Diablo Canyon Nuclear Waste Unsafely Stored

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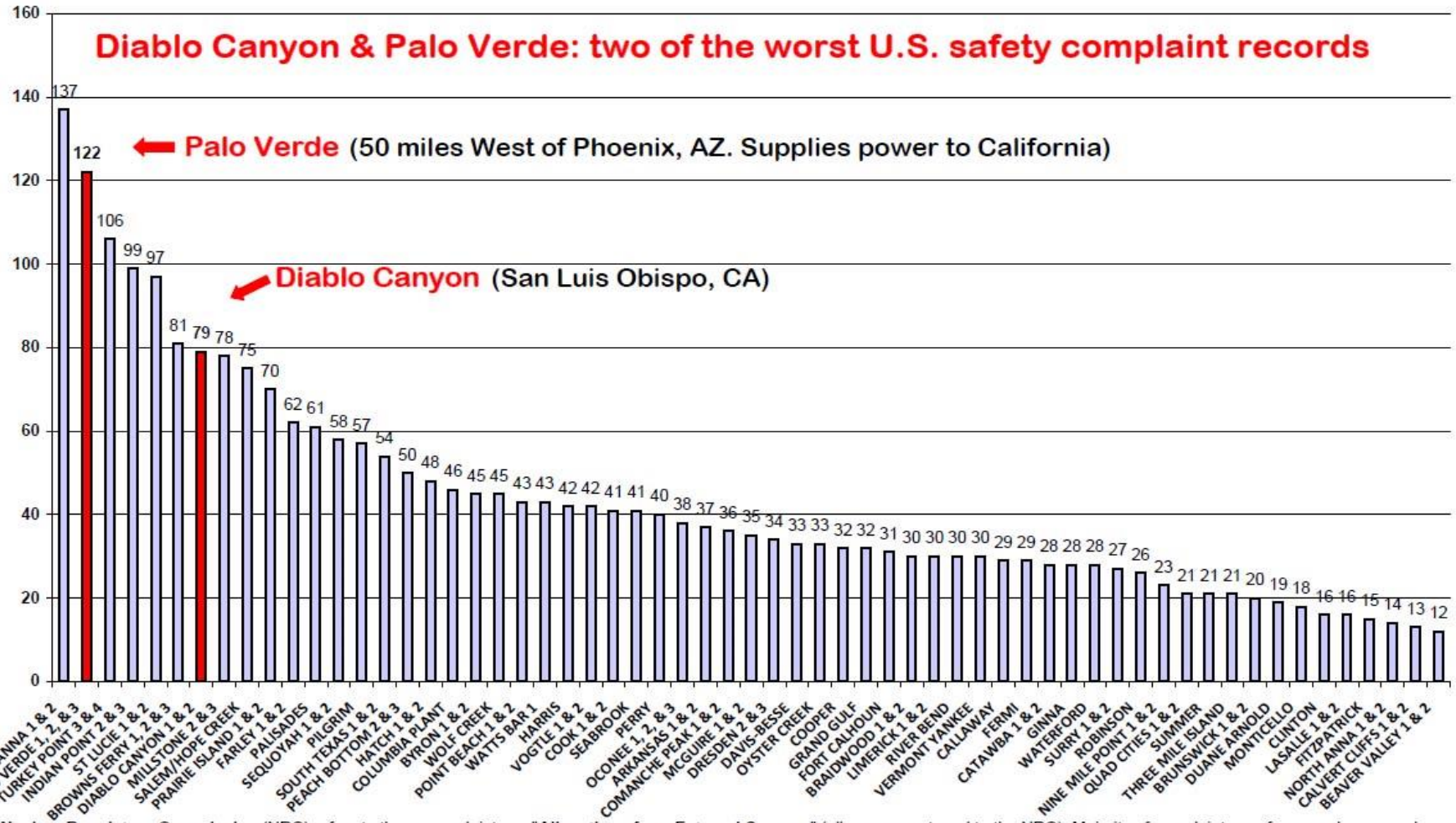
San Luis Obispo, CA October 20, 2017

Safety complaints to NRC from external sources (employees)*

U.S. Operating Nuclear Power Reactors

January 2007 to June 2015 (8.5 years)



*The **Nuclear Regulatory Commission** (NRC) refers to these complaints as "**Allegations from External Sources**" (all sources external to the NRC). Majority of complaints are from employees and other on-site sources. These are reports of impropriety or inadequacy of NRC-related safety or regulatory concerns. Includes all 61 U.S. operating nuclear power plants & 98 reactors. One allegation report may contain multiple allegations. However, the NRC counts it as one allegation in these statistics. A complaint about a safety-conscious work environment (SCWE) problem is important. However, a Notice of Violation cannot be issued, because there is no applicable NRC regulation.

Source: www.nrc.gov/about-nrc/regulatory/allegations/statistics.html

SanOnofreSafety.org

Diablo Canyon Dry Storage Location

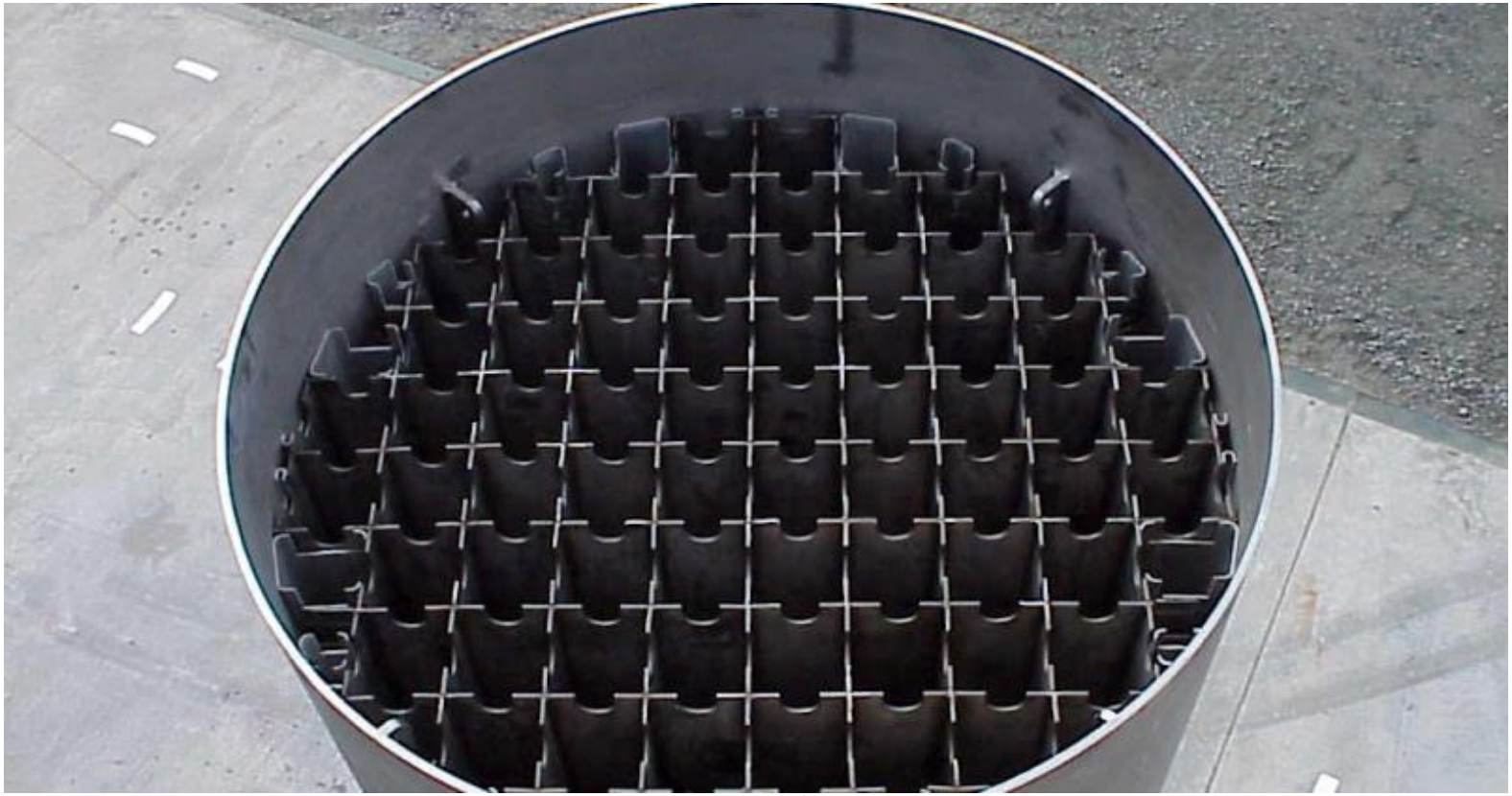
Exposed to harsh marine environment

Diablo Canyon: 49 thin-wall (1/2” thick) Holtec nuclear fuel waste storage cans


San Onofre thin-wall fuel cans:
50 Areva NUHOMS loaded up to 16 years
73 Holtec MPC-37 loading starts Nov/Dec
GTCC: 1 Areva can loaded + 12 more
Nuclear waste storage site under construction,
inches above watertable, 100 feet from the ocean!

Thin-Wall Canisters only ½” thick

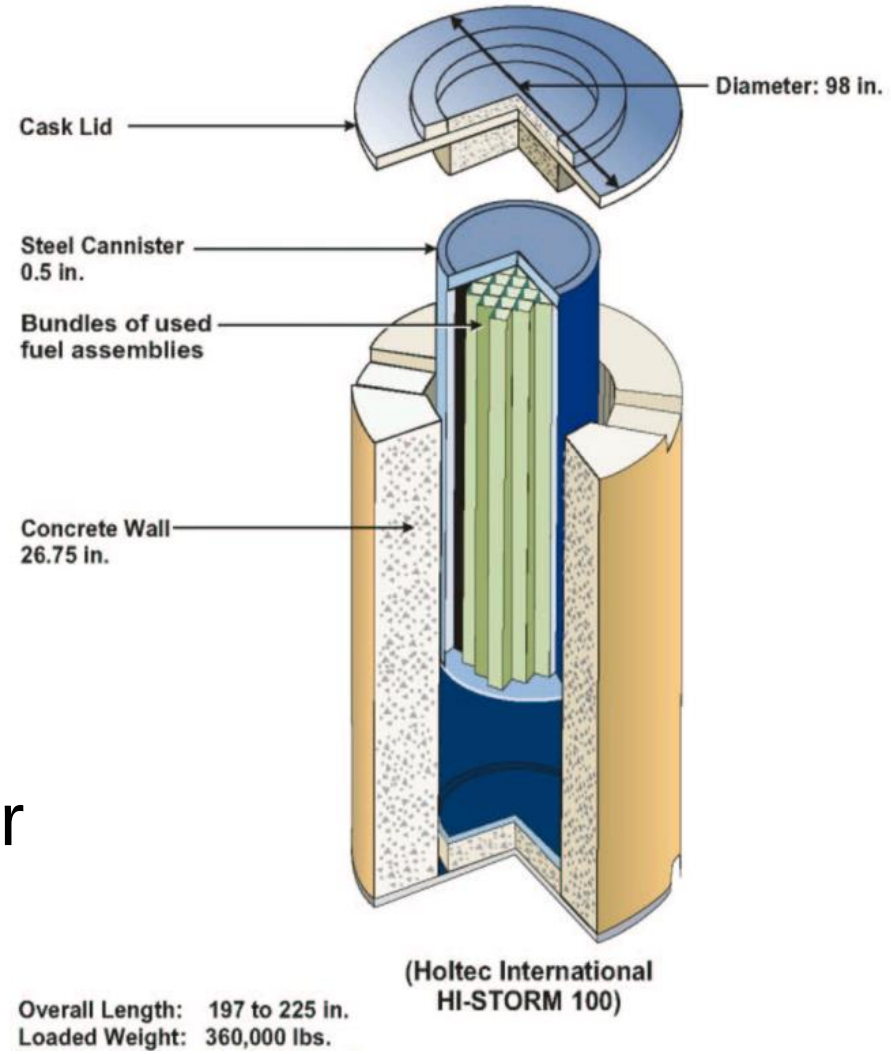
- Holtec MPC and fuel basket for BWR fuel assemblies
- Similar to Diablo Canyon MPC-32 fuel assembly canister



Unproven thin-wall canister systems cannot meet basic safety requirements

- Cannot inspect (inside or out)
- Cannot repair
- Cannot transport with cracks
- Cannot monitor to prevent leaks
- No earthquake rating for cracking canisters

Would you buy a car like this?



(Holtec International HI-STORM 100)

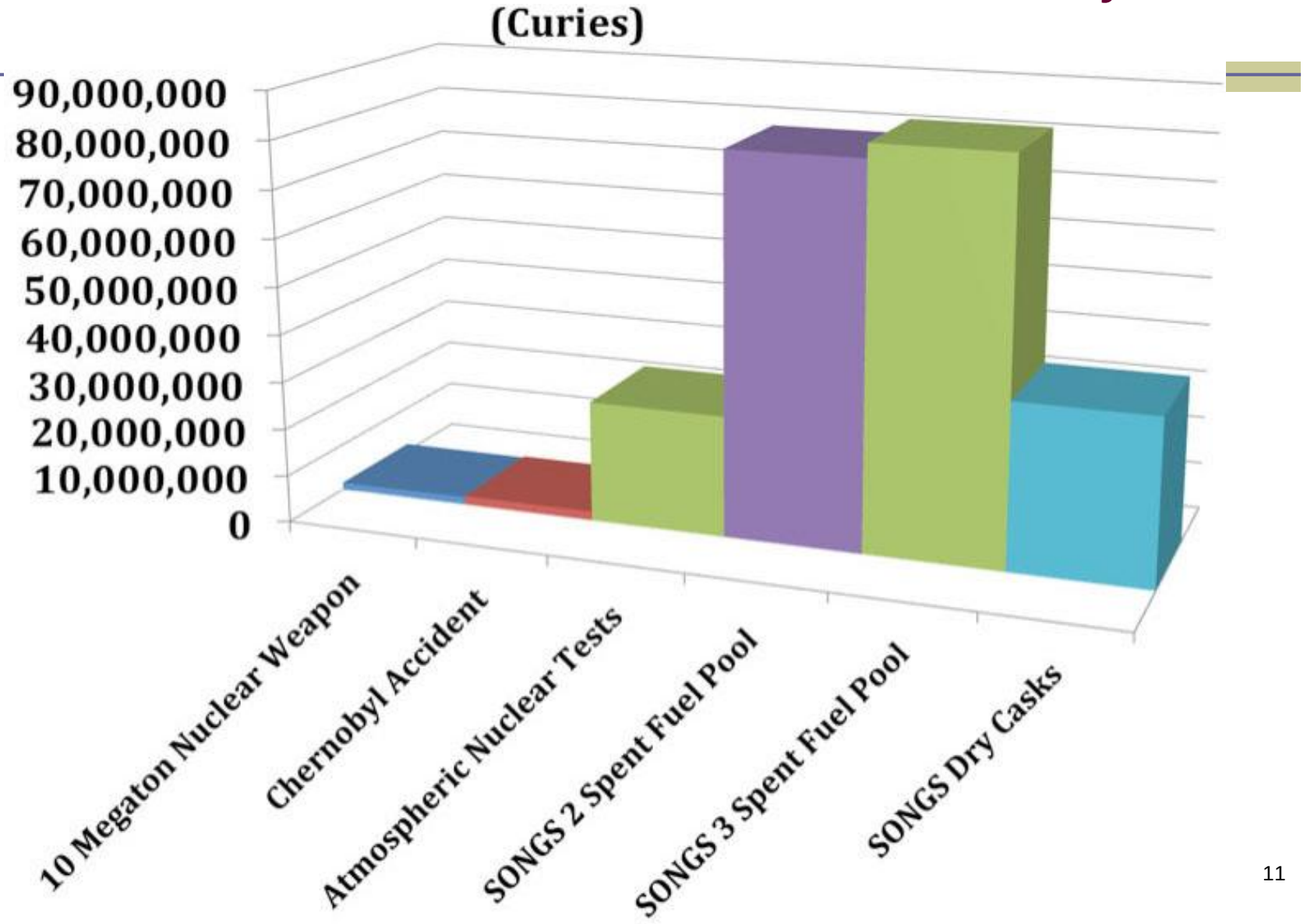
Two-year old Diablo Canyon Holtec canister has *conditions* for cracking

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

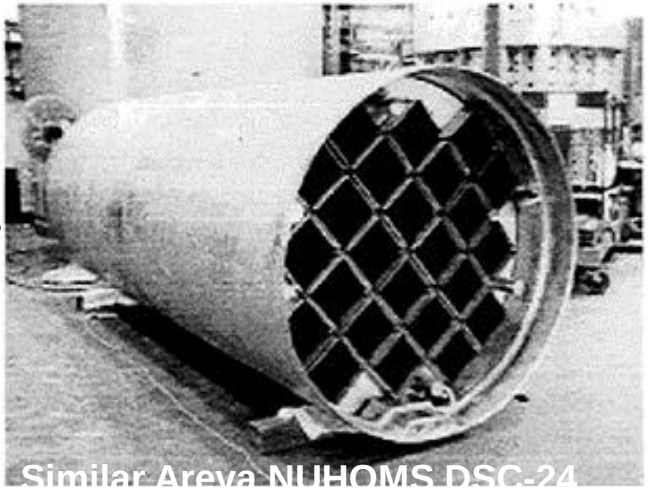
Holtec canister President Kris Singh admits problems

- "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 has 89 times more radioactive Cesium-137 than released from Chernobyl



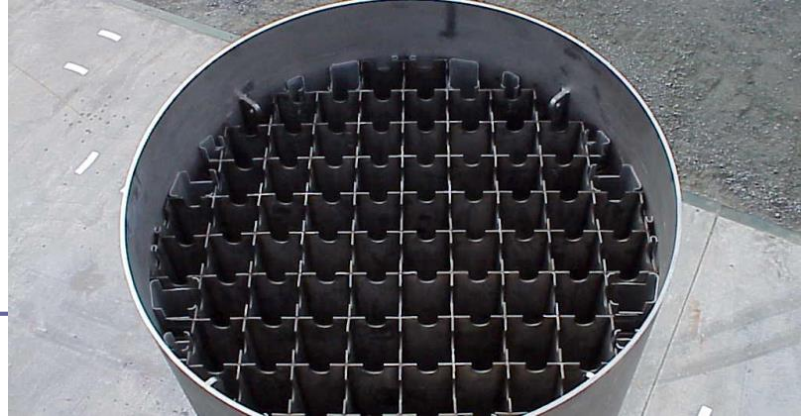
49 “Chernobyl” steel cans stored at Diablo Canyon



- Each can has about as much Cesium-137 as released from the 1986 Chernobyl disaster
- 32 fuel assemblies in each can (MPC-32)
- Loading began **8 years** ago (2009)
- EPRI: Diablo Canyon canister has all conditions for cracking in **2-year old** canister (salt & moisture)
- NRC: Can leak **16 years** after a crack starts
- NRC: Koeberg tank leaked in **17 years**
- NRC: **Cannot inspect for cracks** after fuel loaded

Do not know if any cracked or depth of cracks

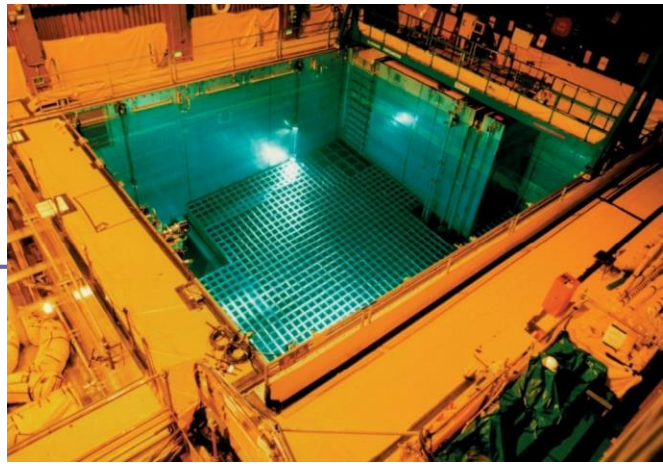
Diablo Canyon Nuclear Fuel Waste



- In spite of inability to inspect, repair, maintain or monitor thin-wall (1/2” thick) canisters to PREVENT leaks, PG&E plans to buy more!
- 1,712 fuel assemblies in spent fuel pools
- 49 canisters in dry storage (1,568 fuel assemblies)
- PG&E plans to buy 25 more canisters by 2022
  - 9 canisters (288 fuel assemblies) in 2018
  - 8 canisters (256 fuel assemblies) in 2020
  - 8 canisters (256 fuel assemblies) in 2022
- Continues to produce more nuclear fuel waste

Photo of Holtec canister for BWR fuel. Diablo uses PWR fuel (MPC-32 fuel assembly canister).

No plan for cracking cans



- No plan in place to handle cracking or leaking cans
- May destroy empty spent fuel pools
  - The only current on-site approved option to replace canisters
- Dry fuel handling building (hot cell) is only other replacement option, but does not exist at site
- Cracking or leaking cans unsafe for transport
  - NRC Transport Regulation 10 CFR § 71.85
- Plans to continue loading cans in spite of these problems

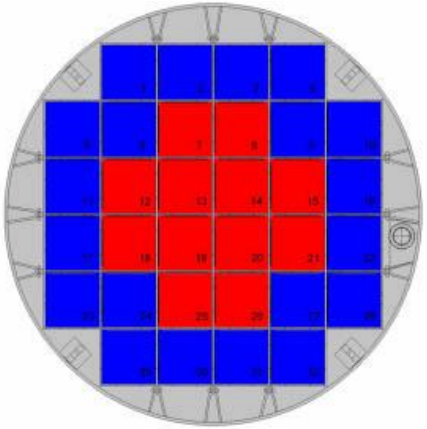
No warning before radiation leaks from thin canisters

- **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**

Over half of Diablo Holtec canisters loaded incorrectly

- **17 of 29 Diablo canisters (prior to the 2015 campaign) were loaded incorrectly by Holtec and PG&E**
- **Older ones should be on outer regions – not inner regions.**

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



Regionalized Storage in the MPC 32

- Region 1 "Hot/Young" Fuel
- Region 2 "Old/Cold" Fuel

NRC ignores regulations

- Ignores aging issues in initial 20 year license
- Allows destruction of pools in spite of knowing it is the only approved on-site option for replacing failing canisters
- Allows canisters vulnerable to short-term cracks in spite of knowing they cannot be transported, inspected, maintained or monitored to prevent leaks.
- Allows high burnup fuel in spite of knowing it may not be safe for transport or storage

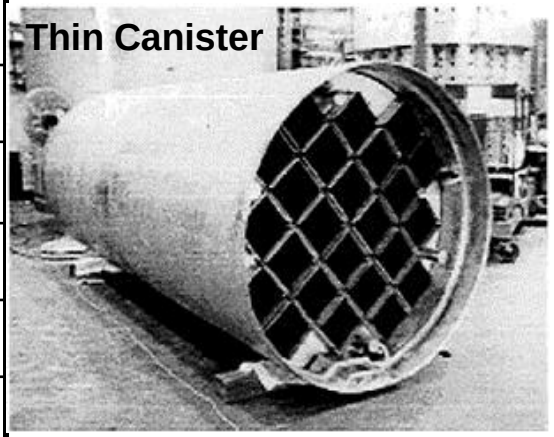
Aging California canisters at risk for cracks and leaks

	Loaded	Oldest
San Onofre	2003	14 years
Rancho Seco	2001	16 years
Humboldt Bay	2008	9 years
Diablo Canyon	2009	8 years

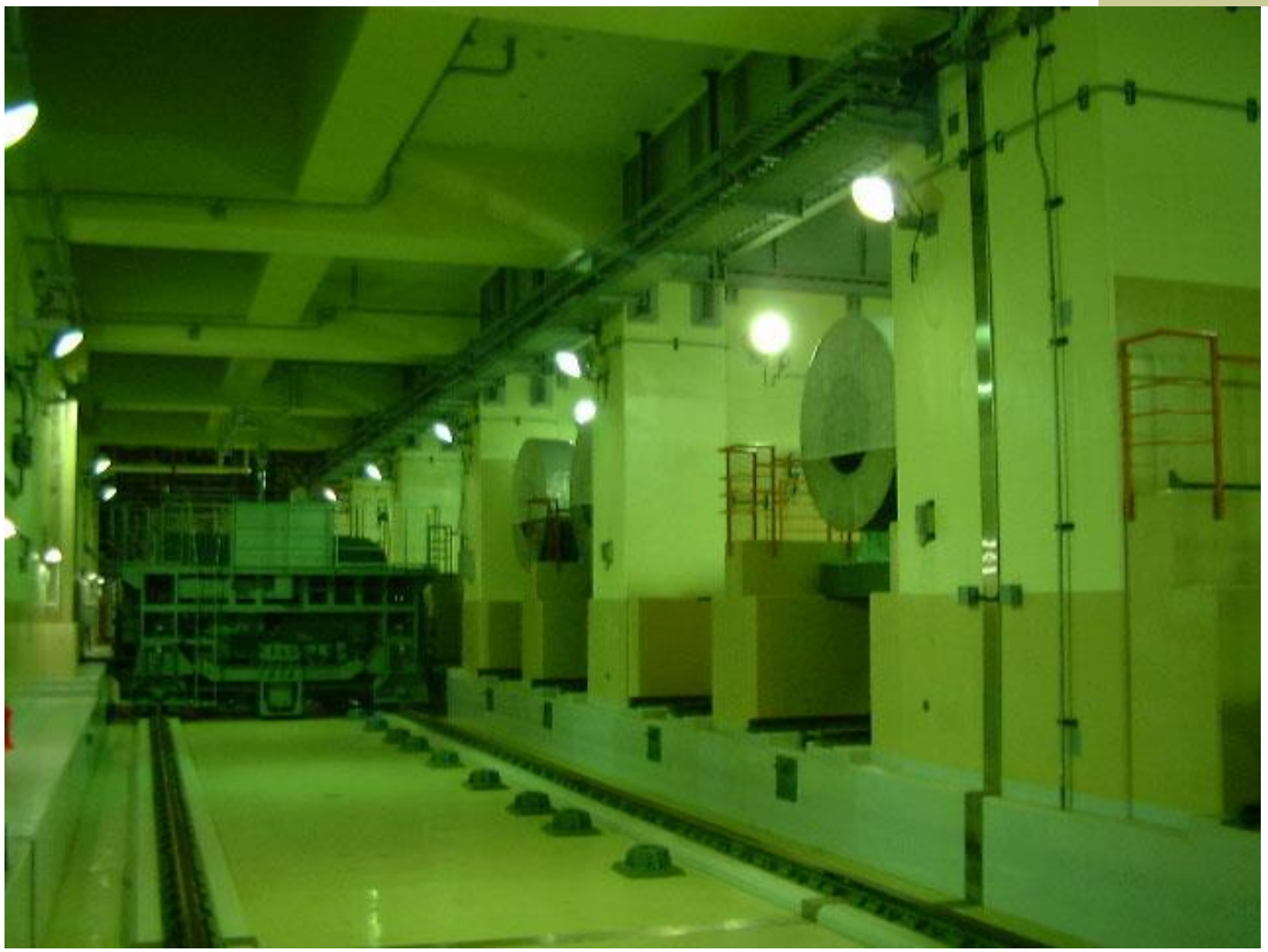
- Most U.S. thin canisters in use less than 12 years
- Earliest: 1989 (Robinson, H.B., SC), 1990 (Oconee, SC), 1993 (Calvert Cliffs, MD)
- NRC renews licenses in spite inadequate aging plan

Reasons thick casks used by most of the world

Safety Features	Thin canisters	Thick casks
Thick walls	1/2”- 5/8”	**10”- 19.75”**
Won’t crack		√
Ability to repair, replace seals		√
Ability to inspect		√
Early warning monitor		√
ASME **container** certification		√
Defense in depth (redundancy)		√
Stored in concrete building		√
Gamma & neutron protection	With concrete overpack	√
Transportable w/o add’l cask		√
Market leader	**U.S.**	**World**



Fukushima thick casks survived 2011 earthquake and tsunami



German interim storage over 40 years

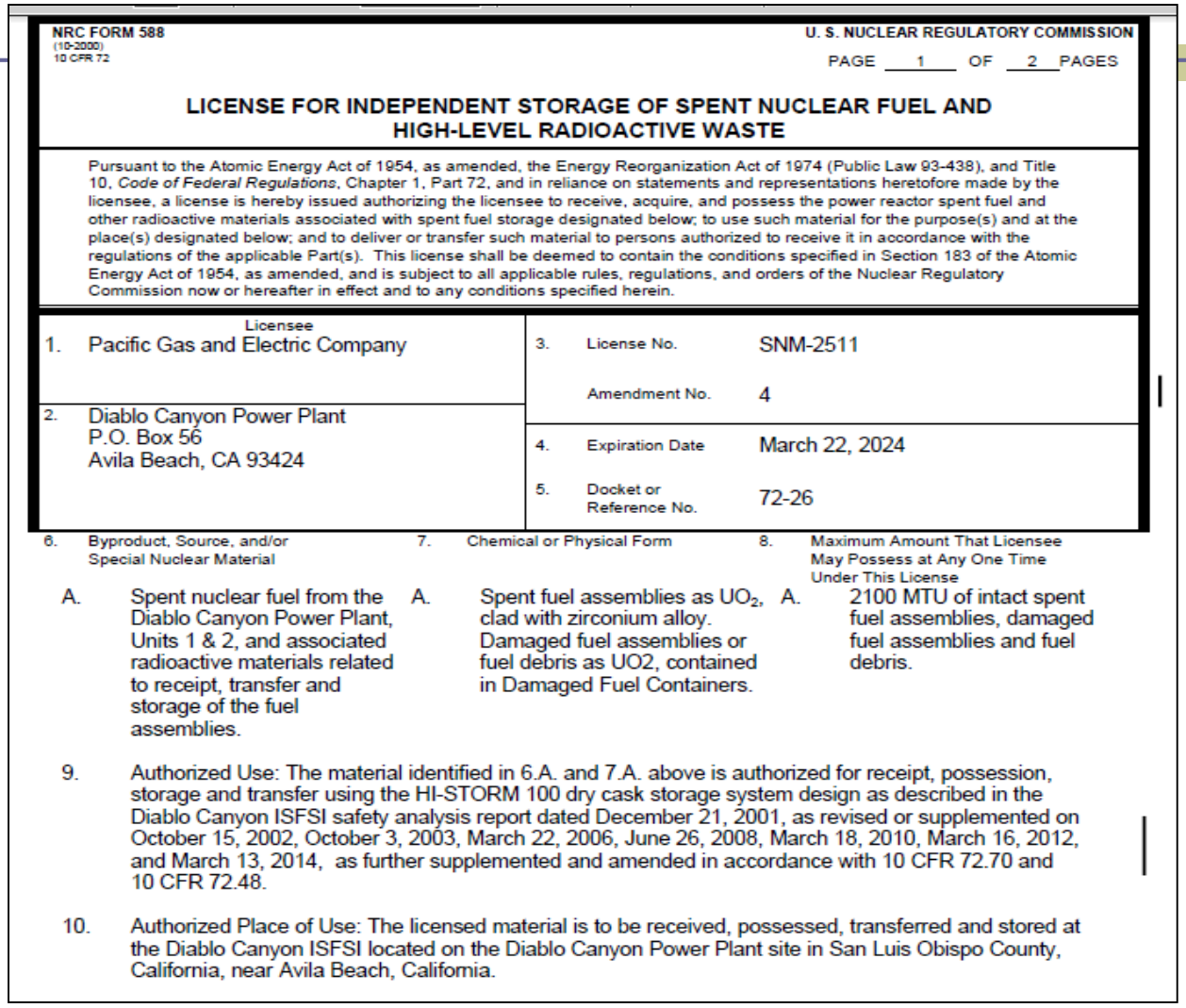
The TN®24 Cask Family

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

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 aging management (NUREG-1927 rev. 1) not enforced**

Diablo Canyon Dry Storage (ISFSI) License Expires 2024



NRC FORM 588
(10-2000)
10 CFR 72

U. S. NUCLEAR REGULATORY COMMISSION

PAGE 1 OF 2 PAGES

LICENSE FOR INDEPENDENT STORAGE OF SPENT NUCLEAR FUEL AND HIGH-LEVEL RADIOACTIVE WASTE

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974 (Public Law 93-438), and Title 10, *Code of Federal Regulations*, Chapter 1, Part 72, and in reliance on statements and representations heretofore made by the licensee, a license is hereby issued authorizing the licensee to receive, acquire, and possess the power reactor spent fuel and other radioactive materials associated with spent fuel storage designated below; to use such material for the purpose(s) and at the place(s) designated below; and to deliver or transfer such material to persons authorized to receive it in accordance with the regulations of the applicable Part(s). This license shall be deemed to contain the conditions specified in Section 183 of the Atomic Energy Act of 1954, as amended, and is subject to all applicable rules, regulations, and orders of the Nuclear Regulatory Commission now or hereafter in effect and to any conditions specified herein.

Licensee		
1. Pacific Gas and Electric Company	3. License No.	SNM-2511
	Amendment No.	4
2. Diablo Canyon Power Plant P.O. Box 56 Avila Beach, CA 93424	4. Expiration Date	March 22, 2024
	5. Docket or Reference No.	72-26

6. Byproduct, Source, and/or Special Nuclear Material	7. Chemical or Physical Form	8. Maximum Amount That Licensee May Possess at Any One Time Under This License
A. Spent nuclear fuel from the Diablo Canyon Power Plant, Units 1 & 2, and associated radioactive materials related to receipt, transfer and storage of the fuel assemblies.	A. Spent fuel assemblies as UO_2, clad with zirconium alloy. Damaged fuel assemblies or fuel debris as UO2, contained in Damaged Fuel Containers.	A. 2100 MTU of intact spent fuel assemblies, damaged fuel assemblies and fuel debris.

9. Authorized Use: The material identified in 6.A. and 7.A. above is authorized for receipt, possession, storage and transfer using the HI-STORM 100 dry cask storage system design as described in the Diablo Canyon ISFSI safety analysis report dated December 21, 2001, as revised or supplemented on October 15, 2002, October 3, 2003, March 22, 2006, June 26, 2008, March 18, 2010, March 16, 2012, and March 13, 2014, as further supplemented and amended in accordance with 10 CFR 72.70 and 10 CFR 72.48.

10. Authorized Place of Use: The licensed material is to be received, possessed, transferred and stored at the Diablo Canyon ISFSI located on the Diablo Canyon Power Plant site in San Luis Obispo County, California, near Avila Beach, California.

Consolidated Interim Storage (CIS)?

- **Legal challenges likely will delay or stop new sites indefinitely**
- **Shimkus/Issa bill H.R. 3053 makes problem worse**
  1. H.R. 3053 opposed by over 50 environmental organizations
  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

None of these issues were 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
- **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**

Recommendations

- Stop PG&E from loading waste in Holtec System
  - Revoke Coastal Permit – cannot meet transport requirements
  - Stop CPUC approval of more Holtec systems
- Store waste in safer thick-walled transportable storage casks
- Store casks in building for security & environmental protection
- Stop PG&E from destroying empty spent fuel pool
- Evaluate need for dry fuel handling facility (hot cell)
- Organize and fund these efforts. Learn more at SanOnofreSafety.org

It can be done – we have no other options to prevent leaks and potential explosions!

Donna Gilmore
SanOnofreSafety.org
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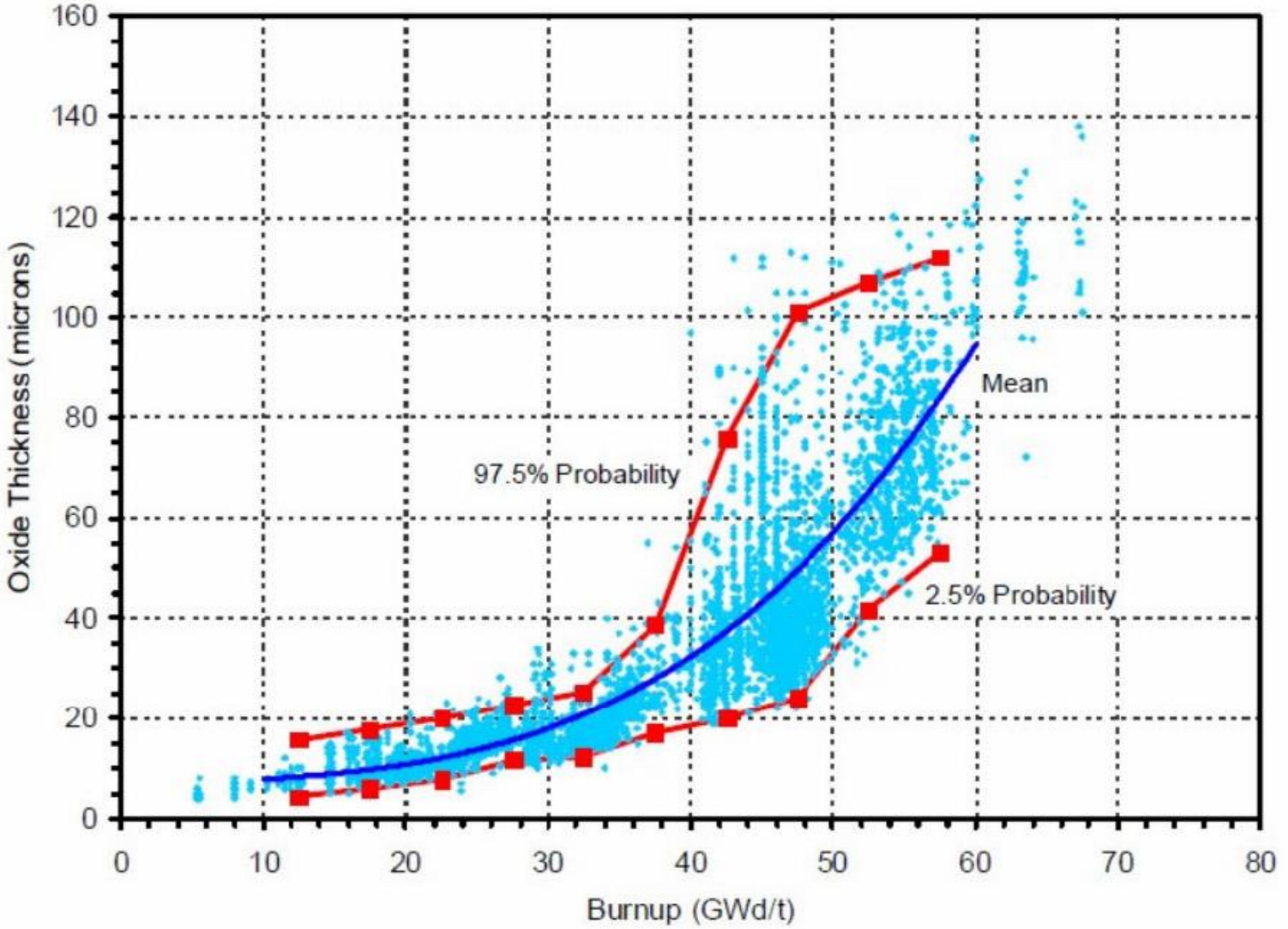
Additional Slides

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

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
  - 80ºC (176°F) in "wicking" tests compared with 50°C (122°F)
- **Crack initiation unpredictable**
  - Cracks more likely to occur at higher end of temperature range up to 80°C (176°F) instead of ambient temperatures
  - Canister temperatures above 85°C will not crack from marine air – chloride salts won't stay and dissolve on canister
- **Many corrosion factors not addressed**. NRC focus is chloride-induced stress corrosion cracking (CISCC).

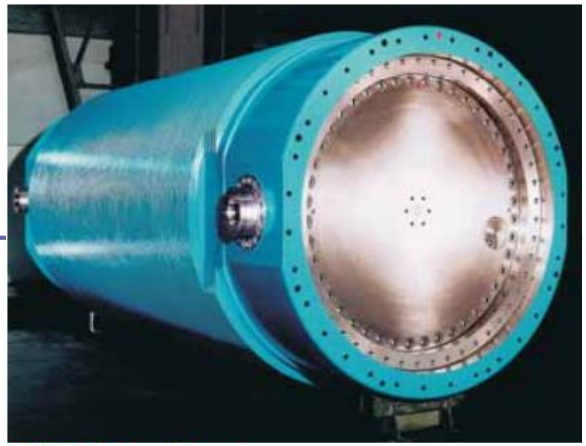
Koeberg steel tank failed in 17 years

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

Can't repair canisters and No plan to replace them

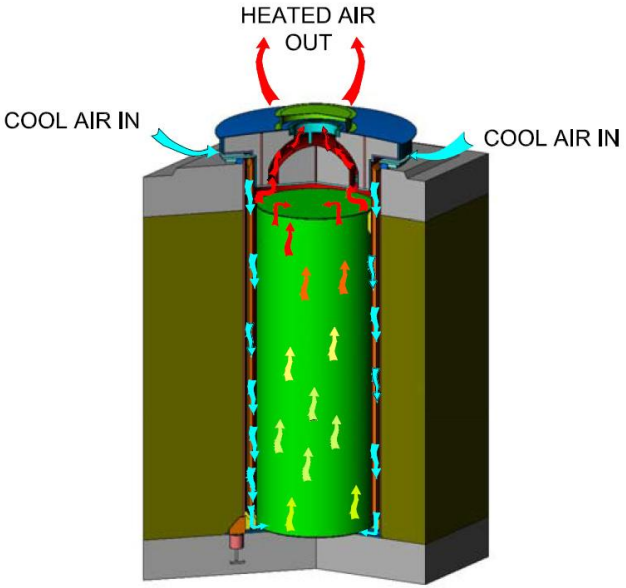
- "**It is not practical to repair a canister if it were damaged**… if that canister were to develop a leak, let's be realistic; you have to find it, that crack, where it might be, and then find the means to repair it. You will have, in the face of **millions of curies of radioactivity coming out of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

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)]

Enforce Public Resources Code Regulation §30253


CASTOR® - Type V/19 cask

New development shall do all of the following:

(a) **Minimize risks to life and property in areas of high geologic, flood, and fire hazard**.

(b) **Assure stability and structural integrity, and neither create nor contribute significantly to erosion, geologic instability, or destruction of the site or surrounding area or in any way require the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs.**

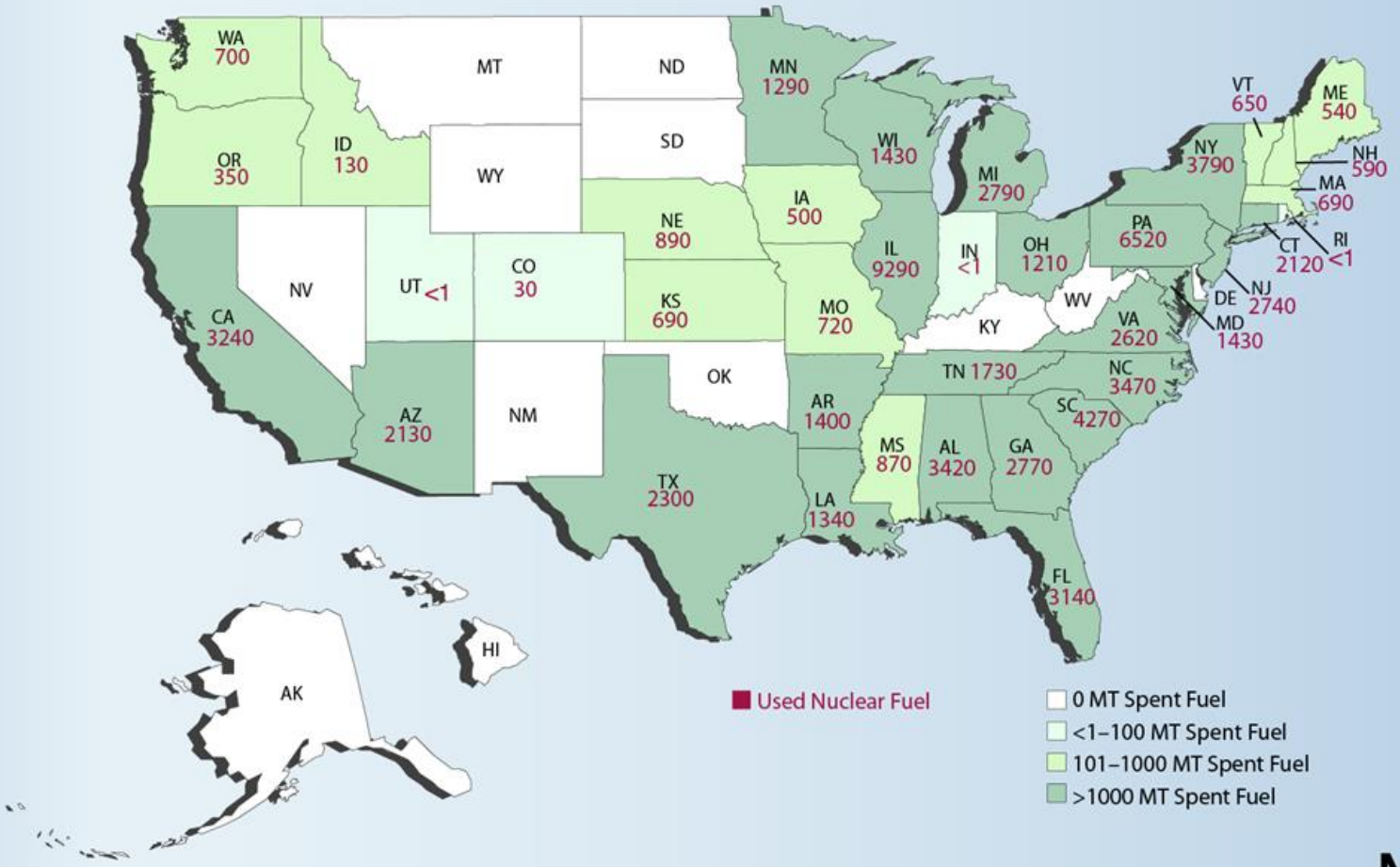
(c) Be consistent with requirements imposed by an air pollution control district or the State Air Resources Board as to each particular development.

(d) Minimize energy consumption and vehicle miles traveled.

(e) Where appropriate, **protect special communities and neighborhoods** that, because of their unique characteristics, are popular visitor destination points for recreational uses.

Used Nuclear Fuel in Storage

(Metric Tons, End of 2013)



NEI
NUCLEAR ENERGY INSTITUTE

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°C and -49°C** exceeding NRC requirements.
- **Conclusions shared by ASTM, ASME, and IAEA**
  - *Fracture Mechanics Based Design for Radioactive Material Transport Packagings Historical Review*, Sandia Labs, SAND98-0764 UC-804, April 1998 http://www.osti.gov/scitech/servlets/purl/654001

Thin canisters not ASME certified

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

Fukushima thick casks

Specification of Dry Casks

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

Additional 11casks are being prepared for installation.

TOKYO ELECTRIC POWER COMPANY

13

Thin canisters not designed to be replaced

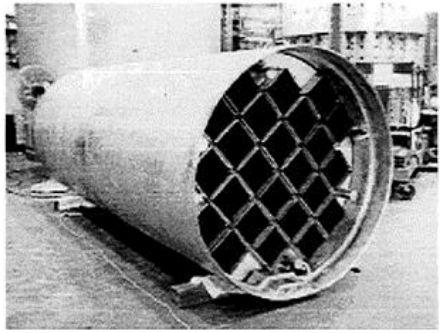
- Welded lid not designed to be removed
- Lid must be unwelded under water
- Fuel transfer from damaged canister to new canister must be done under water
- **No spent fuel has ever been reloaded into another thin canister**
- Thick casks are designed to remove and reload fuel
- Potential problem unloading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

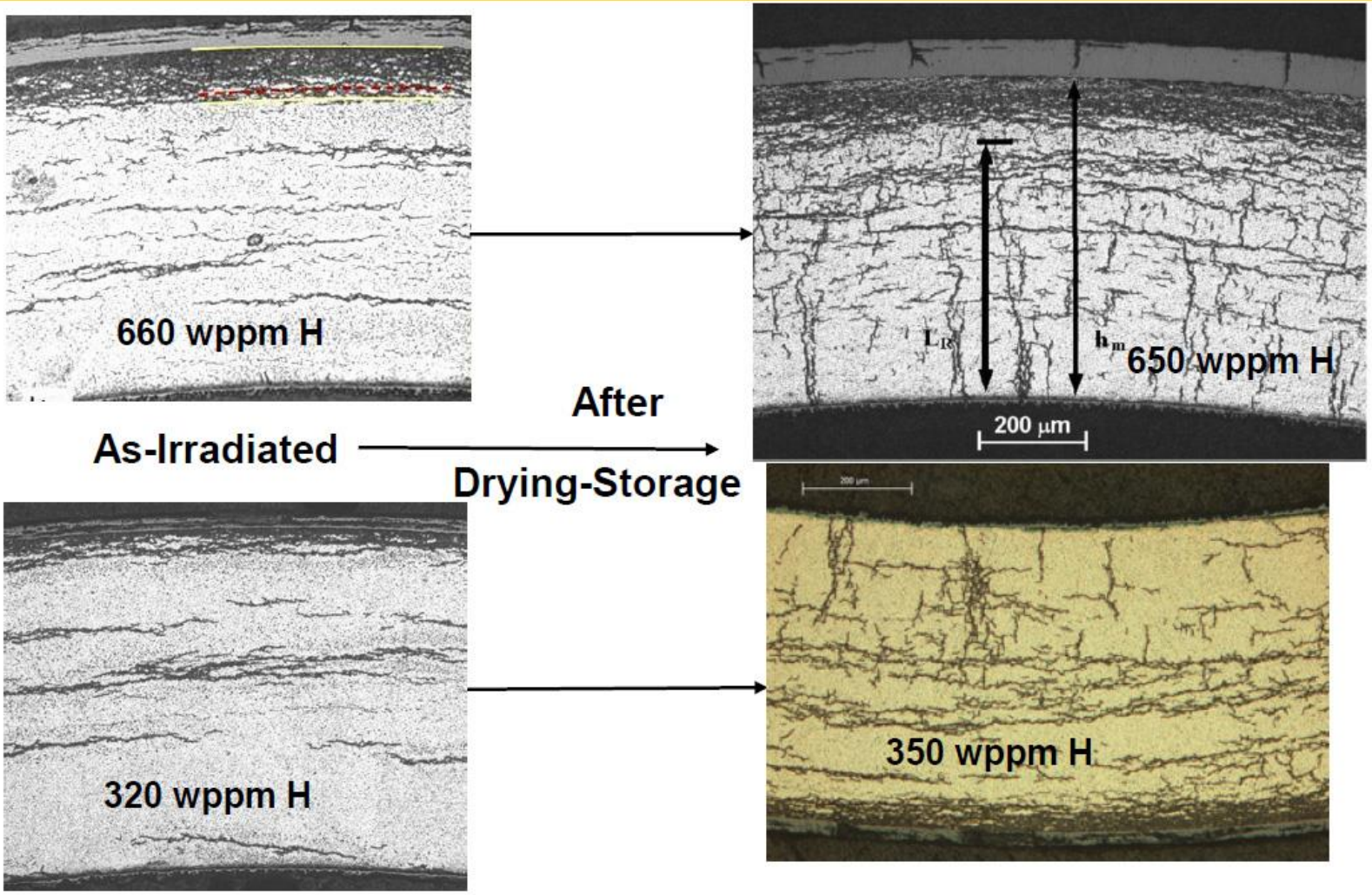
- **Not maintainable**
  - Cannot inspect exterior or interior for cracks
  - Cannot repair cracks
  - Not reusable (welded lid)
- **No warning BEFORE radiation leaks**
- **Canisters not ASME certified**
- **NRC allows exemptions from ASME standards**
- **No defense in depth**
  - Concrete overpack vented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



U.S. DEPARTMENT OF ENERGY

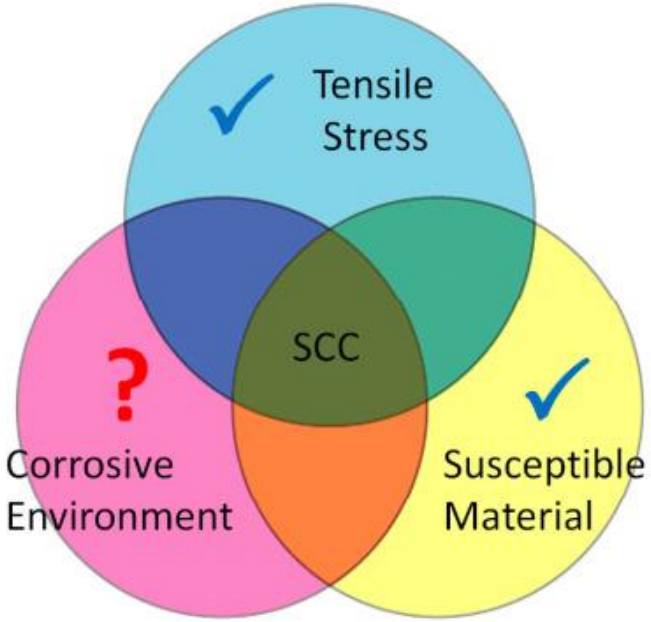
Nuclear Energy

Introduction: Circumferential and Radial Hydrides in HBU Cladding



Stress Corrosion Cracking Background Information

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



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)

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

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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

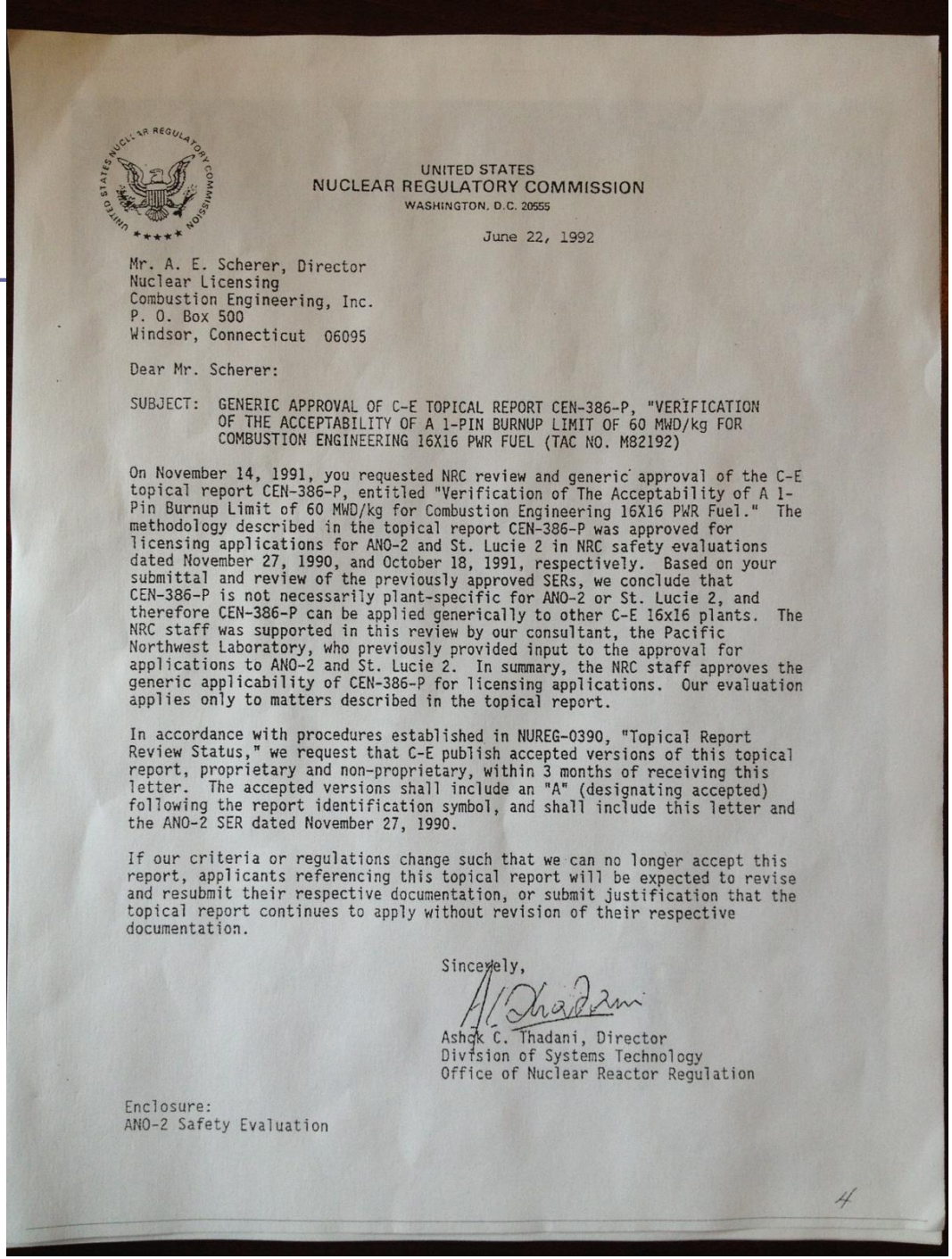
1) Since 1992, allowable burn-up to 47 GWd/MTU, since 2010, up to 52 GWd/MTU
2) All high burn-up fuel is in damaged fuel cans

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,

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

Recommendations

We cannot kick this can down the road


CASTOR® - Type V/19 cask

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

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SanOnofreSafety.org
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