 U.S. nuclear waste thin-wall storage canisters
  - Cannot be **inspected** inside or out
  - Cannot be **repaired** or **maintained**
  - Cannot be **monitored** to **prevent radiation leaks**
- Thin-wall (~ ½") stainless steel canisters can **cracks and leak in the short-term** from various environmental and manufacturing conditions.
- **Can leak 16 years after cracks start** and there is **no plan** in place to deal with this. *NRC 8/5/2014*
- ***Would you buy a car that cannot not be inspected, repaired or maintained and has no early warning system to prevent failure?***

Holtec HI-STORM 100 thin-wall canister system

- Only 1/2 inch thick walls
- Cannot inspect outside
- Cannot inspect inside
- Cannot repair
- No warning until after leaks
- Air vents in concrete will accelerate release of radionuclides
- No adequate plan for failure
- Even partially cracked canisters cannot be transported
- Holtec claims 100 - 300 year lifespan by ignoring data



Koeberg tank leaked in only 17 years

- The Koeberg nuclear plant in South Africa had a comparable container leak in only 17 years from marine environment.
- Cracks were deeper than the thickness of most U.S. thin-wall canisters (0.61" vs 0.50").
- The NRC considers the Koeberg refueling water storage tank (RWST) comparable operating experience to thin-wall canisters.

NRC 8/5/2014

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

- Temperature low enough to initiate cracks in 2 years <85°C (185°F).
- NRC thought it would be 30 years before the temperature was low enough for moisture to stay on a canister and dissolve the salt. Salt is one of the triggers for corrosion & cracks.

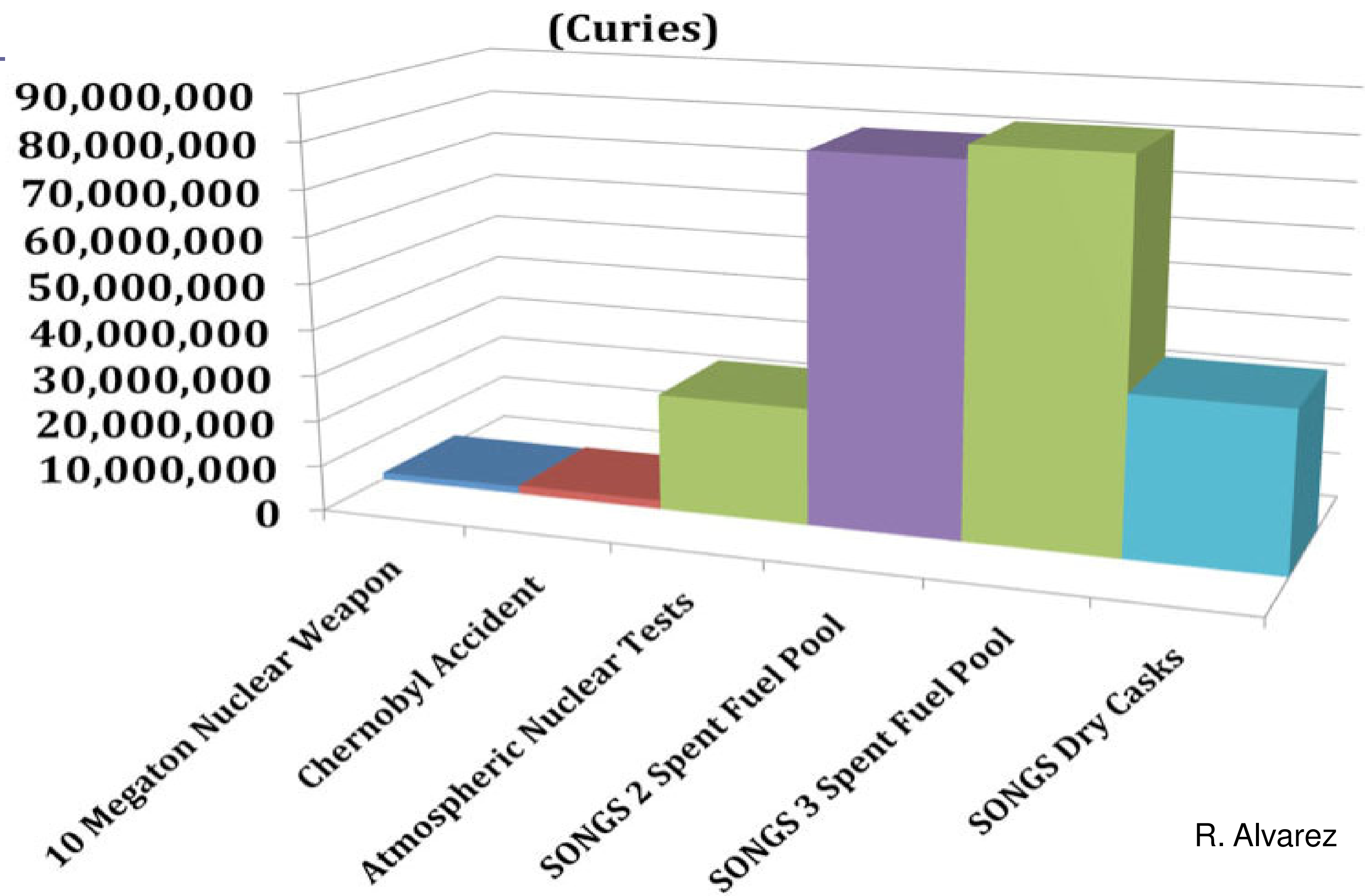
Frequent fog and on-shore surf at San Onofre and Diablo Canyon increases crack risks

NRC and EPRI ignore weather data, claiming insufficient humidity at San Onofre and Diablo Canyon.

Holtec canister President Kris Singh admits problems

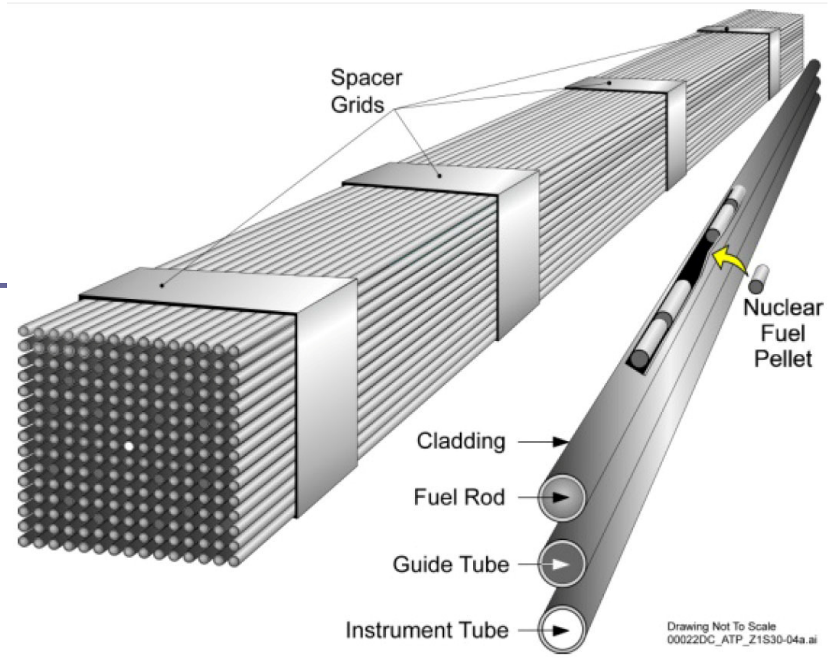
- “It is **not practical to repair** a canister if it were damaged…
- You will have, in the face of **millions of curies of radioactivity coming out of canister**; we think it’s not a path forward.”
  - – Dr. Kris Singh, Holtec CEO & President
    http://youtu.be/euaFZt0YPi4

San Onofre (SONGS): 89 times more lethal Cesium-137 than released from Chernobyl



R. Alvarez

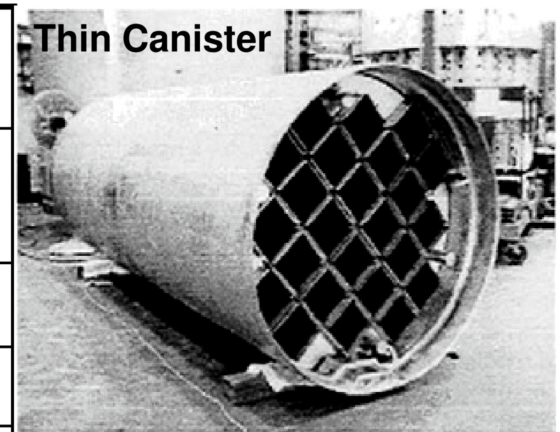
Criticality and explosion risks with cracking cans



- Holtec and NRC admit (unborated) water in canister will cause criticality – an uncontrolled release of radionuclides
  - NRC assumes no through-wall cracks and no water will enter canister from lake, river, ocean, rain, flood, tsunami, fog)
  - Boron metal in fuel basket is only for criticality prevention while transferring fuel assemblies from borated pool to dry storage.
- Hydride buildup from mid and high burnup fuel can trigger hydrogen explosion if exposed to oxygen
  - Zirconium hydrides (fuel rod – cladding)
  - Uranium hydrides (fuel pellets)
  - Aluminum hydrides (fuel assembly basket)

Other nations use safer thick-wall metal casks

Safety Features	**Thin-wall canisters**	**Thick-wall casks**
Thick walls	1/2"- 5/8"	**10" to over 19"**
Won't crack, maintainable		√
Ability to repair, replace seals		√
Ability to inspect outside, inside		√
Early warning monitoring, continuous, prevents leaks		√
ASME ***container*** certification		√
Defense in depth (redundancy)		√
Stored in concrete building		√
Gamma & neutron protection	Vented concrete overpack	√
Transportable w/o add'l cask		√
Market leader	**U.S.**	**World**



CASTOR® - Type V/19 cask

Fukushima thick casks stored in building

German thick-wall cask storage over 40 years

NRC ignores regulations, laws and reality

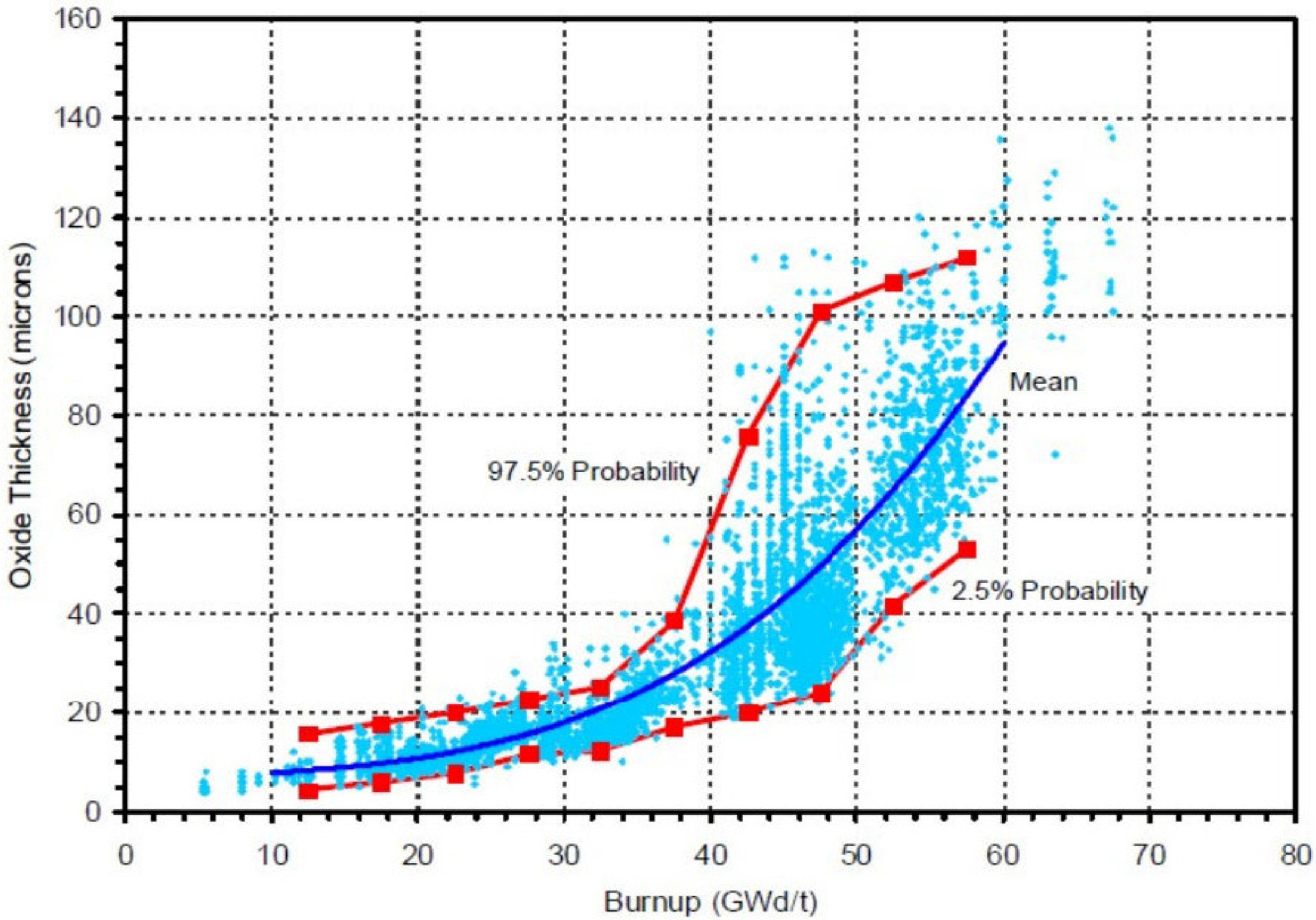
Mark Lombard, NRC Director SFM Division
Donna Gilmore, SanOnofreSafety.org

- NRC transport regulations require intact canisters -- no partial cracks
- Nuclear Waste Policy Act (NWPA) requires monitored retrievable storage.
- NUREG-1927 Rev. 1 requires aging management, but requirements vague and cannot be implemented.
- Aging management issues ignored in canister license.
- Refuses to raise waste storage standards in spite of NRC admission canisters may need to stay on-site indefinitely. (Policy decision by Mark Lombard)
- Allows destruction of empty pools, eliminating the only approved and available method to unload failing canisters or fuel.
- NRC ignores risks of high burnup fuel in storage and transport.

High Burnup Fuel

- **High burnup fuel (HBF) is over twice as radioactive, over twice as hot, and unstable in storage & transport.**
  - Fuel burned longer in the reactor results in Zirconium fuel cladding becoming more brittle. Brittle cladding can shatter like glass. (Zirconium is also used in fireworks).
  - Yucca Mountain was not designed for high burnup fuel.
  - HBF can damage cladding after dry storage, but since canisters are welded shut, we have no idea the condition of the cladding.
  - Japan outlawed aluminum alloy fuel assembly baskets. The U.S. still uses them. If baskets fail, fuel may go critical.
  - NRC approved one HBF transport cask by hiding justification.
  - NRC continues to allow higher and higher burnups in reactors in spite of the evidence of HBF impact on storage and transport.
- **HBF creates more hydrides, increasing explosion risk if fuel is partially exposed to air in pools or dry storage.**
  - Medium burnup fuel also creates hydrides. Higher burnup correlates with more hydrides based on evaluation of HBF rods from reactors.

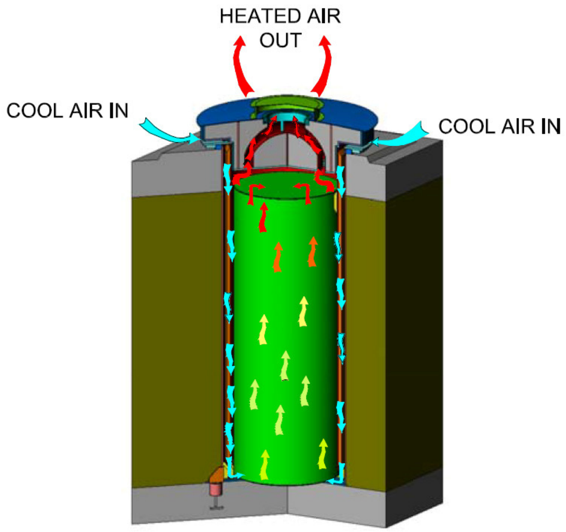
Higher Burnup = Higher Cladding Failure



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

Unproven Holtec UMAX system receives Conditional CA Coastal Permit

- **Fix problems AFTER 20 years -- impossible!**
  - Unproven Holtec UMAX system
  - San Onofre design not NRC approved
  - Cannot inspect, repair, monitor
  - Cannot transport with cracks
  - In ground system even less inspectible
  - Concrete & steel subject to more moisture and corrosion

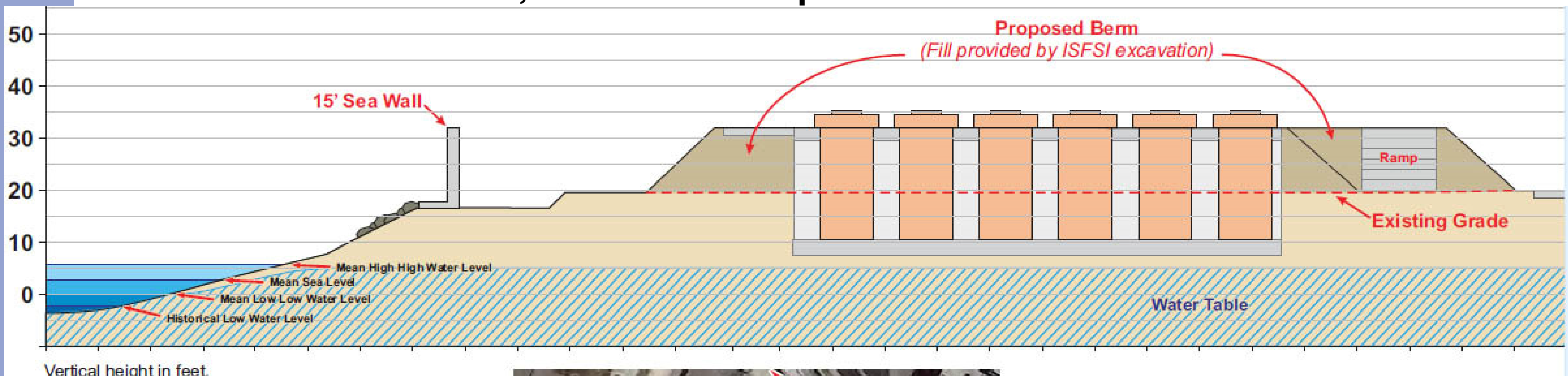


No drain

- **Holtec warranty**
  - 10 years for underground structure
  - 25 years for thin-walled (1/2” to 5/8”) canisters
  - 2 years for existing 51 San Onofre thin-walled canisters

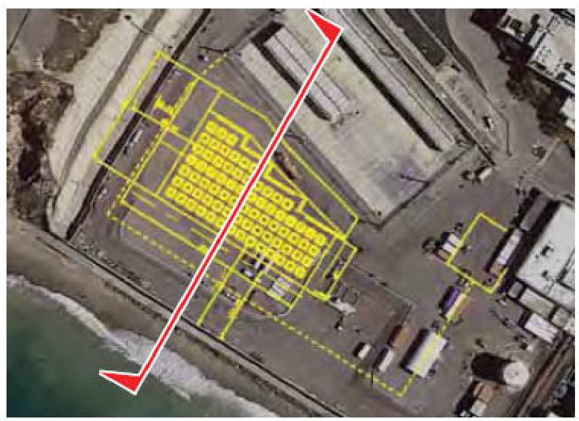
Experimental San Onofre Holtec storage system in highly corrosive environment

Uninspectable system with no drains in holes.
Sea wall not maintained, so no tsunami protection.



73 Holtec cans loading 2018

51 Areva NUHOMS cans loaded above ground, behind Holtec holes (oldest in 2003)



LEGEND

- Concrete
- Low Density Concrete
- Stainless Steel
- Soil
- Soil Backfill
- Water Table

NOTE: Drawn to scale vertically NOT horizontally

When can thin-wall canisters leak?

- Most thin cans installed less than 10 years. A few over 20 years. Oldest are:
  - 1989 (Robinson, H.B., South Carolina)
  - 1990 (Oconee, South Carolina)
  - 1993 (Calvert Cliffs, Maryland)
- U.S. commercial spent fuel canisters and casks loaded as of June 2013 (2 pages, sorted by state, includes first year loaded)
  - *https://sanonofresafety.files.wordpress.com/2015/10/d32-caskinventorybystate2017-05-18.pdf*
- Other reports at SanOnofreSafety.org. For example, damaged fuel assemblies:
  - New York and Illinois take the “prize” for most damaged fuel assemblies. New York =1399, Illinois =1073 as of 6/30/2013

Consolidated Interim Storage?

- New Mexico, Texas and DOE plans are flawed
  - Uses existing inferior canisters. Canisters may already have cracks. These cannot be inspected, repaired or transported.
  - No plan to prevent leaks in storage and transport and no plan if does leak. No pools.
  - Transport infrastructure problems not addressed.
  - New Mexico, Texas and others are being deceived about canister safety
  - Inadequate aging management plan.
  - Unnecessary accident risks in transport and new storage.
  - Legal challenges likely
- Proposed bills eliminate current NWPA requirements for monitored retrievable storage and redirects permanent repository funds.
- Provides false hope to communities with nuclear waste, so they do not focus on advocating for safer storage containers.

Recommendations

- Inform public, media, local, state and federal elected officials and regulators.
- Advocate for safer nuclear waste storage standards.
  - Nuclear waste containers for highly radioactive spent nuclear fuel and for other nuclear waste must be able to be inspected (inside and outside), maintained, repaired and continuously monitored to **prevent** radiation leaks.
  - Don’t destroy empty spent fuel pools until nuclear waste removed from site.
  - Design for longer term storage (e.g., no cracking risks)
  - Include Hardened On-Site Storage safety and security standards.
  - Independent quality control
  - Stop installing thin-wall canister systems and stop making more waste.
  - While on-site, select best temporary location at site (e.g., away from coastal erosion).
  - Replace at risk canisters before they leak.
- Thin-wall canisters will cost more due to short lifespan and risks.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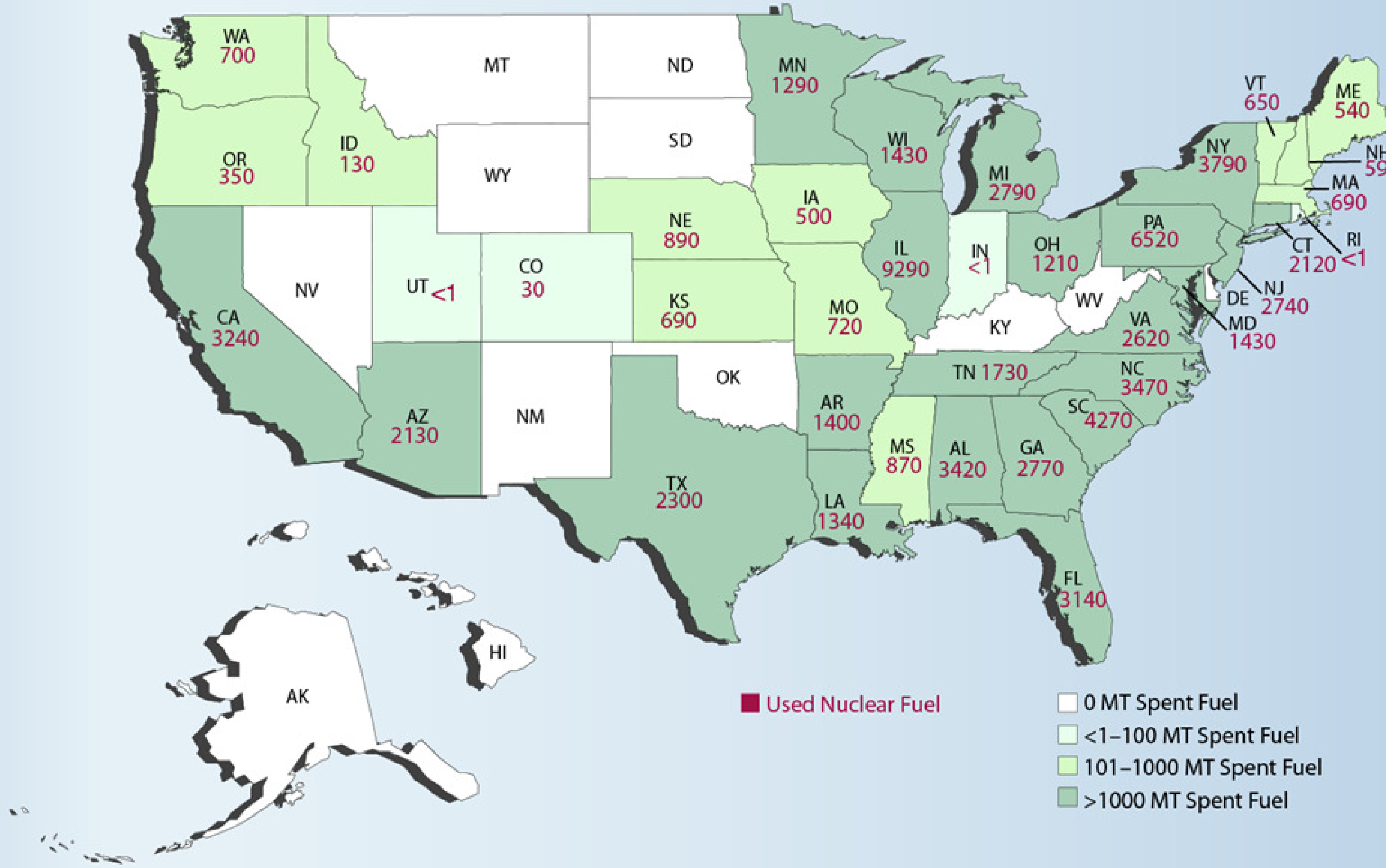
SOS

Additional Background Slides

Used Nuclear Fuel in Storage

(Metric Tons, End of 2013)



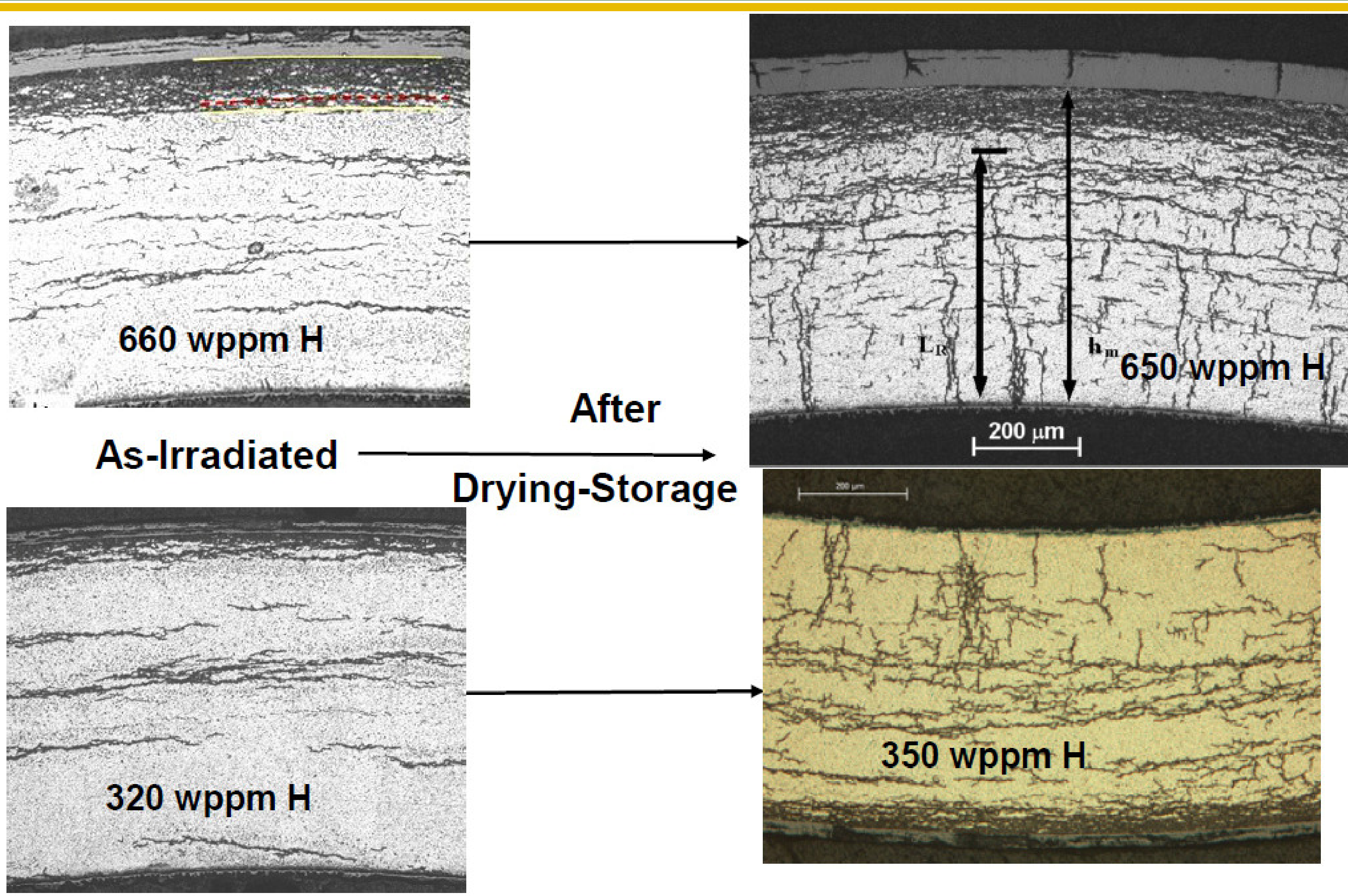
NEI

NUCLEAR ENERGY INSTITUTE

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
- **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
- **State 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**

Introduction: Circumferential and Radial Hydrides in HBU Cladding



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 fuel pools at Humboldt Bay and Rancho Seco**
  - No money allocated for replacement canisters
- **NRC standards revision (NUREG-1927) scheduled for 2015**

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℃ (68℉)
- **Crack growth rate about four times faster** at higher temperatures
  - 80ºC (176℉) in "wicking" tests compared with 50℃ (122℉)
- **Crack initiation unpredictable**
  - Cracks more likely to occur at higher end of temperature range up to 80℃ (176℉) instead of ambient temperatures
  - Canister temperatures above 85℃ 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**

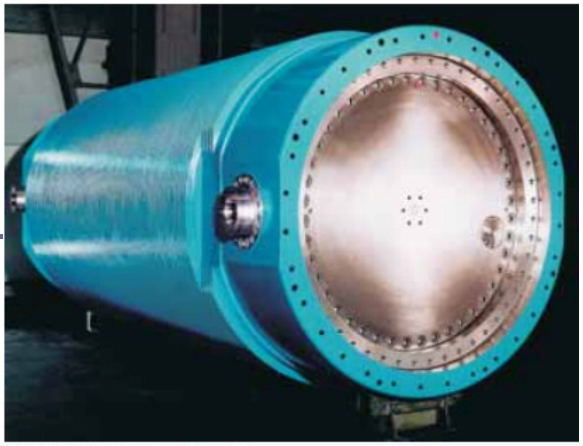
Can't repair canisters and No plan to replace them

- "**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**

The TN®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
TN 24 G	37 PWR	42 000	10	3.81	CH
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
TN 52 L	52 BWR	55 000	mini 2.5	4.95	CH
TN 24 SWR	61 BWR	70 000	mini 5.5	5.0	G
TN 68	68 BWR	45 000	7	4.4	US
TN 97 L	97 BWR	35 000	10	4.0	CH
TN 24 BH	69 BWR	50 000	6	5.0	CH
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

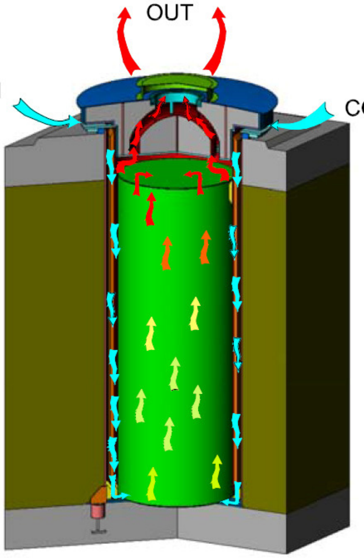
Thick casks designed for longer storage



CASTOR® - Type V/19 cask

- **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**
  - **40 years in service with insignificant material aging.**
  - **Option for permanent storage with added welded lid.**
- **Not currently licensed in U.S. (18 to 30 month process)**
- **Vendors won't request NRC license unless they have customer**
- **Thick cask body** – forged steel or thick ductile cast iron up to 20"
- **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 & international cask certifications for storage and transport**
- **Damage fuel sealed (in ductile cast iron casks)**

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)]

No warning before radiation leaks from thin canisters

- **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
- **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)
    - **Humboldt Bay & Rancho Seco pools destroyed**

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
- Reasons to buy thick nuclear waste dry storage casks and myths about nuclear waste storage, April 16, 2015, D. Gilmore
  https://sanonofresafety.files.wordpress.com/2011/11/reasonstobuythickcasks2015-04-16.pdf
- Donna Gilmore's CPUC Pre-Hearing Conference Statement (A1412007), March 20, 2015
  http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M148/K824/148824935.PDF
- Additional references: **SanOnofreSafety.org**

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 1 OCFR7 1 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℃ and -49℃** 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.

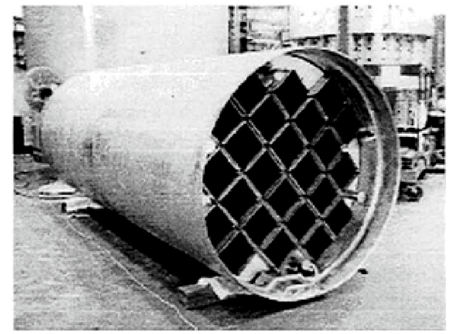
Thin canisters not designed to be replaced

- 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

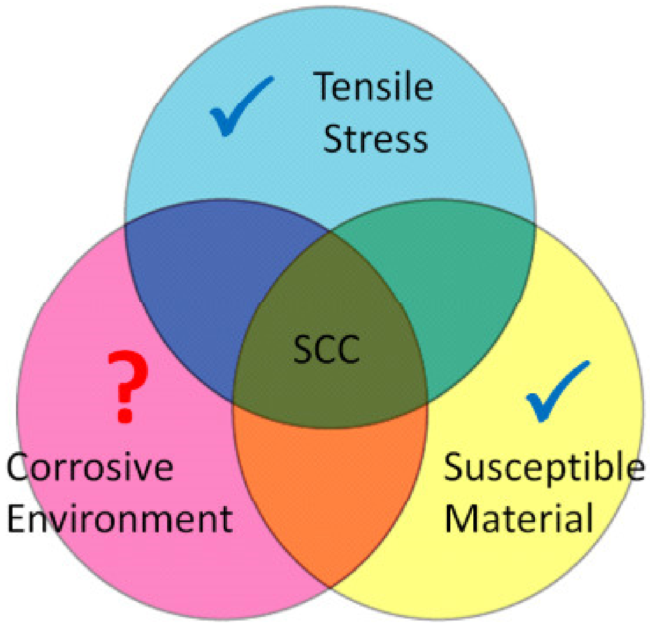
- **No protection** from gamma or neutron radiation in thin canister
  - **Unsealed** concrete overpack/cask required for gamma & neutrons
  - **No other type of radiation protection if thin canister leaks**
  - Thick steel overpack transfer cask required to transfer from pool
  - Thick steel overpack 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

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

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	9.3×10^{-12} to 2.9×10^{-11}	0.29 to 0.91
Ohi	200	Wakasa Bay, Sea of Japan	304L/RWST	1.5 to 7.5	30	5.5×10^{-12} to 7.9×10^{-12}	0.17 to 0.25
St Lucie	800	Atlantic	304/RWST pipe	6.2	16	1.2×10^{-11}	0.39
Turkey Point	400	Biscayne Bay, Atlantic	304/pipe	3.7	33	3.6×10^{-12}	0.11
San Onofre	150	Pacific Ocean	304/pipe	3.4 to 6.2	25	4.3×10^{-12} to 7.8×10^{-12}	0.14 to 0.25

- CISCC growth rates of 0.11 to 0.91 mm/yr for components in service
  - Median rate of 9.6×10^{-12} m/s (0.30 mm/yr) reported by Kosaki (2008)
- Activation energy for CISCC 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

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[1]
  - 2015 Transnuclear-NUHOMS 1004
  - 2020 NAC-UMS; Holtec-Hi-STORM
- Storage of high burn-up fuel is relatively recent
  - 9 years – Maine Yankee[2] (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

NEI

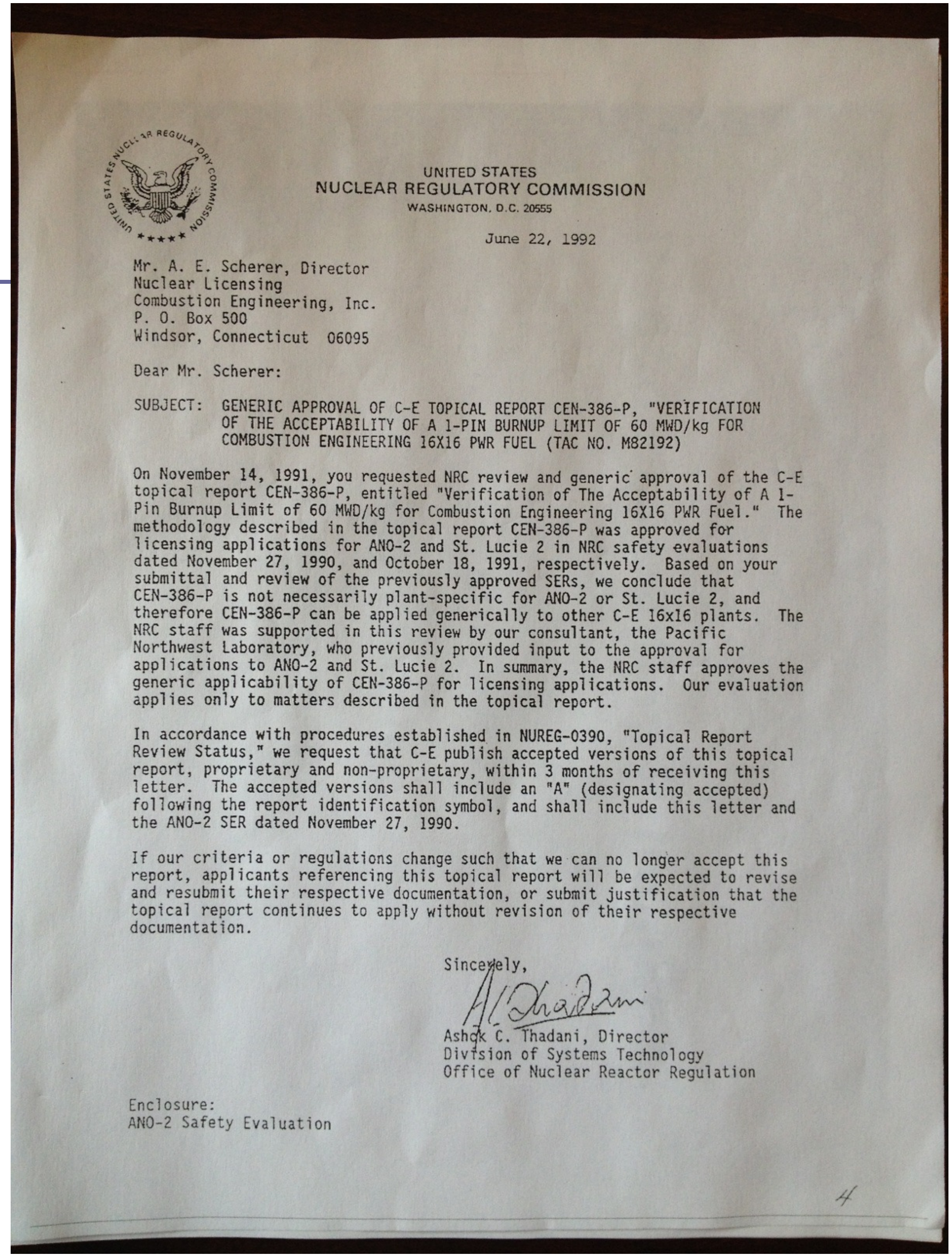
1) Since 1992, allowable burn-up to 47 GWd/MTU, since 2010, up to 52 GWd/MTU
2) All high burn-up fuel is in damaged fuel cans

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 C Thadani

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

Enclosure:
ANO-2 Safety Evaluation

4

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

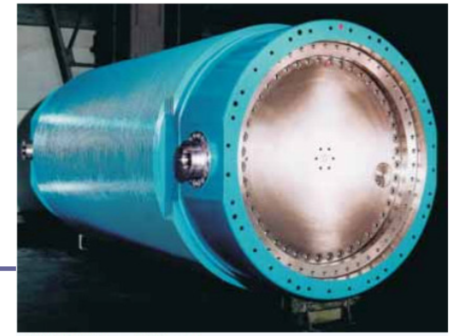
Recommendations to NRC

CASTOR® - Type V/19 cask

- **Require best technology used internationally**
- **Base standards on longer term storage and transport 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**
- **Transfer fuel from thin-wall canisters – may require on-site "hot cell"**
- **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 (inside and out), repairable** and **don't crack**
  - **Cost-effective for 100 year storage, transportable**
  - **Ability to reload fuel without destroying container**
- **Don't allow purchase of vendor promises (vaporware)**
- **Require bids from leading international vendors**
- **Replace existing thin canisters before they fail – likely requires an on-site "hot cell" (dry fuel handling facility).**
- **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**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SOS