Spent Nuclear Fuel Dry Storage Urgent Problems and Solution

Donna Gilmore, SanOnofreSafety.org NRC Commission Meeting, February 11, 2021 Regulatory Framework for Dry Cask Storage & Transportation of Spent Nuclear Fuel and Related Research Activities Transporting uninspected thin-wall canisters 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.



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 ISFSI 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.

Unsafe thin-wall nuclear waste canisters must be replaced.

When you're in a hole – quit digging.

NRC should approve only thick-wall



metal dry storage casks (10" to over 19" thick) designed to be inspected, maintained, repaired & monitored in a manner to PREVENT radioactive releases, criticalities & hydrogen explosions.

- Only proven world standard bolted lid thick-wall metal cask systems can meet minimum American (ASME N3) nuclear dry storage and transport containment safety standards now.
- Current unsafe uninspectable welded thin-wall canisters are vulnerable to short-term cracking and do not meet safety codes. Sandia 2019 DOE Technology Gap Report. <u>https://doi.org/10.2172/1592862</u>
 - Even after decades of trying, there are no real solutions only unsubstantiated hope – and we're running out of time.
 - Thin-wall canisters do not meet NRC and Nuclear Waste Policy Act (NWPA) requirements for monitored retrievable spent nuclear fuel.
 - No pressure monitors or pressure relief valves, and no other method in place to prevent or stop major radiological releases from canisters.

Only thick-wall casks can meet safety requirements

Safety Features	Thin canisters	Thick casks	Thin Canister
Thick walls	1/2"- 5/8"	10"- 19.50"	
Won't crack		\checkmark	
Ability to repair, replace seals		\checkmark	
Ability to inspect (inside & out)		\checkmark	
Monitor to prevent failure		\checkmark	
ASME N3 storage & transport		\checkmark	Thick Cask
Defense in depth (redundancy)		\checkmark	
Store in concrete building		\checkmark	
Gamma/neutron protection	With concrete vented overpack	\checkmark	
Transportable	unknown w/o inspection	\checkmark	
Market leader	U.S.	World	CASTOR [®] - Type V/19 cask

Fukushima thick-wall casks survived 2011 earthquake and tsunami



As long as NRC allows unsafe dry storage standards, quality vendors with quality products will have problems competing against inferior products

- For example, Southern California Edison refused to require high quality standards. They refused to solicit thick-wall cask bids and used flimsy excuses to justify their decision.
- Orano/Areva sells high quality thick-wall casks, but won't compete with themselves against their thin-wall lower standard products.
 - The Orano/Areva thick-wall casks currently used in the U.S. are not their top of the line casks. They had some design features that caused premature rusting of seals.
 - An Areva thick-wall cask is being used for the high burnup demonstration project.
- CASTOR® vendor GNS has continuous interest in the U.S. market and is high quality. GNS filed the package design approval application for their cask type CASTOR® geo69 according to 10CFR71 with the NRC. The geo69 is designed to solve the problem of pool cranes that could not handle the thick cask weight. It still has the other high quality CASTOR features. The CASTOR V/21 (an older model) was used to justify dry storage in the U.S.
- Both Orano/Areva and CASTOR® thick-wall casks have been used in the U.S. for decades longer than the thin-wall canisters.
- The Swiss selected only top of the line casks from Orano/Areva and GNS. They rejected the Holtec thick-wall cask design. SanOnofreSafety.org

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

- Gap Priority 1: Welded canisters Atmospheric Corrosion, short-term risks of through-wall cracks
 - Focus only on chloride induced stress corrosion cracking.



Microscopic cracks

- [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 <u>https://www.osti.gov/servlets/purl/1592862/</u>

Transport not a straight path forward

- Cannot inspect canisters or contents to ensure integrity for transport.
 - 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)

<u>Response to 2nd Request for Additional Information, Holtec International, Docket No. 71-9373 HI-STAR 190</u> <u>Transportation Package 2/26/2017 (ML17031A363)</u>

Unknown if normal train vibrations will cause fuel rod failure.

Interim Storage Plans (CIS): return leaking canisters to sender.

- Sender has no method to handle leaking canisters.
- Limit to how long leaking canister can stay inside transport cask before overheating.
- Canisters may need decades of cooling before meeting transport regs.
- NRC should not approve transport casks until issues resolved.

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



This is a NOW problem

We cannot kick these "Chernobyl cans" down the road any longer. Consequences are too high.



- No plan in place when something goes wrong.
- Need dry transfer system (hot cell) facility to replace canisters.
 - **None** in the U.S. large enough or designed for this.
 - Spent fuel pools not a proven 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 CNOs admit: cannot unload fuel back into pools.
 - Proposed solution to store breached canister in sealed thick metal overpack is not an option. Fuel will overheat due to loss of air cooling.
- Once cracks start in canisters, cracks can grow though the wall in only 16 years. NRC 8/5/2014
- Thin-wall canisters are already up to 32 years old (1989).

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

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

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



SanOnofreSafety.org

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

NRC & EPRI claim not enough humidity at San Onofre for corrosion. Ignore frequent fog, surf, on-shore winds



New Holtec UMAX system lids corroding

Metal sprays on top of lower air vents is an attempt to stop corrosive Seagull poop from sliding inside air vents. Seagull poop is highly corrosive to stainless steel.



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/00000003002002785

Diablo Canyon: corrosive coastal environment



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
 <u>http://youtu.be/euaFZt0YPi4</u>

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).

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

STOP exemptions to ASME N3

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.

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
- Most countries use thick casks that can meet ASME N3 standards
 - Switzerland, Germany, Belgium Czech Republic, France, Italy & others.

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

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



Some aging canisters at risk for cracks and leaks

Loaded	Age (2021)
1993	28 years
2001	20 years
2002	19 years
2003	18 years
2008	13 years
2009	12 years
	Loaded 1993 2001 2002 2003 2008 2009

Most U.S. thin canisters in use less than 16 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



Explosion Risks (partial list)

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/powder ignites at 270 degrees Celsius Zirconium powder used to make fireworks ignite.



 Water remaining after drying converts to hydrogen from irradiation. Canisters may over pressurize, but have no pressure monitors or pressure relief valves. Unknown amount of water in canisters.

Fuel can go critical if exposed to unborated water

 NRC states there will not be a criticality by assuming there will never be through-wall cracks. Not credited to prevent criticality if exposed to water. Boron in canisters only for loading from pool to dry storage. (NRC, Holtec).

Explosion risk information & references (NUREG-2224 Comments, D.Gilmore) https://www.nrc.gov/docs/ML1826/ML18269A037.pdf

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

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Significant high burnup fuel cladding embrittlement in dry storage

Nuclear Energy

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."

<u>Ductile-to-Brittle Transition Temperature for High-Burnup Zircaloy-4 and ZIRLO™ Cladding Alloys Exposed</u> <u>to Simulated Drying-Storage Conditions</u> 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

ENERGY

Summary of Results

Nuclear Energy

- 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

 - DBTT for HBU M9^a 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
 Embritted by circumferential hydrides: 015±82 wppm 520±90 wppm 640±140 wppm
 - HBU Zry-4 with 300±15 wppm was highly ductile at 20°C
- 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

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

- 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

No technology to make geological repositories work shortterm or long-term, even for 20 years.

- No idea how they will ever have the technology.
- May 2018 NWTRB Geological Repository meeting (nwtrb.gov)

Swiss Solution for Thick Cask Storage



SanOnofreSafety.org

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

Only thick-wall casks can meet safety requirements

Safety Features	Thin canisters	Thick casks	Thin Canister
Thick walls	1/2"- 5/8"	10"- 19.50"	
Won't crack		\checkmark	
Ability to repair, replace seals		\checkmark	
Ability to inspect (inside & out)		\checkmark	
Monitor to prevent failure		\checkmark	
ASME N3 storage & transport		\checkmark	Thick Cask
Defense in depth (redundancy)		\checkmark	
Store in concrete building		\checkmark	
Gamma/neutron protection	With concrete vented overpack	\checkmark	t
Transportable	unknown w/o inspection	\checkmark	
Market leader	U.S.	World	CASTOR [®] - Type V/19 cask

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Background Slides

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

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





Sea Salt crystal with MgCl inside found on Diablo Canyon Canister

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. Cr ack 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 o f 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 x 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)

August 5, 2014

NRC Public meeting with NEI on CISCC RIRP

Problems with U.S. thin-wall stainless steel dry storage 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 N3 certified



- NRC allows exemptions from ASME standards
- No defense in depth
 - Concrete overpack vented to prevent over heating
 - Unsealed damaged fuel cans
 - No current plan for failed canisters
- Early stress corrosion cracking risk
- Inadequate aging management plan

Thick casks designed for longer storage

- Market leader internationally
- No stress corrosion cracking
- Maintainable
 - Inspectable
 - Replaceable parts (metal seals, lids, bolts)



CASTOR[®] - Type V/19 cask

- 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)
- 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)

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.

Up toSanOnofreSafety.org

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



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 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





No warning before major radiation releases from thin-wall 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.



Microscopic cracks

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.



SanOnoneSalety.org

German interim storage over 40 years



Thick casks used worldwide The TN®24 Cask Family

Packaging	Number of	Burn-up	Cooling time	Enrichment	Country
ruckugnig	fuels	(MWd/tU)	(years)	(%)	Country
TN 24 D	28 PWR	36 000	8	3.4	в
TN 24 DH	28 PWR	55 000	7	4.1	в
TN 24 XL	24 PWR	40 000	8	3.4	в
TN 24 XLH	24 PWR	55 000	7	4.3	в
TN 24 SH	37 PWR	55 000	5	4.25	в
TN 24 G	37 PWR	42 000	10	3.81	СН
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	СН
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	СН
TN 24 BH	69 BWR	50 000	6	5.0	СН
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	1
INTERNATIONAL					

Dry Storage & Innovation - ISSF 2010 - Tokyo, November 2010 - p.8



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 and similar bills make problem worse
 - 1. Allows license transfer to federal government at existing sites
 - 2. Removes safety requirements needed to **prevent** major leaks
 - 3. Removes site specific environmental requirements
 - 4. Removes oversite of DOE (*existing DOE waste sites leak*!)
 - 5. Removes state, local, public rights to oversite, 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 (becomes discretionary)

None of these issues discussed in House hearings!

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.
- 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).



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)]



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°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 <u>http://www.osti.gov/scitech/servlets/purl/654001</u>

Fukushima thick casks

Specification of Dry Casks

	Large type	Mediu	m type
Weight (t)	115	9	6
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.

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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

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

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

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Summary of Results

Nuclear Energy

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: $80^{\circ}C \rightarrow 70^{\circ}C \rightarrow <20^{\circ}C \rightarrow <20^{\circ}C$
- DBTT for **HBU ZIRLO**TM after slow cooling: $185^{\circ}C \rightarrow 125^{\circ}C \rightarrow 20^{\circ}C \rightarrow <20^{\circ}C$
- DBTT for **HBU Zry-4** after slow cooling: $55^{\circ}C \rightarrow \langle 20^{\circ}C \rightarrow \rangle \rightarrow \rangle 90^{\circ}C$
 - 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-NUHOMS¹
 - 2015 Transnuclear-NUHOMS 1004
 - 2020 NAC-UMS; Holtec-Hi-STORM
- Storage of high burn-up fuel is relatively recent
 - 9 years Maine Yankee² (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</p>
- ~ 200 loaded-casks contain high burn-up fuel
- Most fuel in pools for future loading is high burn-up



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