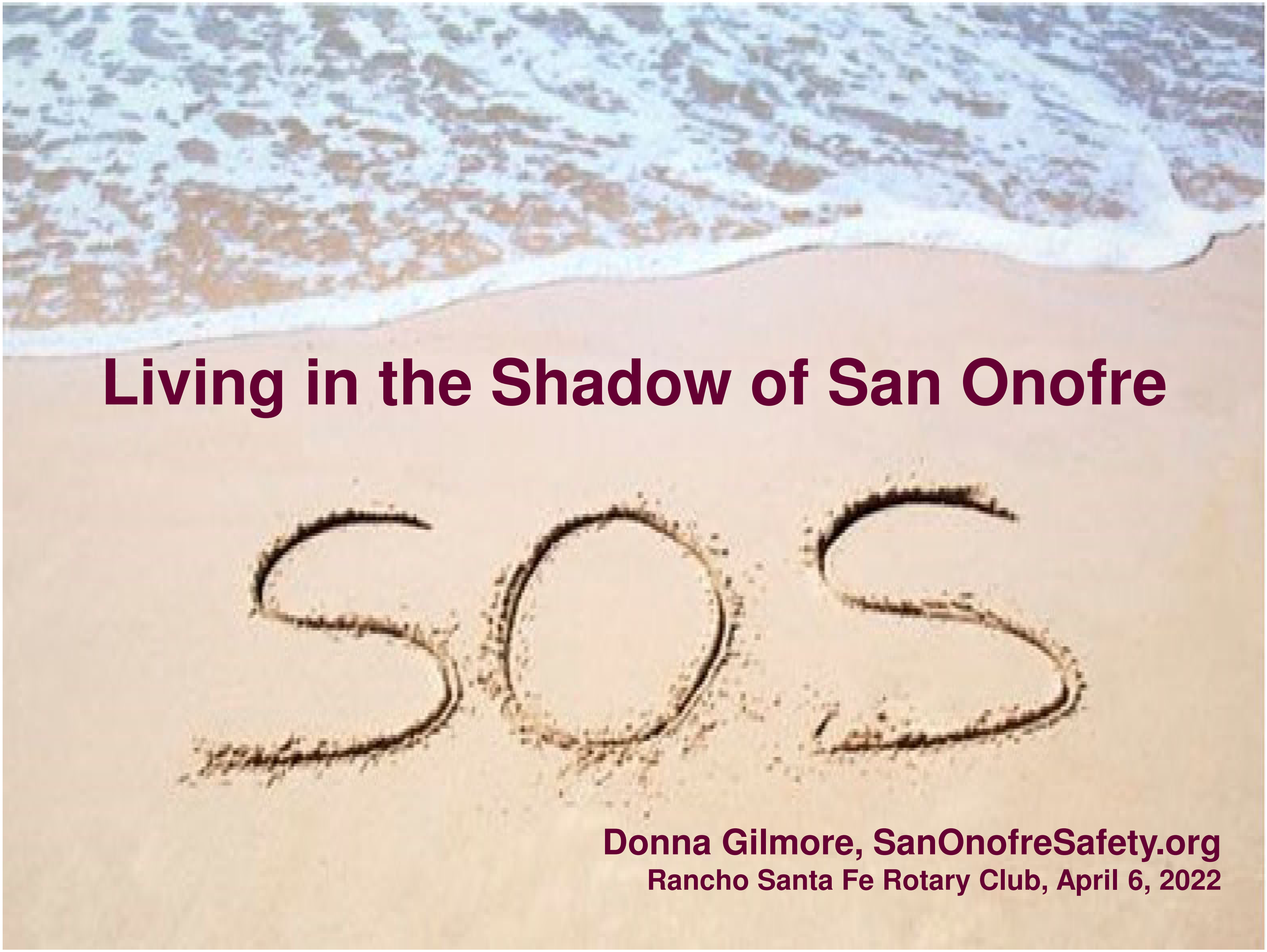
Living in the Shadow of San Onofre



Donna Gilmore, SanOnofreSafety.org

Rancho Santa Fe Rotary Club, April 6, 2022

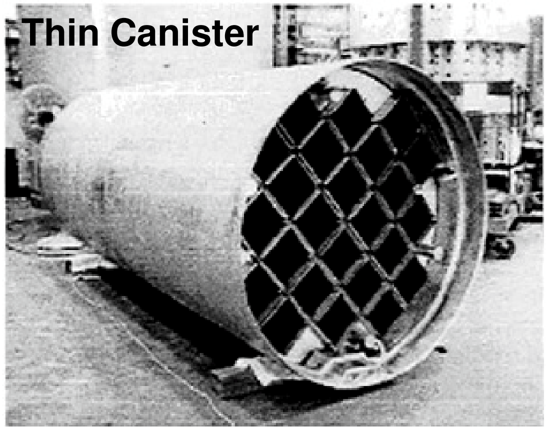
U.S. Nuclear Waste Technical Review Board recommendations to Congress & Energy Secretary for short-term & long-term storage of highly radioactive nuclear fuel waste.

- **Spent nuclear fuel and it's 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*
- **There is 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)*

This critical information is being ignore in the USA

Only thick-wall casks can meet safety requirements

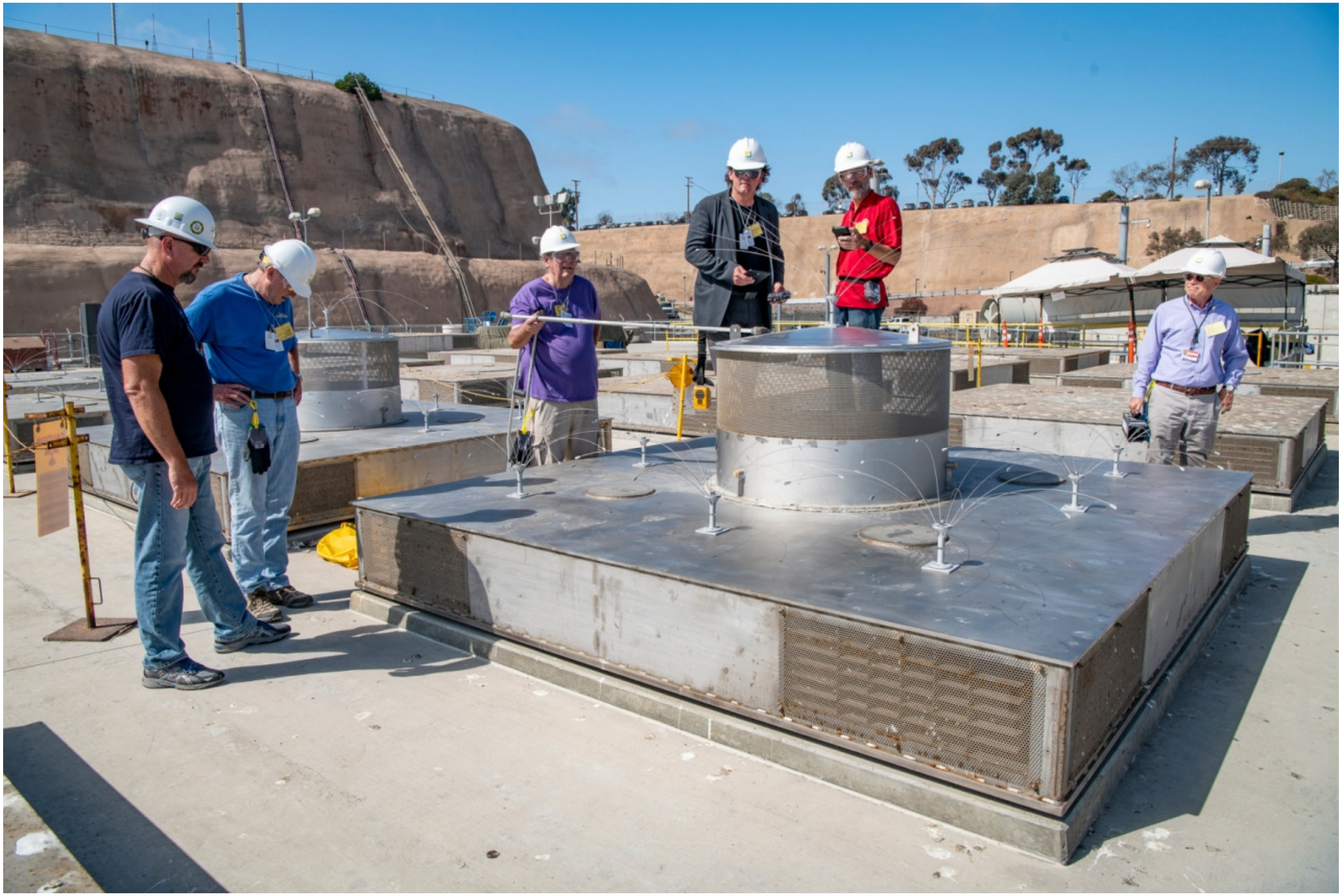
Safety Features	Thin canisters	Thick casks
Wall thickness	1/2"- 5/8"	10"- 19.50"
Won't crack		√
Ability to repair, replace seals		√
Ability to inspect (inside & out)		√
Monitor to **prevent** disaster		√
ASME N3 storage & transport		√
Defense in depth (redundancy)		√
Store in concrete building		√
Gamma/neutron protection	With concrete vented overpack	√
Transportable	Unsafe without inspection	√
Market leader	**U.S.**	**World**



CASTOR® - Type V/19 cask

Each thin canister holds roughly a Chernobyl disaster
124 San Onofre canisters (51 Areva + 73 Holtec)

Waste not buried -- Huge air vents in Holtec lids covering the 73 holes where thin-canisters are unsafely stored



51 Areva NUHOMS thin-wall canisters in vented concrete above-ground system

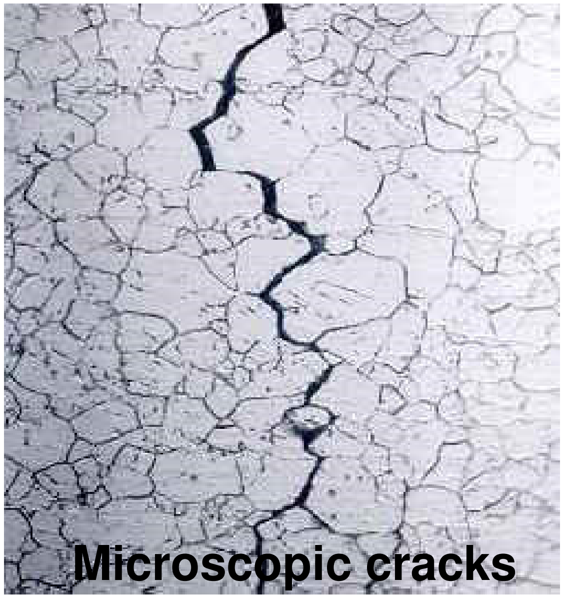
Huge Areva inlet air cooling vents

Huge Areva outlet air cooling vents on roof

Through-wall canister cracks can occur 16 years after cracks initiate (NRC 8/5/2014)

NRC solution: Stop measuring radiation levels at outlet air vents.

	Loaded	Age as of 2022
Calvert Cliffs	1993	29 years
Rancho Seco	2001	21 years
Oyster Creek	2002	20 years
San Onofre	**2003**	**19 years**
Indian Point	2008	14 years
Diablo Canyon	2009	13 years

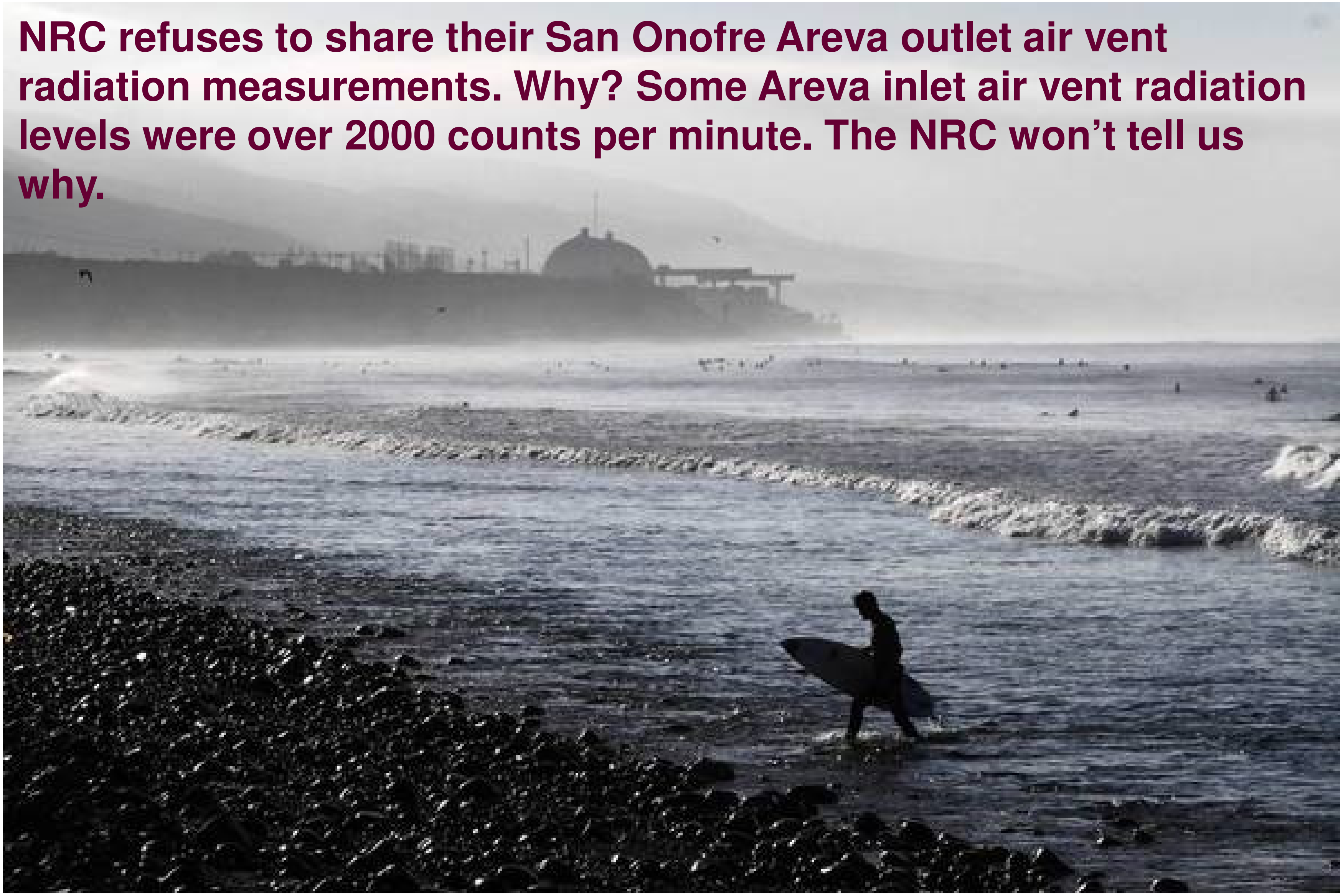


- Most U.S. thin canisters in use less than 17 years

2-page Commercial Canister/Cask DOE inventory, 6/30/2013 [DOE has not updated inventory]
https://sanonofresafety.files.wordpress.com/2018/07/d32-caskinventorybystate2018-07-14a.pdf

NRC & EPRI: Not enough humidity at San Onofre for canister corrosion. Ignore frequent fog, surf, wind

NRC refuses to share their San Onofre Areva outlet air vent radiation measurements. Why? Some Areva inlet air vent radiation levels were over 2000 counts per minute. The NRC won’t tell us why.



Holtec President Kris Singh admits cannot repair canisters

- "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; we think it's not a path forward."
- 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

Two-year old Diablo Canyon Holtec canister has all the *conditions* to start cracking

- NRC thought it would take 30 years for cracks to start
  - Temperature low enough on surface to dissolve sea salt and initiate cracking (<85℃ (185℉). One of many triggers for cracking of thin-wall canisters.
- NRC, SCE & PG&E solution: Hide information

Demand ASME N3 certification

American Standards of Mechanical Engineers **ASME N3 certification** for nuclear pressure vessels for **both** storage and transportation containments of spent nuclear fuel and other high level nuclear waste.

N3

- **Other countries meet ASME N3 (thick-wall metal casks)**
  - Switzerland, Germany, Belgium Czech Republic, France, Italy & others.
- **NRC exemptions result in thin-wall canisters that cannot be inspected or maintained to ensure safe short-term or long-term dry storage and transport**
  - **Cannot inspect inside or out for cracks & other major defects**
  - **Cannot repair or maintain to prevent cracks**
  - **Cannot monitor adequately to PREVENT short-term failure (e.g., no pressure monitoring or pressure relieve valves)**
  - **Not safe against earthquakes (unknown cracks inside & outside)**
  - **No backup plan in place to stop or prevent major radioactive releases**

Why demand the ASME mark. https://www.asme.org/certification-accreditation/why-demand-the-mark

Fukushima thick-wall casks survived 2011 earthquake and tsunami

Swiss Solution for Thick Cask Storage

https://www.zwilag.ch/en/cask-storage-hall-_content---1--1054.html

German interim storage over 40 years

DOE Technology Gap Report Priority #1 risk: SHORT-TERM through wall cracks in thin-wall welded canisters (2019 Sandia Lab)

Microscopic cracks

- **Gap Priority 1: Welded canisters – Atmospheric Corrosion, short-term risks of through-wall cracks**
  - Focus only on chloride induced stress corrosion cracking.
  - [Report ignores earthquake risks with partially cracked canisters and ignores option of replacing canisters with thick-wall casks.]
- **Gap added: Consequence Assessment of Canister Failure poorly understood and of primary importance.**
- **Raised Priority: Fuel Transfer Options -- fuel should be able to be transferred without returning to the pool for inspection and transfer.**
  - Recent work on the Thermal Profile and Stress Profile gaps indicate that the fuel should be able to be transferred without returning to the pool for inspection and transfer. This priority has been raised recognizing the need for data to support a surface facility design concept for opening a cask for inspection or repackaging…
  - [Report recognizes need for dry handling ("hot cell") facility at interim storage sites, but does not address need to replace canisters at existing sites prior to transport or failure.]

Gap Analysis to Guide DOE R&D in Supporting Extended Storage and Transportation of Spent Nuclear Fuel: An FY2019 Assessment SAND2019-15479R, December 23, 2019 https://www.osti.gov/servlets/purl/1592862/

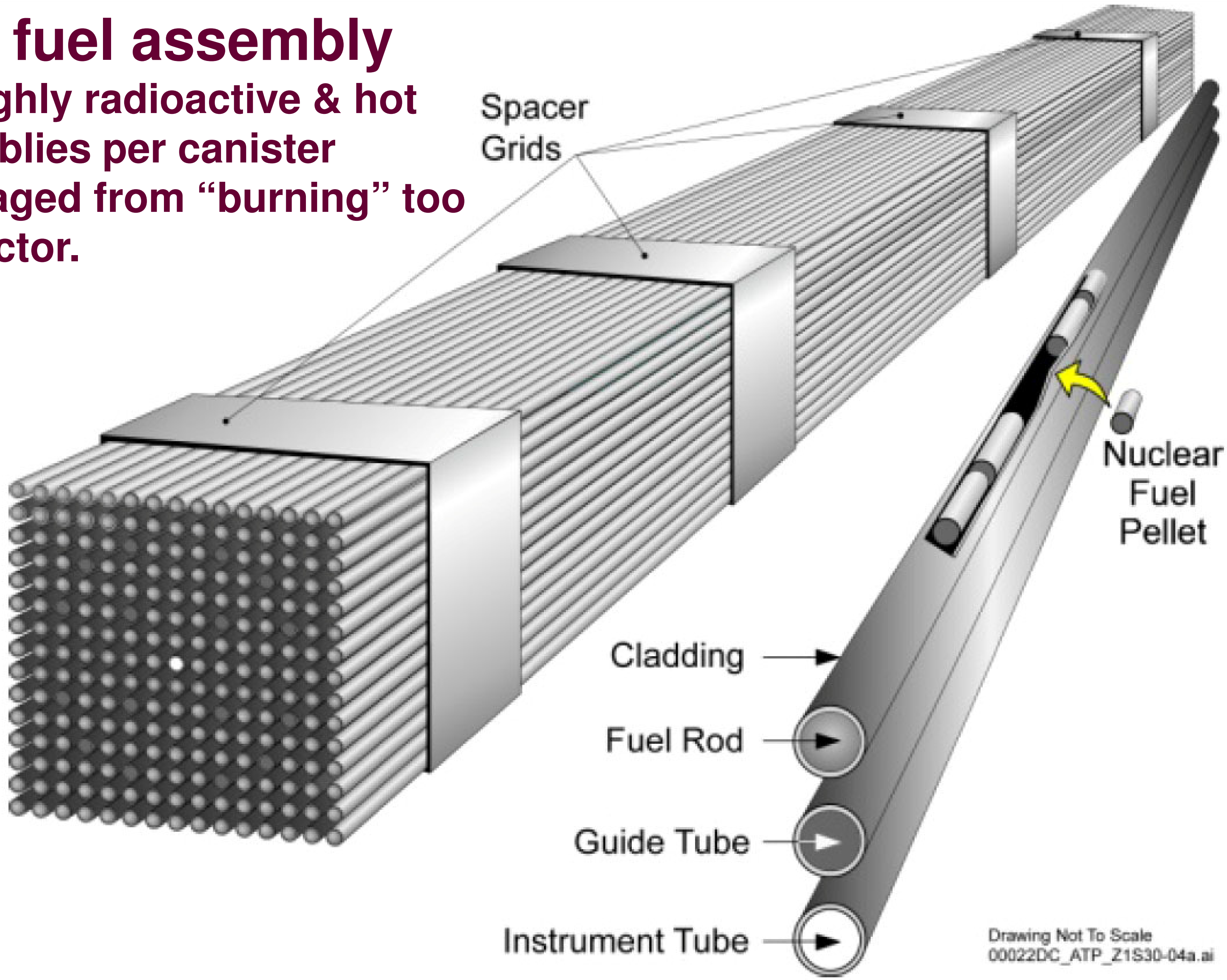
Hydrogen explosion & criticality risks

- Canisters filled with **helium** to prevent explosions.
- **Air** in canisters can trigger hydrogen explosions from damaged fuel
  - Uranium/zirconium hydrides in small particles/gas
- **Irradiation of water** in canisters creates hydrogen gas. Unknown amount of water in canisters after drying.
- Canisters may over pressurize, but have **no pressure monitor or pressure relief valve**.
- **Criticality (meltdown) if water enters canisters** through cracks (NRC, Holtec).
  - Boron in canisters credited only for loading from pool to dry storage.

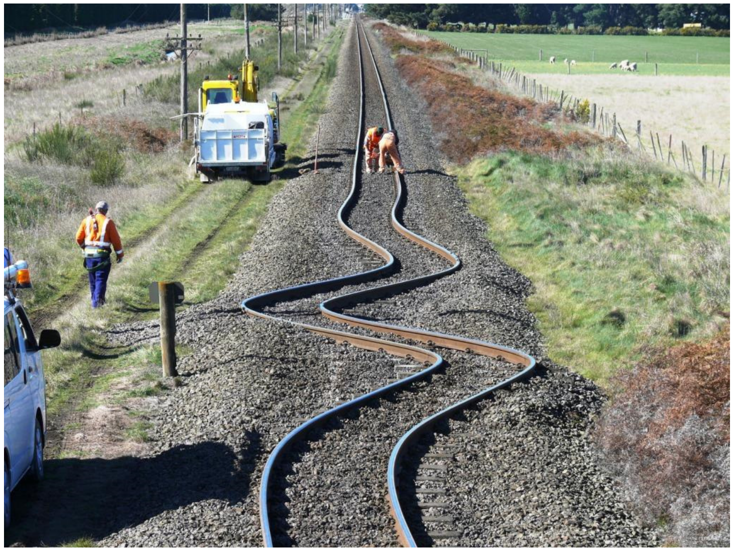
References: NRC NUREG-2224 Comments, D.Gilmore
https://www.nrc.gov/docs/ML1826/ML18269A037.pdf

Nuclear fuel assembly

24 or 37 highly radioactive & hot fuel assemblies per canister
Many damaged from "burning" too long in reactor.



Transport
not a straight path forward



- **Cannot inspect canisters or contents to ensure integrity**
  - ***NRC RAI 2-1****: …MPCs [thin-wall canisters], with degraded conditions exceeding* ***surface defects equal to or greater than 2mm depth, will be identified prior to transport.*** *10 CFR 71.71 and 71.73*
  - ***NRC RAI 7-1*** *..****confirm*** *..****analyzed configuration of stored high burnup fuel [HBF] has been maintained throughout the renewed storage period of the MPC prior to transport****. 10 CFR 71.55(e), 71.73 & 71.85(a)*

  Response to 2nd Request for Additional Information, Holtec International, Docket No. 71-9373 HI-STAR 190 Transportation Package 2/26/2017 (ML17031A363)
- **Train vibrations may cause fuel rods or canister failure.**
- **CIS plans: return leaking canisters to sender**
  - Sender or receiver have no method to handle leaking canisters.
  - Limit to how long leaking canister can stay inside sealed transport cask before overheating.
- **Canisters need decades of cooling before transport.**

Real agenda of various legislation promising to move waste: Eliminate nuclear industry liability

- **Feinstein legislation: allows title transfer of waste to federal government at existing sites.**
- **Legislation also:**
  - **Removes mandatory funding:** we'll be at mercy of Congress to adequately fund waste management.
  - **Removes critical storage and transport safety requires**
  - **Removes site specific analysis for storage sites**
  - **Removes other federal, state, local, public rights to oversight, input, transparency and rights over land use, utilities, such as water rights.**
  - **Removes funding & cost analysis for storage & transport**
  - **Removes transport infrastructure safety requirements.**

None of these issues discussed in House hearings!

Roadblocks to moving waste

- **Yucca Mountain & other 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: no legal authority over radiation safety (only cost & permits**
- **Major transport infrastructure issues, accident risks, cracking canisters, fragile fuel rods, funding**
- **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.
- **Inspection of damaged fuel assemblies is inadequate**

This is a NOW problem

- **No plan in place when something goes wrong**.
- **Proposed solution to store breached canister in sealed thick metal overpack is not an option. Fuel will likely overheat** due to loss of air cooling. And no way to do this even temporarily, since no warning system.
- **Need dry transfer system (hot cell) facility to replace canisters with ASME N3 certified thick-wall metal casks.**
  - **No hot cell** in the U.S. large enough or designed for this.
  - **Spent fuel pools not a real option**. Sites either have **no spent fuel pools or fuel is too hot to return to pools**. No welded thin-wall canisters ever unloaded in pools. Edison CNO's admit cannot unload fuel back into pools.
- **Once cracks start in canisters, cracks can grow though the wall in only 16 years.** NRC 8/5/2014.
- **U.S. thin-wall canisters are already up to 33 years old (1989).**

U.S. Canisters and Casks Inventory DOE June 2013
https://sanonofresafety.files.wordpress.com/2018/07/d32-caskinventorybystate2018-07-14a.pdf

D. Gilmore Comments to NUREG-2224 High Burnup Fuel Storage and Transport, 2018
https://www.nrc.gov/docs/ML1826/ML18269A037.pdf

Recommendations

- ## Step One
  - **Require thick-wall maintainable, transportable storage casks before thin-wall canisters fail (which maybe soon).** Swiss use high standard casks
    - Orano/Areva TN24GB & TN24BHL/BH
    - Castor V/19 & V/52
    - https://sanonofresafety.org/swiss/
  - **Require ASME N3 Nuclear Pressure Vessel certification for storage and transport** containment of spent nuclear fuel and high level radioactive waste.
  - **Require "hot cell" dry fuel handling system** at waste storage sites.
  - **Stop decommissioning fund disbursements and thin-wall canister approvals.** Thick-wall casks are less expensive considering maintainability, life span, and reduced risks of nuclear disasters that can cause evacuations, radioactive contamination, and economic and security instability.
- ## Step Two (Must do Step One before Step Two)

Store thick-wall casks in air cooled buildings for environmental and security protection, **away from coastal and flood risks.**

Transporting uninspectable cracking canisters with fragile fuel rods across the country will no more solve our nuclear waste problems than rearranging the deck chairs on the Titanic would have stopped it from sinking.

Titanic sinking. Willy Stöwer, 1912, via Wikimedia Commons

Additional slides available below

EPRI cherry picked data to reach false conclusions about canister lifespan

EPRI falsely claimed it would be 80+ years before cracks can grow through canister walls.

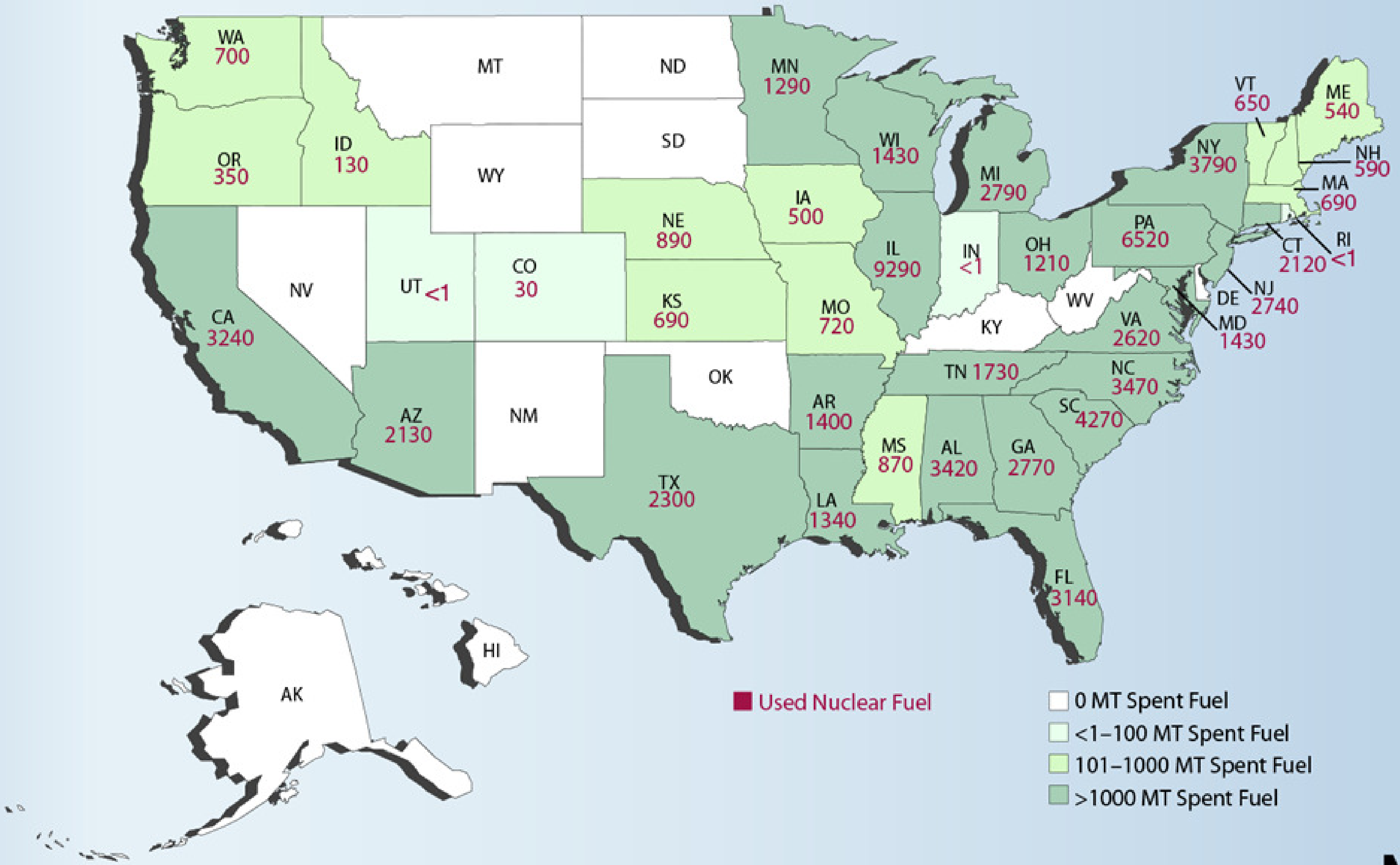
- **Ignored crack initiating coastal conditions**
  - Claimed insufficient moisture at San Onofre and Diablo Canyon to dissolve salt particles, in spite of frequent fog and on-shore coastal winds along Pacific Coast.
- **Ignored low enough temperature on 2-year old Diablo Canyon canister for moisture to stay on surface and dissolve salts.**
  - EPRI found corrosive salts on canisters. No way to know cracking condition of canisters.
- **Ignored South Africa Koeberg tank that leaked in only 17 years**
  - Koeberg cracks up to **0.60"** long. Most thin-wall canister only **0.50" to 0.65**" thick.
  - Koeberg tank is comparable component to thin-wall canisters NRC 8/5/2014
- **Used assumptive words over 254 times in EPRI report**
  - Assume (69), expected (38), uncertainty (10), estimate (18), general (11), model (101), approximat (7)

Critique of EPRI Flaw Growth and Flaw Tolerance Assessment for Dry Cask Storage Canisters, D. Gilmore, 5/17/2015
https://sanonofresafety.files.wordpress.com/2013/06/epri-critiqueandkoebergplant2015-05-17.pdf

Flaw Growth and Flaw Tolerance Assessment for Dry Cask Storage Canisters. EPRI 3002002785, 10/14/2014
https://www.epri.com/research/products/000000003002002785

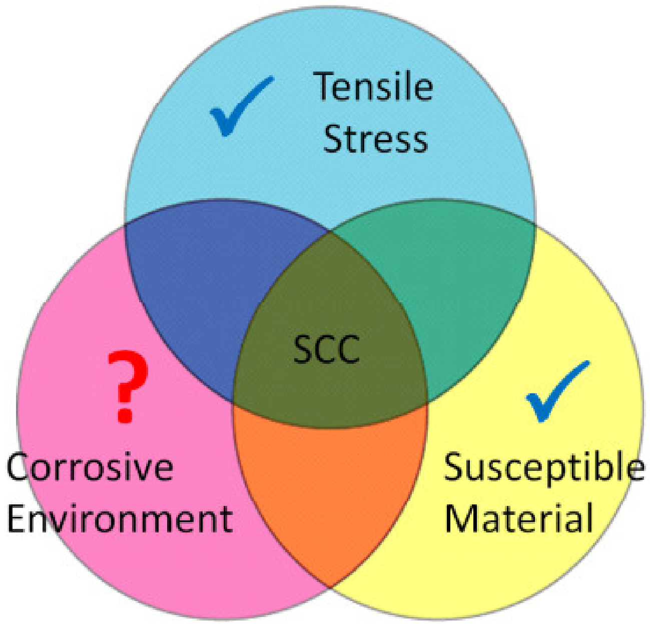
Used Nuclear Fuel in Storage

(Metric Tons, End of 2013)



NEI
NUCLEAR ENERGY INSTITUTE

Stress Corrosion Cracking Background Information



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

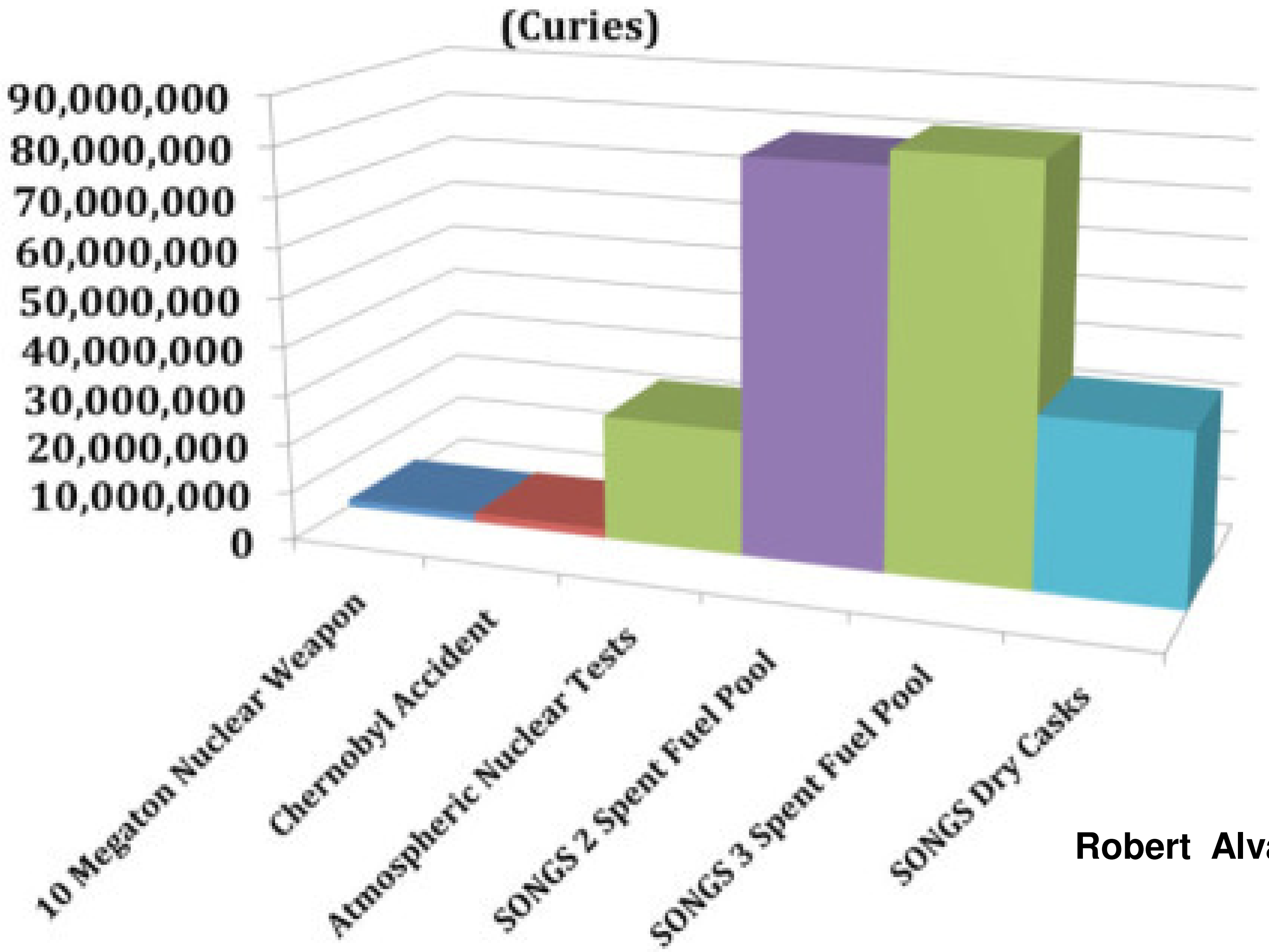
- 304 and 316 Stainless steels are susceptible to chloride stress corrosion cracking (SCC)
  - Sensitization from welding increases susceptibility
  - Crevice and pitting corrosion can be precursors to SCC
  - SCC possible with low surface chloride concentrations
- Welded stainless steel canisters have 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

Cannot find or characterize cracks with cameras – only can see **some** precursors

- **Gouges in canister walls.** Crack growth unknown.
- **Impossible to examine & eliminate surface defects per ASME code, NRC Senior Inspector Lee Brookhart.**
  - *The original [Holtec] FSAR statement for no scratches mirrored the CoC/TS design basis that **no scratches would ensure the code adherence to ASME Section III.** Essentially, the change is adding an alternative to the code to **not have to do inspections and repair these new defects**. Alternatives to the code can only be done via license amendment*. [**NRC allowed continued loading without license amendment**]
  - ***ASME Section III NB-2538,** "Elimination of Surface Defects" requires that **defects are required to be examined by either magnetic particle or liquid penetrant method to ensure that the defect has been removed or reduced to an imperfection of acceptable size.“***
  - ***Instead of doing that (which I understand is impossible) which would maintain code compliance,** the 72.48 deviates using a calculational method to bound the defect. **The only "method" that should be used to disposition these defects is some method allowed or described in the BPVC code** or the licensee would need an alternative to the code to maintain compliance with the regulatory licensing basis*.

NRC R*esponse to NRC question on ASME Code Application, 3/25/2019*
https://sanonofresafety.files.wordpress.com/2019/10/ml19261a089foia-p180-186asme-non-comphilite.pdf

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

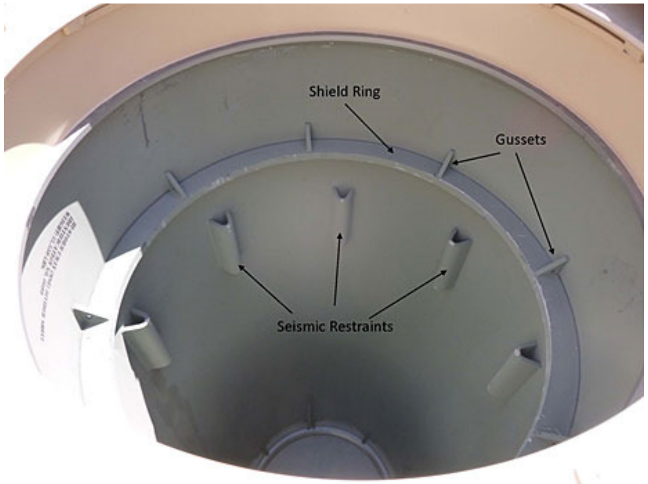


Robert Alvarez

Swiss Zwilag Hot Cell (Dry Transfer System) Inspect or transfer fuel to new cask

https://www.zwilag.ch/en/hot-cell-_content---1--1056.html

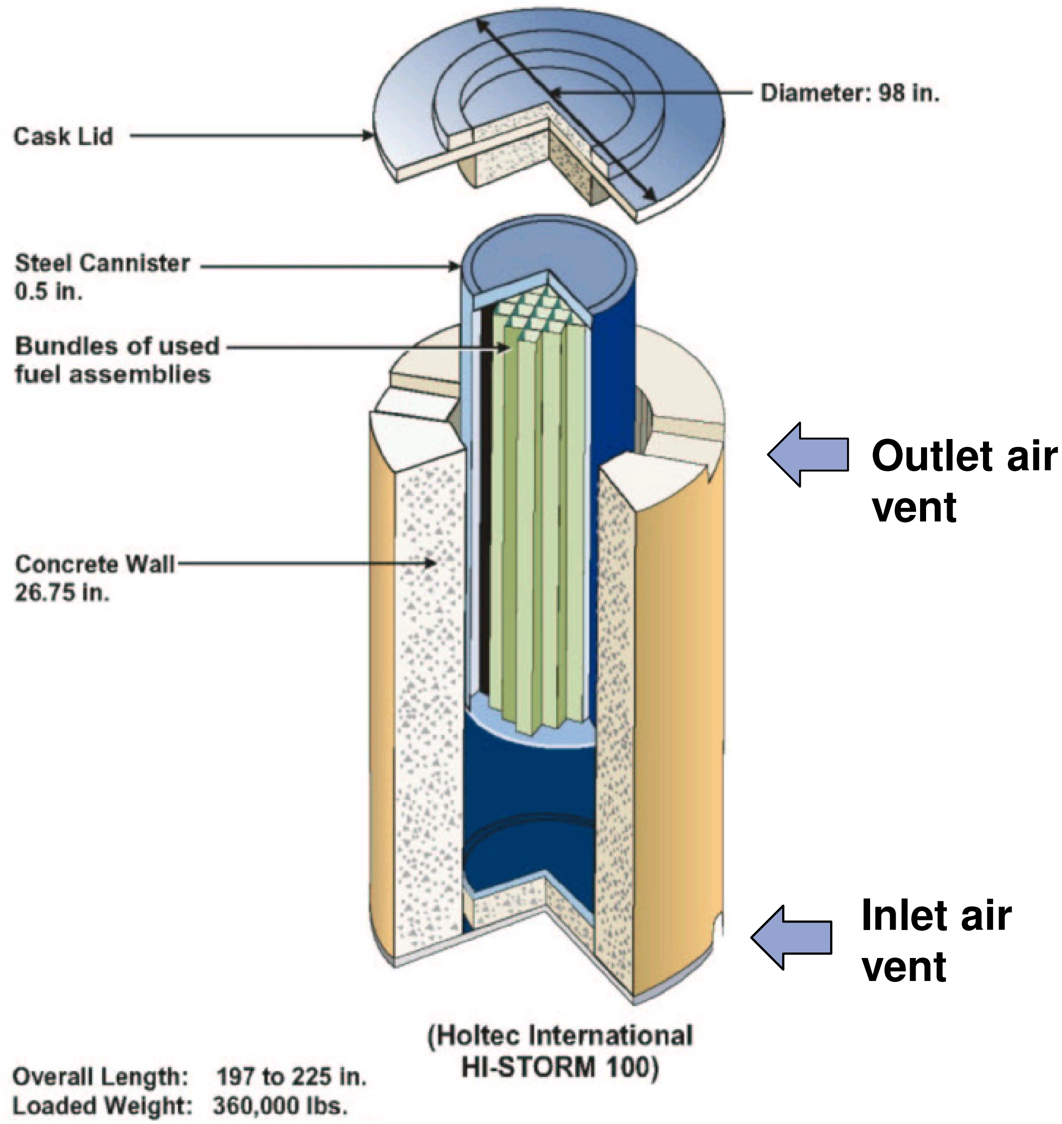
Holtec canisters damaged due to inferior engineering design



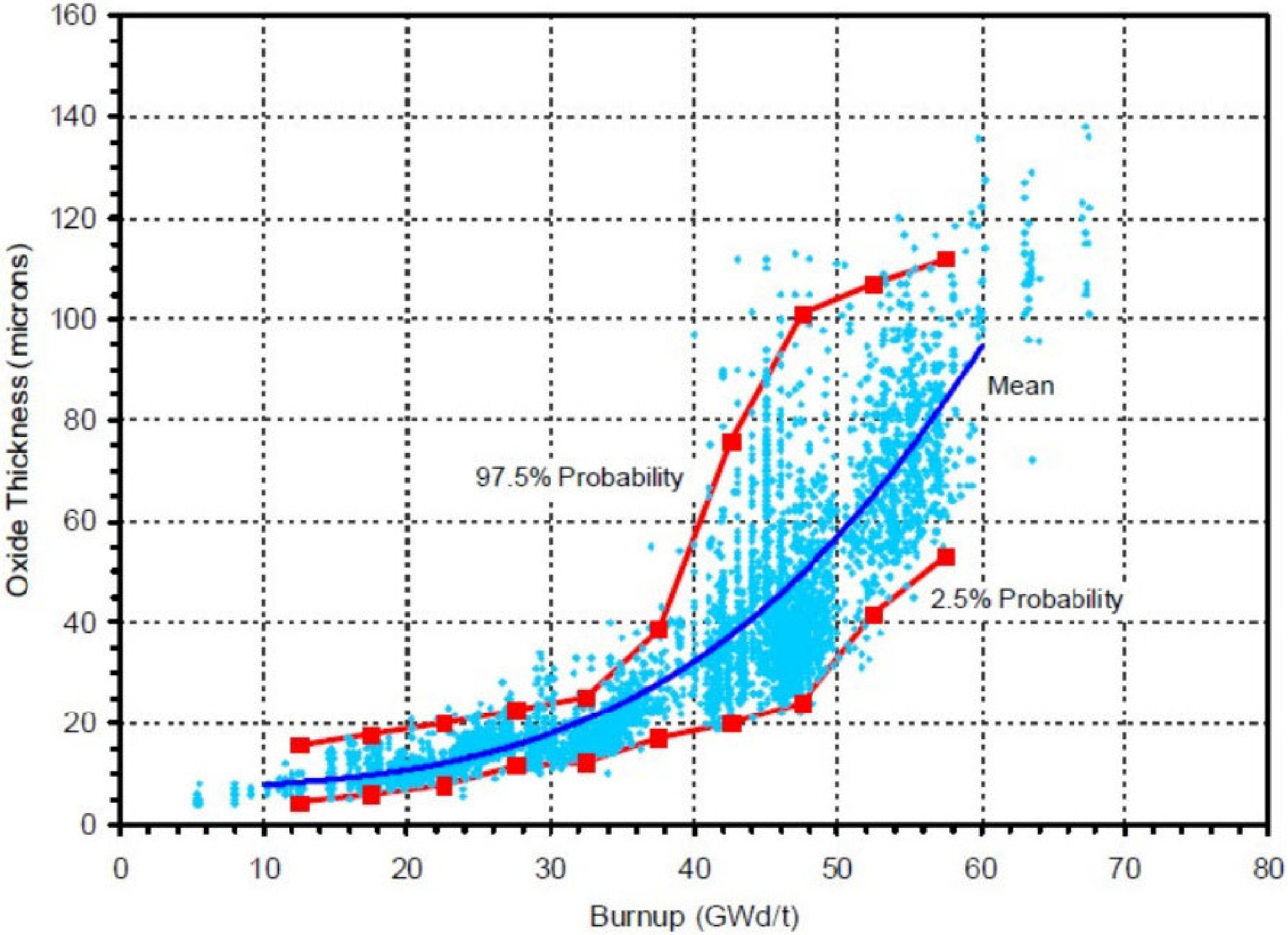
- **Both Holtec HI-STORM UMAX and above ground Holtec systems unavoidably damage canisters during downloading into carbon steel lined concrete casks and storage holes.**
  - Stainless steel canister walls are **scraped, scratched or gouged** against carbon steel protrusions inside storage casks and storage holes.
  - **Carbon particles** are embedded in canisters during downloading process from carbon steel protrusions in UMAX system and from vertical channels in above ground systems. No evaluation by NRC.
  - These are triggers for stress corrosion **cracking** and **shortened lifespan**.
- **Problem due to poorly engineered Tarzan-like swinging downloading system combined with narrow clearances.**
  - Cannot be corrected with procedures. Cannot view canister hole when downloading. Clearances too tight and lack of precision loading system.
  - Holtec and NRC have no solutions, but continue use of these systems.
  - Similar or worse damage will likely happen when unloading (and reloading).

NRC not evaluating most thin-wall stainless steel canister cracking risks

- **Triggers for cracking** (partial list)
  - Chlorides (moist salt air, potash, other chlorides)
  - Carbon particles
  - Gouges, scrapes, scratches
  - Poor engineering of canister downloading causing scrapes, gouges & scratches in canister walls.(e.g., Holtec subterranean & above ground systems)
  - Manufacturing defects
  - Pitting
  - Mishandling
  - Bird poop

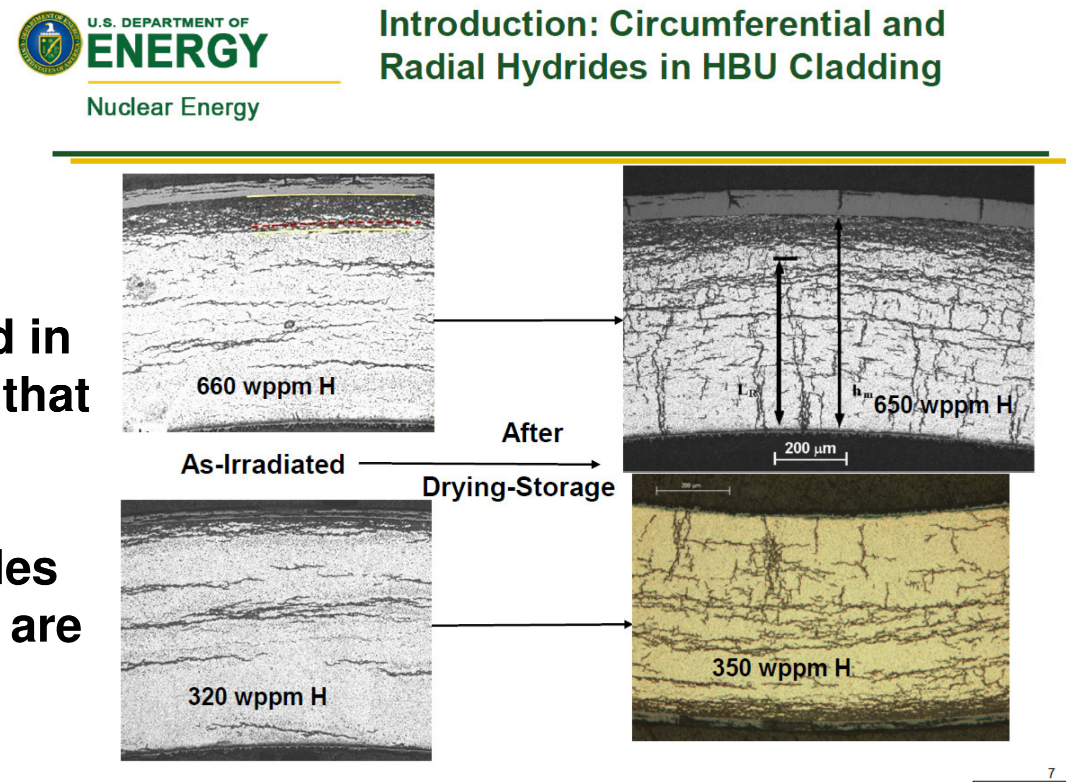


Hydrogen explosion risk increases at medium burnup



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

Significant high burnup fuel cladding embrittlement in dry storage



M.C. Billone, T.A. Burtseva, and Y. Yan, Argonne National Laboratory September 28, 2012

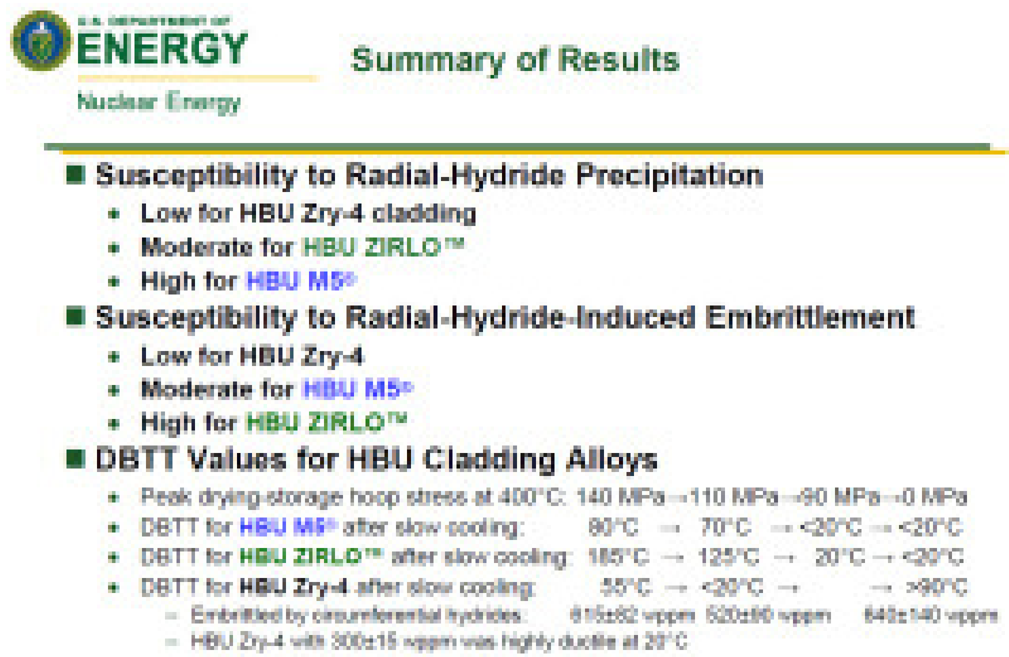
"…the trend of the data generated in the current work clearly indicates that failure criteria for high-burnup cladding need to include the embrittling effects of radial-hydrides for drying-storage conditions that are likely to result in significant radial-hydride precipitation…

A strong correlation was found between the extent of radial hydride formation across the cladding wall and the extent of wall cracking during RCT [ring-compression test] loading."

[Ductile-to-Brittle Transition Temperature for High-Burnup Zircaloy-4 and ZIRLO™ Cladding Alloys Exposed to Simulated Drying-Storage Conditions] http://pbadupws.nrc.gov/docs/ML1218/ML12181A238.pdf

HBF: Unknown failure limits following storage

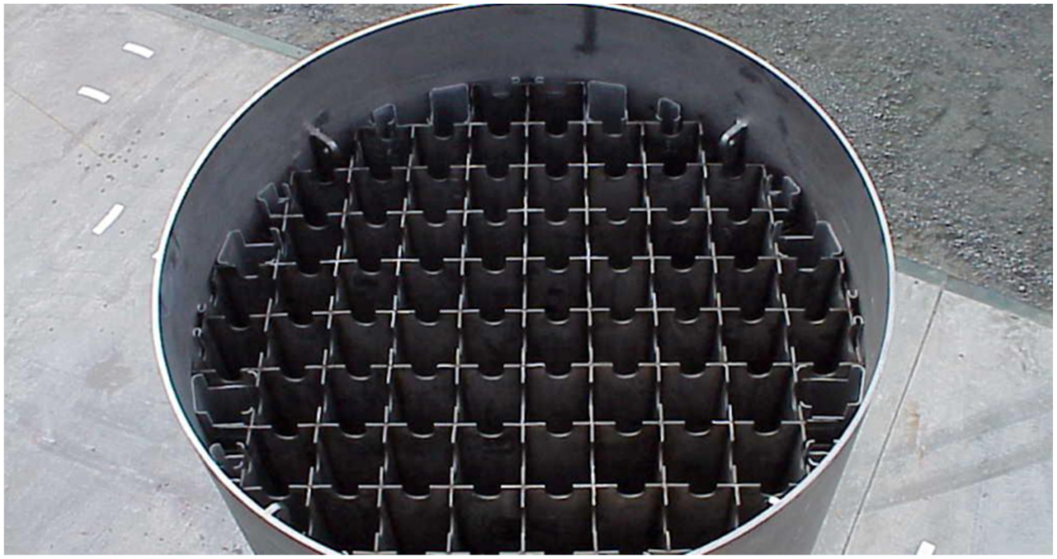
Mike Billone, Yung Liu,
Argonne National Laboratory,
November 20, 2013:



- Newer Zirconium alloy claddings (Zirlo and M5) degrade faster with high burnup fuel (HBF) than earlier claddings
- Data needs
  - Tensile properties of **HBU M5® and ZIRLO**™ cladding alloys
  - Failure limits for **all cladding alloys** following drying and storage
    - Radial hydrides can embrittle cladding in elastic deformation regime

Ductile-to-Brittle Transition Temperatures for High-Burnup PWR Cladding Alloys Mike Billone and Yung Liu Argonne National Laboratory U.S. NWTRB Winter Meeting November 20, 2013, DOE Slide Presentation https://www.nwtrb.gov/docs/default-source/meetings/2013/november/billone.pdf?sfvrsn=7

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 was able to open thick-wall casks after Fukushima and found aluminum fuel baskets were starting to degrade. Unknown status of U.S. fuel baskets (aluminum or stainless steel).
- US has older stainless steel baskets, but now standardizes on aluminum baskets**. No US fuel baskets have been inspected.** Baskets critical to maintaining fuel assemblies.
- Holtec BWR basket holds up to 68 smaller fuel assemblies. PWR basket normally hold 24, 32 or 37 larger fuel assemblies.

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

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

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 at the air vents**
  - 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)

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**

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).

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