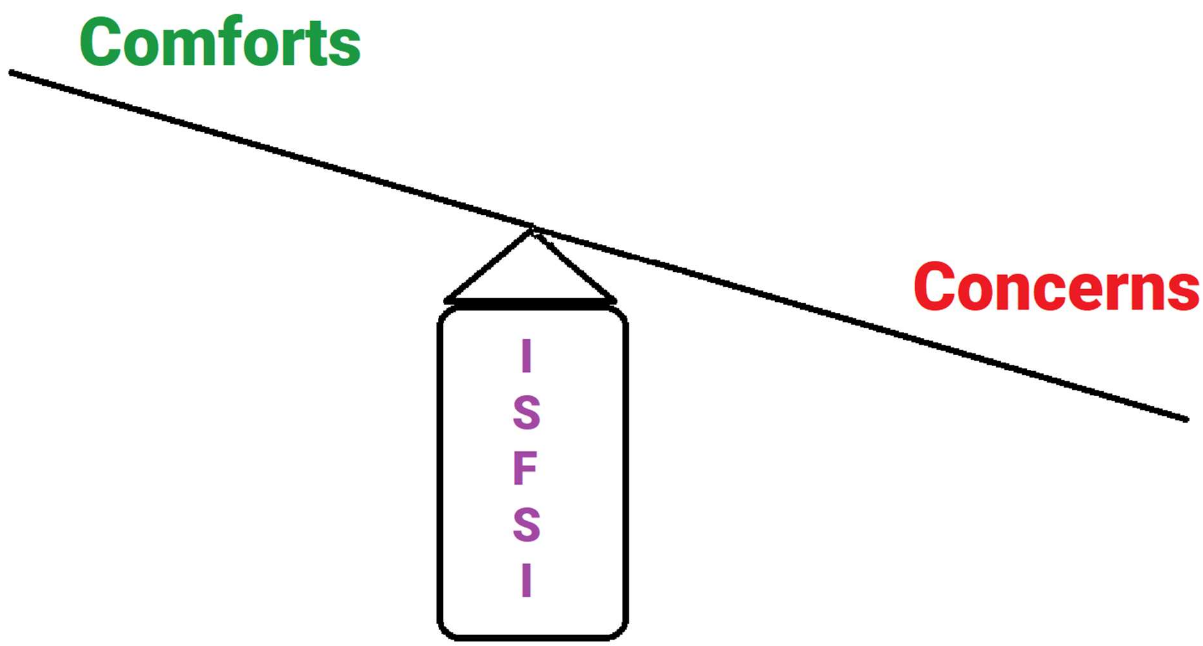
INDEPENDENT SPENT FUEL STORAGE INSTALLATIONS:

Comforts and Concerns



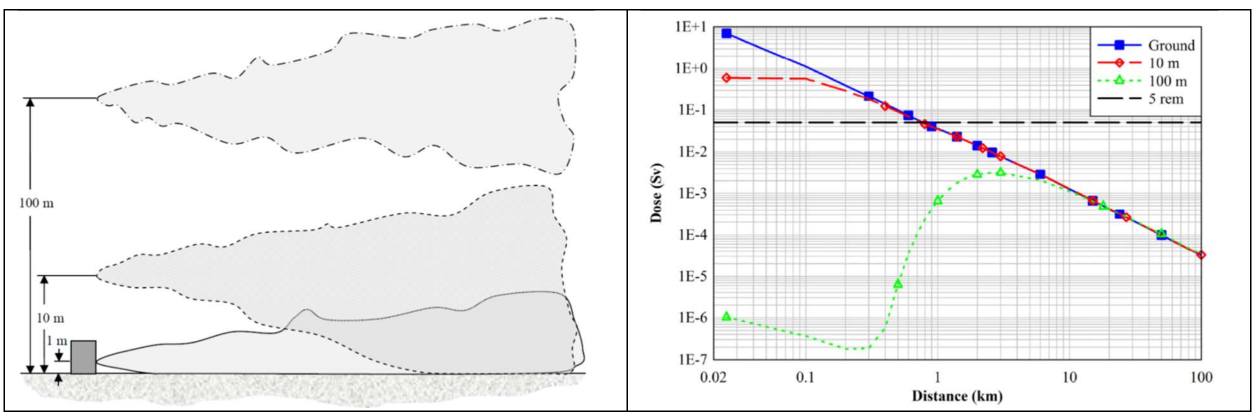
David Lochbaum
November 2023

When inside the core of an operating reactor, nuclear fuel is so hazardous that its owners must be protected by federal liability insurance from the financial consequences of an accident.[1] When inside a geological repository, spent nuclear fuel is so hazardous that the public must be protected from it for at least 10,000 years.[2] Between these uniquely hazardous endpoints,[*] spent nuclear fuel inside an Independent Spent Fuel Storage Installation (ISFSI) is deemed by the federal government so benign that safety, security and liability requirements are significantly lessened during that period.

Via the Nuclear Waste Policy Act (NWPA) of 1982, the federal government began collecting money from plant owners to site, construct, and operate a geological repository.[3] By 2020, the Nuclear Waste Fund balance exceeded $40 billion.[4] By the end of 2019, the federal government had placed a grand total of zero ounces of spent fuel in a geological repository. Because the U.S. Department of Energy (DOE) breached contracts it had signed with plant owners to begin removed spent fuel by January 1998, owner have sued and collected over $8 billion dollars by 2019.[5] And because NONE of the spent fuel has been placed in a geological repository, about 86,000 metric tons of spent fuel was being stored by 2019 at 75 operating or permanently shutdown nuclear plants in 33 states.[6] Since a typical reactor core holds about 100 metric tons of nuclear fuel, this means that roughly the equivalent of 860 reactor cores' worth of spent fuel are languishing in ISFSIs from sea to shining sea. And operating reactors are adding about 2,000 metric tons (or about 20 cores' worth) of spent fuel annually to the ISFSIs.[7]

According to the NRC, ten years after being removed from the core of an operating reactor, the radiation dose rate on the surface of a typical spent fuel assembly is 10,000 rem per hour. The LD50 (lethal dose of radiation expected to kill 50% of individuals so exposed) is 500 rem.[8] Thus, it would take 3 minutes or 180 seconds (whichever comes first) for a person to receive the LD50 from exposure to that dose rate.

Scientists at the Sandia National Laboratory (SNL) calculated the radiation dose consequences to the public from the postulated release of 0.1 percent of the radioactivity from one pressurized water reactor spent fuel assembly from a breached canister under various conditions.



The conditions studied by SNL included releases from canisters at ground level, canisters 32.8 feet off the ground (perched on a tower?) and canisters 328 feet above the ground (dangling from a hot air balloon?). The release from a breached ground-level canister was calculated to yield a radiation dose of 5 rem at about one-half mile downwind.[9] For context, federal regulations limit the annual radiation dose to a member of the public to 0.025 rem or 2.5E-4 Sieverts (Sv) from radioactivity released from nuclear power

[*] "Unique" because other all commercial enterprises in the United States obtain private liability insurance and the waste byproducts from all other commercial enterprises can be responsibly disposed of with considerably less than ten millennium isolation requirements.

plants to the air and water. The calculated dose 100 kilometers (km) or 62.14 miles from the breached canister exceeds the annual radiation dose limit for a member of the public.

The U.S. Nuclear Regulatory Commission (NRC) believes onsite spent fuel storage will end in the short-term, or perhaps as long as infinity. "Short-term" is merely six decades, a blink of an eye (for a statue or mannequin). Infinity is forever, give or take a week.

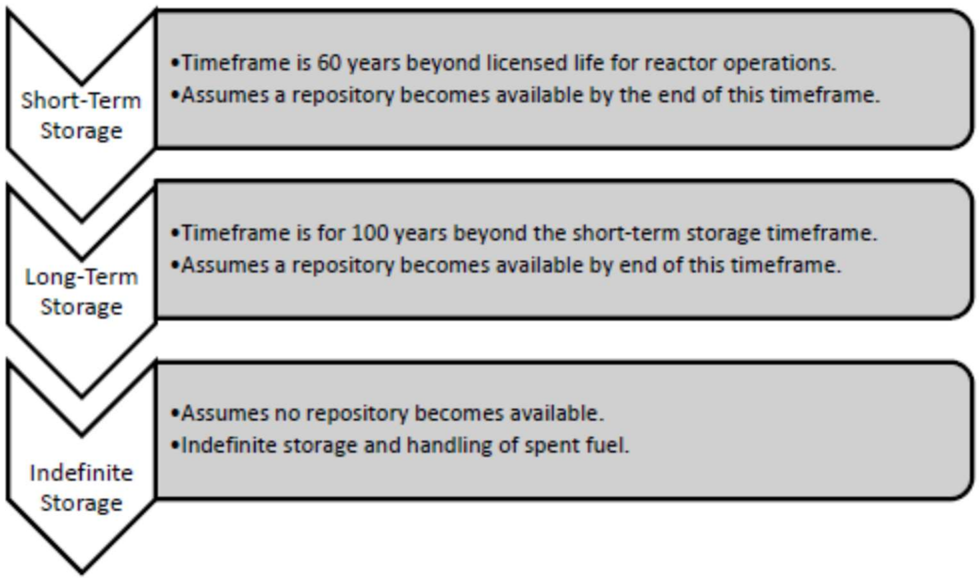


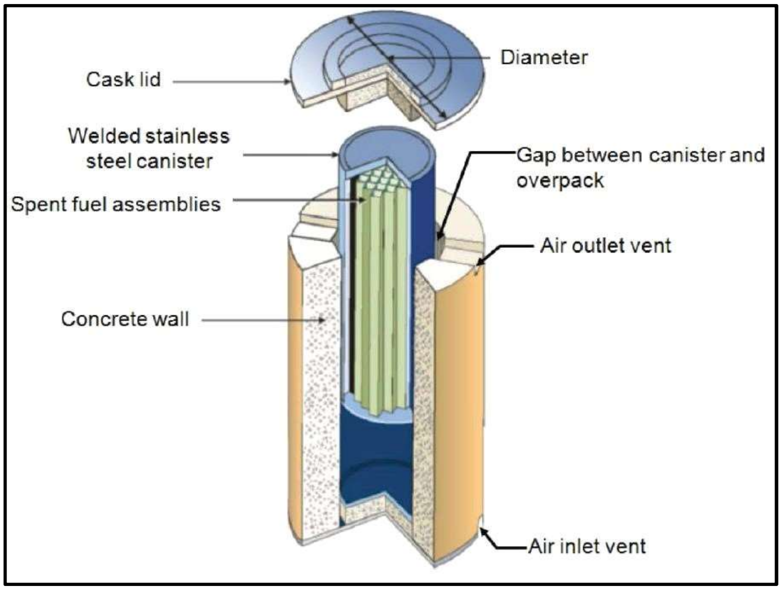
Figure ES-1. Three Storage Timeframes Addressed in this GEIS [10]

Initially, the NRC certifies ISFSIs for 20 years, merely four decades shorter than the NRC's projected short-term residence time. The NRC permits ISFSI certifications to be renewed for up to an additional 40 years, provided they conclude the proposed aging management programs (AMPs) for the ISFSIs are adequate to sustain the safety functions throughout the storage period.[11] The safety functions that ISFSIs must perform are defined in Section 72 of Title 10 of the Code of Federal Regulations, specifically §72.122, "Overall Requirements."[12] The ISFSI safety functions defined by these regulatory requirements include:

> "*Confinement barriers and systems*. (1) The spent fuel cladding must be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage. This may be accomplished by canning of consolidated fuel rods or unconsolidated assemblies or other means as appropriate."
>
> "Storage confinement systems must have the capability for continuous monitoring in a manner such that the licensee will be able to determine when corrective action needs to be taken to maintain safe storage conditions. For dry spent fuel storage, periodic monitoring is sufficient provided that periodic monitoring is consistent with the dry spent fuel storage cask design requirements. The monitoring period must be based upon the spent fuel storage cask design requirements."
>
> "The high-level radioactive waste and reactor-related GTCC waste must be packaged in a manner that allows handling and retrievability without the release of radioactive materials to the

environment or radiation exposures in excess of part 20 limits. The package must be designed to confine the high-level radioactive waste for the duration of the license."

Dry storage systems have been compared to Russian dolls where spent fuel assemblies are loaded into metal canisters which are placed inside concrete overpacks. The requirements above seek to (a) protect the spent fuel assemblies from degradation during storage, (b) ensure that canisters are monitored to ensure degradation, if any, is detected in time to implement appropriate fixes, and (c) the condition of the spent fuel assemblies and canisters must permit their safe removal (i.e., retrievability) at some point in the future.



The SNL study of public radiation doses from postulated releases from a breached illustrate the importance of these requirements. If the spent fuel assemblies do not degrade during storage, the amount of radioactivity available to be released is minimized. If canister degradation is found and fixed before integrity is lost, radioactivity releases are minimized.

This report focuses on these three safety functions, identifying **comforts** that these requirements will be successfully met throughout the period of dry storage as well as **concerns** that they will be violated.

Spent Fuel Assemblies Will Not Degrade During Storage

An empty metal canister is lowered into a spent fuel pool. Spent fuel assemblies are then moved underwater one at a time from storage racks into the canister. The decay heat levels of the loaded spent fuel assemblies must comply with limits depending on the design and certification of the canister. The loaded canister is removed from the pool, drained of water, and sealed with a lid welded or bolted in place. The canister is moved to the ISFSI and placed inside a protective overpack or vault.

The regulatory requirement against spent fuel assembly degradation during storage ensures the spent fuel can be moved with the canister when that day arrives.

The primary causes of spent fuel assembly degradation within a canister are overheating and corrosion. Overheating occurs when the decay heat produced by the spent fuel isn't conducted through the canister's wall as fast as it is generated. Corrosion is essentially rusting of the metal fuel rod cladding.

COMFORTS

In Holtec's HI-STORM design, after water is removed from the canister, it is replaced by helium. The helium guards against degradation due to overheating and corrosion:

> "After moisture removal, the MPC [multi-purpose canister, the purposes being storage followed by transport without repackaging to a geological repository] cavity is backfilled with helium. The helium backfill provides an inert atmosphere within the MPC cavity that precludes oxidation and hydride attack of the SNF [spent nuclear fuel] cladding. Use of a helium atmosphere within the MPC contributes to the long-term integrity of the fuel cladding, reducing the potential for release of fission gas or other radioactive products to the MPC cavity. Helium also aids in heat transfer within the MPC and reduces the maximum fuel cladding temperatures. MPC inerting, in conjunction with the thermal design features of the MPC and storage cask, assures that the fuel assemblies are sufficiently protected against degradation, which might otherwise lead to gross cladding ruptures during long-term storage."[13]

> "The inert helium atmosphere in the MPC provides a non-oxidizing environment for the SNF cladding to assure its integrity during long-term storage. ... Maintaining an inert environment in the MPC mitigates conditions that might otherwise lead to SNF cladding failures."[14]

> "The primary confinement boundary against the release of radionuclides is the cladding of the individual fuel rods. The spent fuel rods are protected from degradation by maintaining an inert gas atmosphere (helium) inside the MPC and keeping the fuel cladding temperatures below the design basis values." [15]

> "The helium backfill gas plays an important role in the MPC's thermal performance. The helium fills all the spaces between solid components and provides an improved conduction medium (compared to air) for dissipating decay heat in the MPC. Within the MPC the pressurized helium environment sustains a closed loop thermosiphon action, removing SNF heat by an upward flow of helium through the storage cells."[16]

> "The principle objective of the vacuum drying [i.e., removal of all water from the canister before refilling with helium] analysis is to ensure that fuel temperatures are below ISG-11, Rev. 3 temperature limits."[17]

"The MPC thermal design maintains the fuel rod cladding temperatures below the values stated in Chapter 4 such that fuel cladding is not degraded during the long term storage period." [18]

"The MPC, which is filled with helium, provides a nonaqueous and inert environment. Insofar as corrosion is a long-term time-dependent phenomenon, the inert gas environment in the MPC precludes the incidence of corrosion during storage on the ISFSI." [19]

The canister's design also guards against criticality of the spent fuel assemblies. Criticality, a nuclear chain reaction, releases considerable energy that can cause overheating damage. Protection against criticality thus also protects against overheating damage:

"Criticality is controlled by geometry and neutron absorbing materials in the fuel basket. The MPC-24/24E/24EF (all with lower enriched fuel) and the MPC-68/68F/68FF do not rely on soluble boron credit during loading or the assurance that water cannot enter the MPC during storage to meet the stipulated criticality limits."[20]

Scientists at the Argonne National Laboratory examined spent fuel rods that had been in dry storage at the Surry nuclear plant's ISFSI for over 15 years. The examinations looked at fuel pellets for microstructure changes and at fuel rods for oxide thickness on the cladding's outer surface, cladding hardness, cladding hyriding, and other parameters. The researchers concluded that 15 years of dry storage "caused no discernible degradation of the Surry rods."[21]

CONCERNS

The dual benefits of inerting protecting against overheating and damage corrosion are lessened if a canister's integrity is breached, allowing the helium to leak out and air to leak in. Air is not as good a conduit for transferring heat as helium as shown in the following table: [22]

SUMMARY OF HI-STORM SYSTEM MATERIALS
THERMAL CONDUCTIVITY DATA

Material	At 200°F (Btu/ft-hr-°F)	At 450°F (Btu/ft-hr-°F)	At 700°F (Btu/ft-hr-°F)	At 1000°F (Btu/ft-hr-°F)
Helium	0.0976	0.1289	0.1575	0.1890
Air*	0.0173	0.0225	0.0272	0.0336

If air replaces helium within a canister, its lower thermal conductivity results in the fuel cladding temperature rising. While not inherently meaning that overheating damage occurs, it does mean that margin to overheating damage will be reduced.

Holtec's analyses for the canisters assumes that the inerted condition within the canister is preserved:

"The helium gas is therefore assumed to be retained in an undiluted state, and may be credited in the thermal analyses." [23]

Inerting is assumed, but is it assured? Holtec's analyses report no credible failure of the confinement system (i.e., canister) during all conditions:

"No credible scenario has been identified that would cause failure of the confinement system." [24]

> "The MPC confinement boundary ensures that the helium atmosphere inside the MPC is maintained during normal, off-normal, and accident conditions of storage and transfer." [25]

The Electric Power Research Institute (EPRI) conducted a Failure Modes and Effects Analysis (FMEA) for dry cask storage systems and found confinement boundary failure to be credible:

> "In this FMEA, the credible canister degradation failure modes almost exclusively affect the regulatory requirement to maintain a confinement boundary. The most credible failure mode identified is a loss of confinement boundary integrity by through-wall cracking."[26]

EPRI further stated the obvious:

> "For a canister with a through-wall flaw, some loss of helium is likely to have occurred in the interval between through-wall growth and discovery of the flaw by inspection."[27]

If – or rather, when – the canister's wall cracks, helium leaks out.

The NRC revised its regulation governing dry storage systems in February 2011 to permit renewal of ISFSI Certificates of Compliance (CoC) provided the application described Aging Management Programs (AMPs) for Structures, Systems and Components (SSCs):

> "The NRC is amending §§ 72.42 and 72.240 to require that applicants for specific license and CoC renewals describe a program, in their applications, for the management of issues associated with aging that could adversely affects SSCs. … AMP requirements will ensure that SSCs will perform as designers intended during the renewal period. … For specific licensees, AMP requirements will be reflected in the terms and conditions of the renewed specific license."[28]

> "An AMP is a program for addressing aging effects that may include prevention, mitigation, condition monitoring, and performance monitoring. The final rule adds a definition of AMP to the part 72 definitions section, § 72.3, because SSCs must be evaluated to demonstrate that aging effects will not compromise the SSC's intended functions during the renewal period." [29]

If ISFSIs were really and truly immune to aging degradation throughout the duration of their storing spent fuel, aging management programs would not be required. Since the NRC requires aging management programs, ISFSIs are clearly susceptible to degradation. Holtec's notion that failure of the confinement systems is not a credible event is thus what is not credible.

EPRI reviewed operating experience and concluded that chloride-inducted stress corrosion cracking (CISCC) was the most likely way for a canister's integrity to be breached:

> "Based on the literature review, a failure modes and effects analysis (FMEA) was performed, and it concluded that a tight through-wall crack growing by CISCC was the most likely way in which the canister could be penetrated. The FMEA further concluded that the locations of greatest susceptibility were regions of the surface near welds that had elevated aerosol deposition rates and lower surface temperatures (i.e. locations more likely to support deliquescence of chloride salts) … ."[30]

But CISCC is not a concern if the time needed for a crack to compromise a canister's integrity is longer than the duration spent fuel is stored (i.e., the bend but not break theory). Scientists at the Sandia National Laboratory were unable to conclude that canisters would out-last the cracking threat:

"This progress report describes work performed during FY20 at Sandia National Laboratories (SNL) to assess the localized corrosion performance of container/cask materials used in the interim storage of spent nuclear fuel (SNF). **Of particular concern is stress corrosion cracking (SCC), by which a through-wall crack could potentially form in a canister outer wall over time intervals that are shorter than possible dry storage times**."[31] [boldfacing added]

Flaws on the outer surface of a canister invite CISCC:

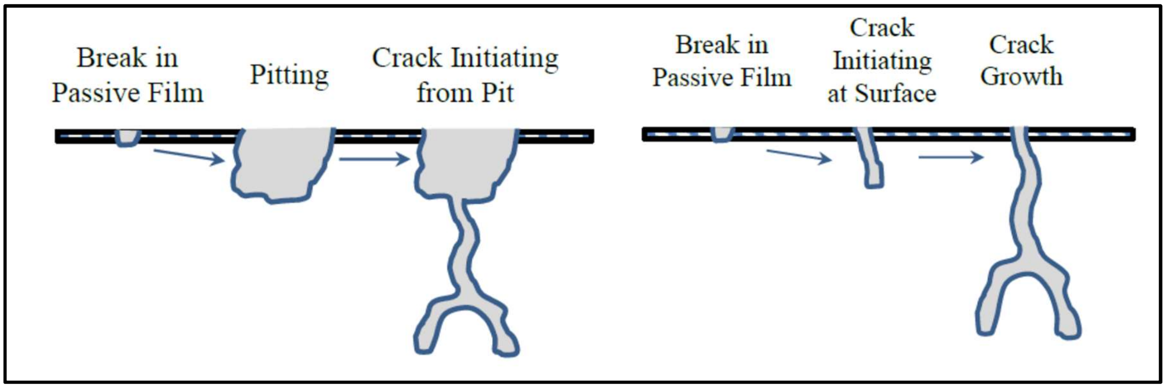
"Atmospheric CISCC typically initiates at a location of pitting or crevice corrosion and propagates along the surface and into the material. Atmospheric CISCC typically initiates at a location of pitting or crevice corrosion and propagates along the surface and into the material."[32]

In fact, surface flaws (e.g., gouges) are very conducive to CISCC degradation: [33]

Most Likely Locations for CISCC Degradation (Adapted from Reference [21])

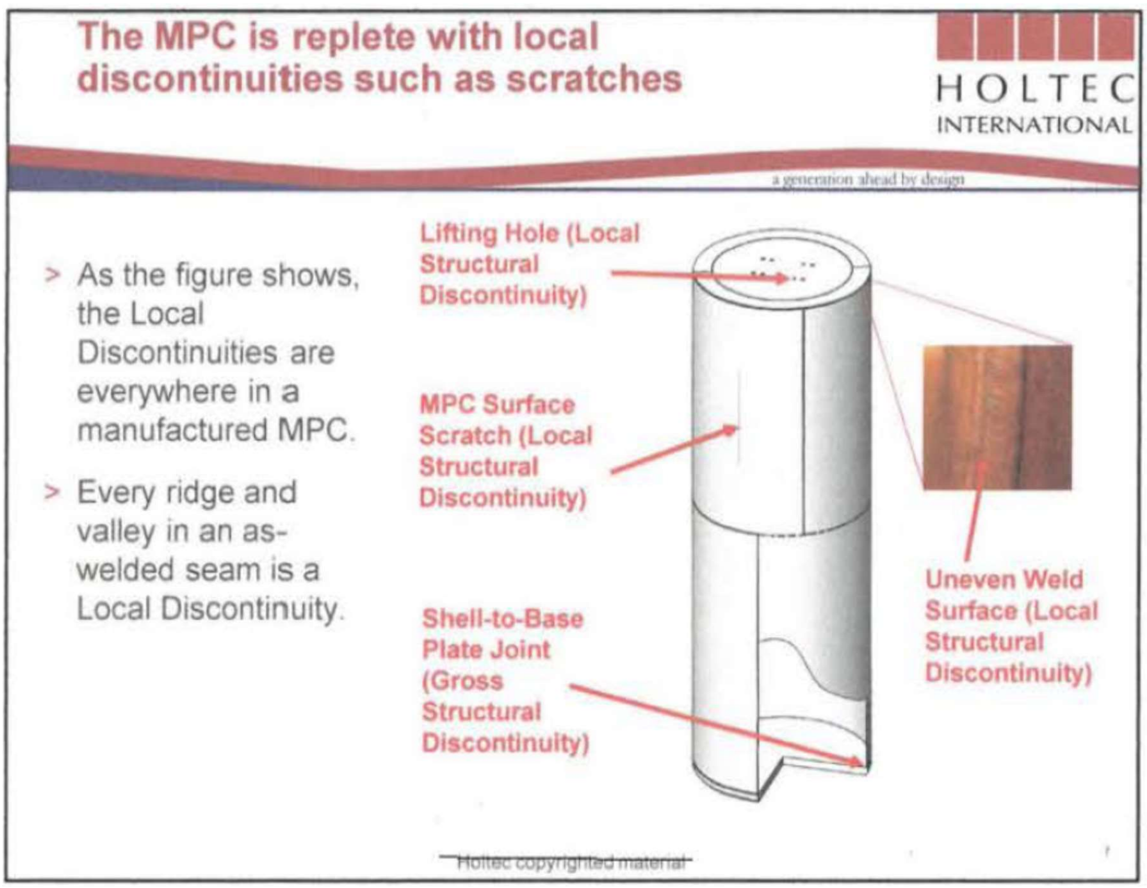
Factor for CISCC Susceptibility	Locations on Horizontal Canister	Locations on Vertical Canister
Tensile Stresses on OD	Regions in the vicinity of welds (e.g. within about 2 thicknesses)	Regions in the vicinity of welds (e.g. within about 2 thicknesses)
Low Surface Temperature(1)	Lids; shell along canister underside and along ends	Lower region of canister OD
Elevated Chloride Deposition	Upward-facing surfaces of canister shell	Top lid; possibly the areas in the vicinity of the overpack inlets
Crevice-like Geometry	Support rail contact region	Areas where canister contacts the overpack channels/standoffs(2)
Material Condition	Areas of heavy grinding or mechanical damage (e.g. gouges)	Areas of heavy grinding or mechanical damage (e.g. gouges)
Most Susceptible Location(s)	Shell welds at canister ends (top surface); support rail interface near welds	Canister sides near welds at the bottom of the canister

The EPRI report[34] illustrated how cracks propagate from surface flaws:



Holtec conceded that flaws on canister outer surfaces are far from rare:

> "Scratches in plates and shells in the manufacture of any weldment are present everywhere. From the time a stack of plates arrives at the factory, the rubbing between the plate layers causes scratches to develop. Most plates come from the mill bearing scratches. Rolling, bending, forming, shearing, machining, etc., necessary to fabricate are all potential scratch-making operations. **Surface scratches are commonplace and expected in MPCs**."[35] [boldfacing added]



EPRI described the consequences if the integrity of a canister is breached:

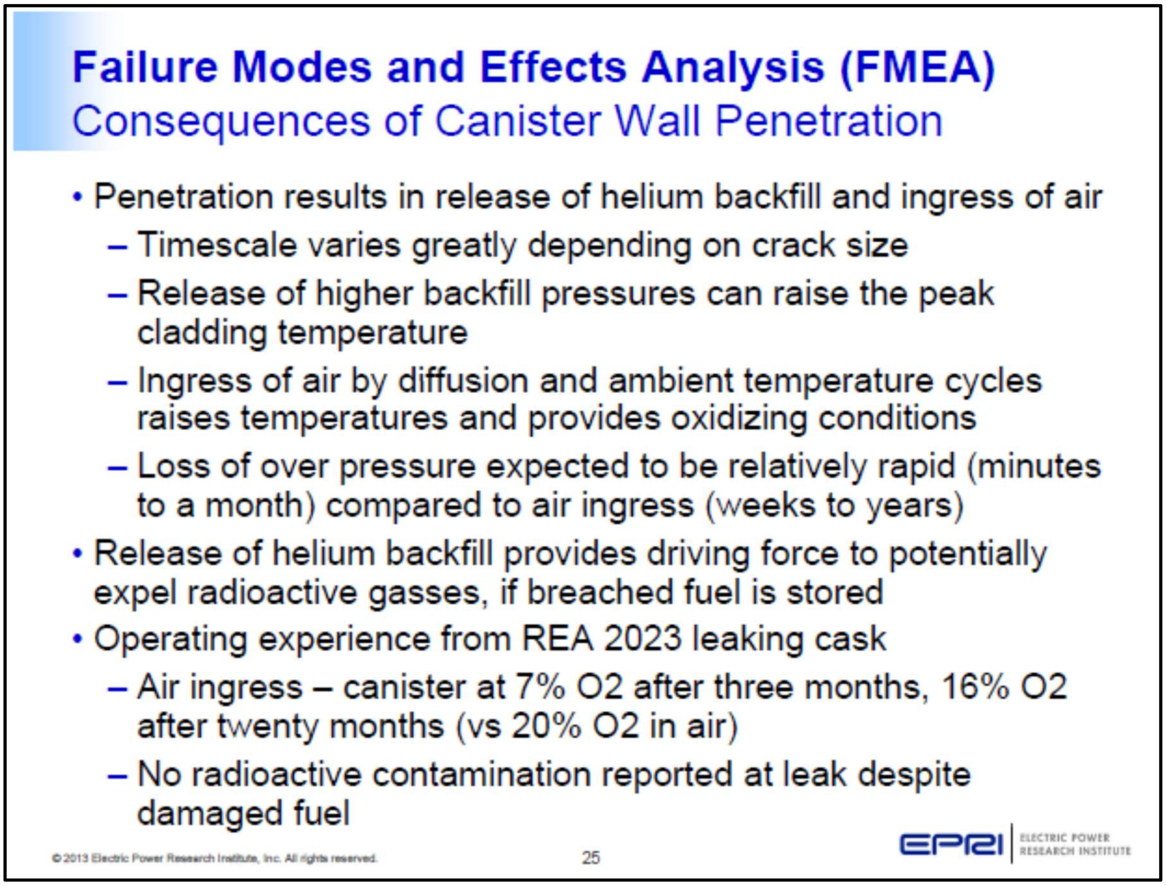
> "Subsequent to loss of canister confinement, the helium backfill would escape the canister, potentially entraining and releasing radioactive gases or particles from the canister. After depressurization, the remaining helium would gradually be displaced as air and moisture enter due to diurnal and seasonal thermal expansion. Considering the criteria in Section 3.1.2, **the potential effects of the new environment surrounding the stored fuel assemblies include: (1) release of radiation following loss of fuel cladding integrity, (2) exceeding cladding temperature limits due to loss of helium backfill and consequential degradation of heat transfer, and (3) difficulty in removal of fuel from the canister due to gross fuel assembly degradation or fuel basket deformation.** A criticality event is considered not credible due to the non-mechanistic changes in stored fuel geometry required to lead to criticality even after the ingress of moderator."[36] [boldfacing added for emphasis]

Fortunately, protection against criticality seems undiminished by through-wall cracking of the canister's wall. Unfortunately, protection against degradation of the spent fuel, protection against overheating damage, and protection against corrosion may be diminished.

An analysis of the overheating and corrosion consequences of a Holtec canister being breached has not been located (recall from above Holtec's assumption that container integrity can never be compromised for any reason). An analysis for the partial loss of helium following the postulated breach of another canister showed a significant increase in the spent fuel rod cladding temperature (from 700°F to 1,100°F):

> "Depending on the canister, replacement of helium with air can significantly affect the peak cladding and fuel temperature. For example, per the MAGNASTOR FSAR, the effect of a reduction in the helium backfill pressure from 100 psig to 15 psig leads the peak cladding temperature to increase from roughly 700°F to about 1100°F (370°C to 595°C) for the design basis heat load (35.5 kW)."[37]

An EPRI slide presentation[38] transforms the question from whether a canister can be breached to when will the next canister be breached:



The Final Safety Analysis Report for Holtec's HI-STORM 100 canister design defines the limiting condition for operation (LCO):

> "LCO: A dry, helium filled and sealed MPC establishes an inert heat removal environment necessary to ensure the integrity of the multiple confinement boundaries. Moreover, it also ensures that there will be no air in-leakage into the MPC cavity that could damage the fuel cladding over the storage period."[39]

An LCO defines the minimum conditions for continued safety. When an LCO is not met, Action Statement(s) define what response measures are required. Holtec's HI-STORM 100 FSAR defines these Action Statements when the inerted helium LCO is not met:

> "ACTION C.1: If the helium backfill quantity limit has been determined not to be met during TRANSPORT OPERATIONS or STORAGE OPERATIONS, an engineering evaluation is necessary to determine the quantity of helium within the MPC cavity. **Since too much or too little helium in the MPC during these modes represents a potential overpressure or heat removal degradation concern, an engineering evaluation shall be performed in a timely manner**."[40] [boldfacing added for emphasis]

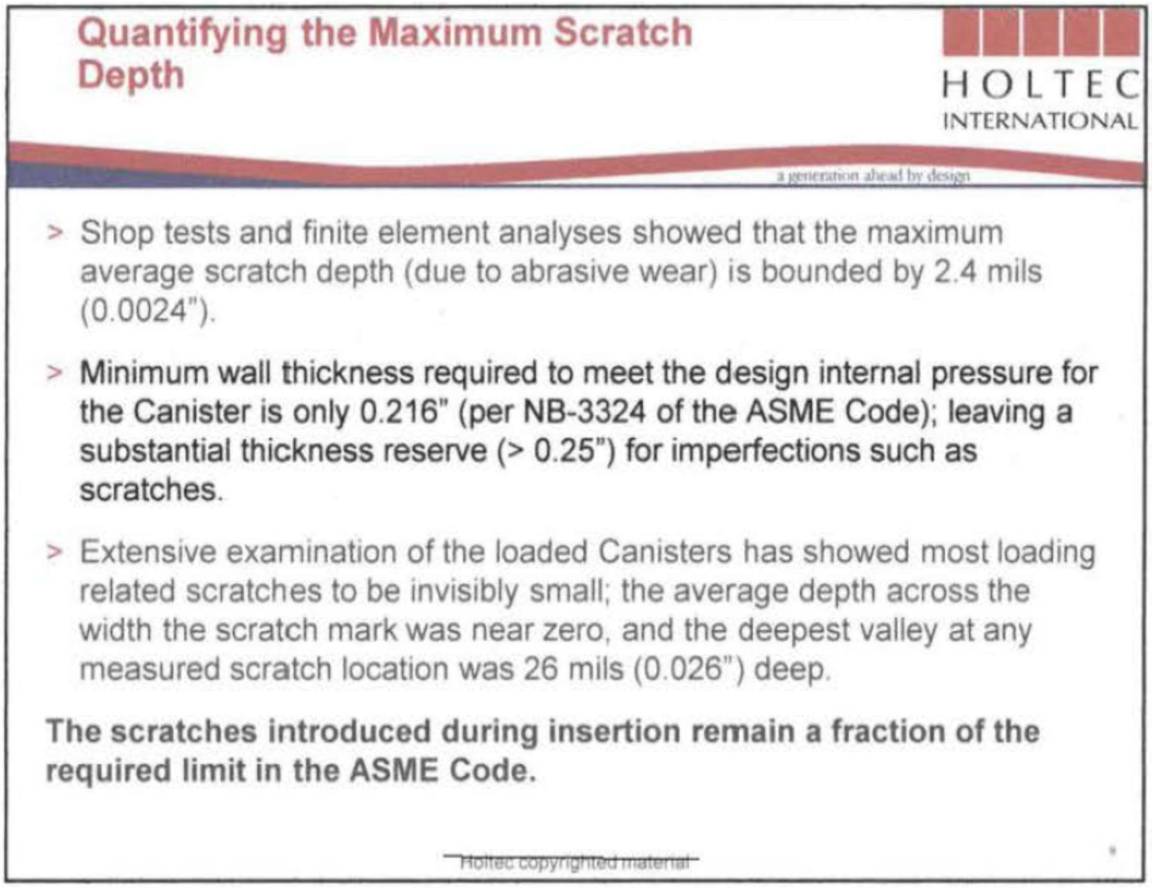
> "ACTION D.1: If the helium leak rate limit has been determined not to be met during TRANSPORT OPERATIONS or STORAGE OPERATIONS, an engineering evaluation is necessary to determine the impact of increased helium leak rate on heat removal and off-site dose. Since the HI-STORM OVERPACK is a ventilated system, any leakage from the MPC is transported directly to the environment. **Since an increased helium leak rate represents a potential challenge to MPC heat removal and the off-site doses, reasonably rapid action is warranted**."[41] [boldfacing added for emphasis]

If a canister's integrity is breached, "reasonably rapid action is warranted" in the form of an engineering evaluation performed in a timely manner. The implication therefore is that a through-wall crack must be identified in a prompt manner; otherwise reasonably rapid action simply cannot be performed.

Canister Degradation, if it occurs, Will be Detected to Permit Timely Corrective Actions

COMFORTS

Following a near-miss drop of a canister at San Onofre's ISFSI, Holtec provided information to the NRC regarding scratches on the outer surfaces of canisters:[42]



Surface flaws, while "commonplace," are reported as being shallow relative to the thickness of the canister wall. The greater the difference between flaw depth and wall thickness, the larger the margin for finding and fixing degradation before canister integrity is lost.

Fuel assemblies damaged in the March 1979 partial meltdown of the Three Mile Island Unit 2 reactor were loaded into NUHOMS-12T horizontal storage modules (HSMs) and transported to the Idaho National Laboratory in 1999. The following year, cracks in the HSMs were noted, but dismissed then as being "cosmetic and insignificant." In less than a decade, this dismissal was dismissed.

> "However, in 2007, the licensee observed continued cracking, crazing and spalling as well as increased efflorescence on the HSM surfaces. ... The licensee performed an evaluation in 2007, during which it determined that the HSMs were capable of performing their design basis functions. In 2008, the licensee noted that 28 of the 30 HSMs [93.3%] had cracks, mostly emanating from the anchor bolt blockout holes with widths up to 0.95 centimeters (0.38 inches). At that time, the licensee determined that the HSMs appeared to be prematurely deteriorating and

> that continued crack growth could impact the ability of the HSMs to fulfill their originally planned 50-year design service life."[43]

93.3% of the storage containers developing significant degradation is comforting because it shows the need to identify the most vulnerable or susceptible canister may not be crucially important – nature will degrade all canisters, albeit at varying rates. And, the identification of significant degradation within 10 years revealed the root cause (water intrusion) and steps being taken to prevent water intrusion and continued degradation.

CONCERNS

The American Society of Mechanical Engineers (ASME) developed standards covering manufacture and inspection of dry cask storage systems. The inspection protocols have limited scope (i.e., one, maybe two casks) and infrequent frequency (i.e., every ten, maybe twenty, years):

> "ASME Code Case N-860 further defines inspection recommendations. This code case leverages EPRI guidance to categorize susceptibility of canisters to CISCC. Code Case N-860 defines an inspection population of one or two (dependent on susceptibility per EPRI guidance) casks from the total population. The initial inspection interval defined by the code case is every 10 years. The interval is decreased to 5 years after a finding of corrosion of a specified significance. The code case allows for an increase in inspection interval to 20 years if repeat inspections result in no findings of CISCC and the site susceptibility is low (per the EPRI guidance)."[44]

The NRC accepts limited-scope inspections provided that factors like fabrication issues (e.g., surface gouges) are considered:

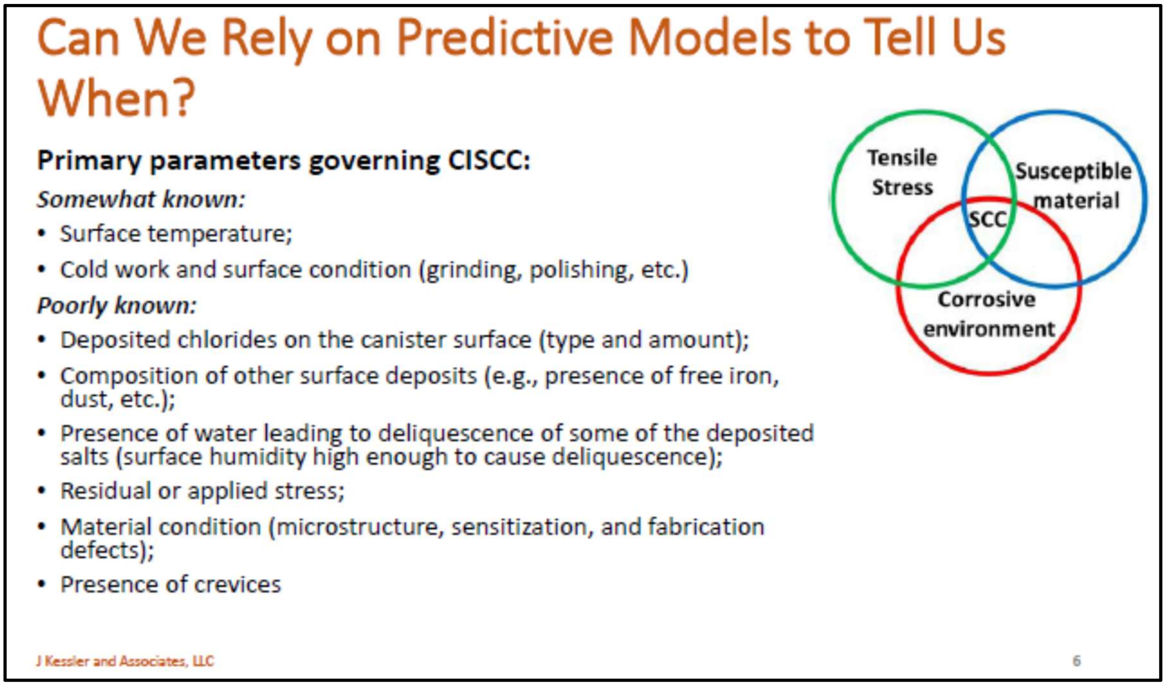
> "For a limited sample size, the applicant should identify and justify the number of SSCs to be evaluated per inspection, including the extent of the inspection for each SSC (e.g., all accessible areas of five concrete overpacks in service), and criteria for selection of the specific SSCs for inspection based on parameters that may contribute to the operable aging mechanisms and effects. Consideration should also be given to event-driven fabrication or operational issues that may contribute to degradation when selecting SSCs for inspection (e.g., welding repairs, occurrence of natural or man-induced events, exposure to potentially corrosive environments before the storage term, duration of time between fabrication of an SSC and the start of the storage term)."[45]

Recall that surface flaws (e.g., gouges) invite CISCC. EPRI reported the ying and yang of CICSS cracking:

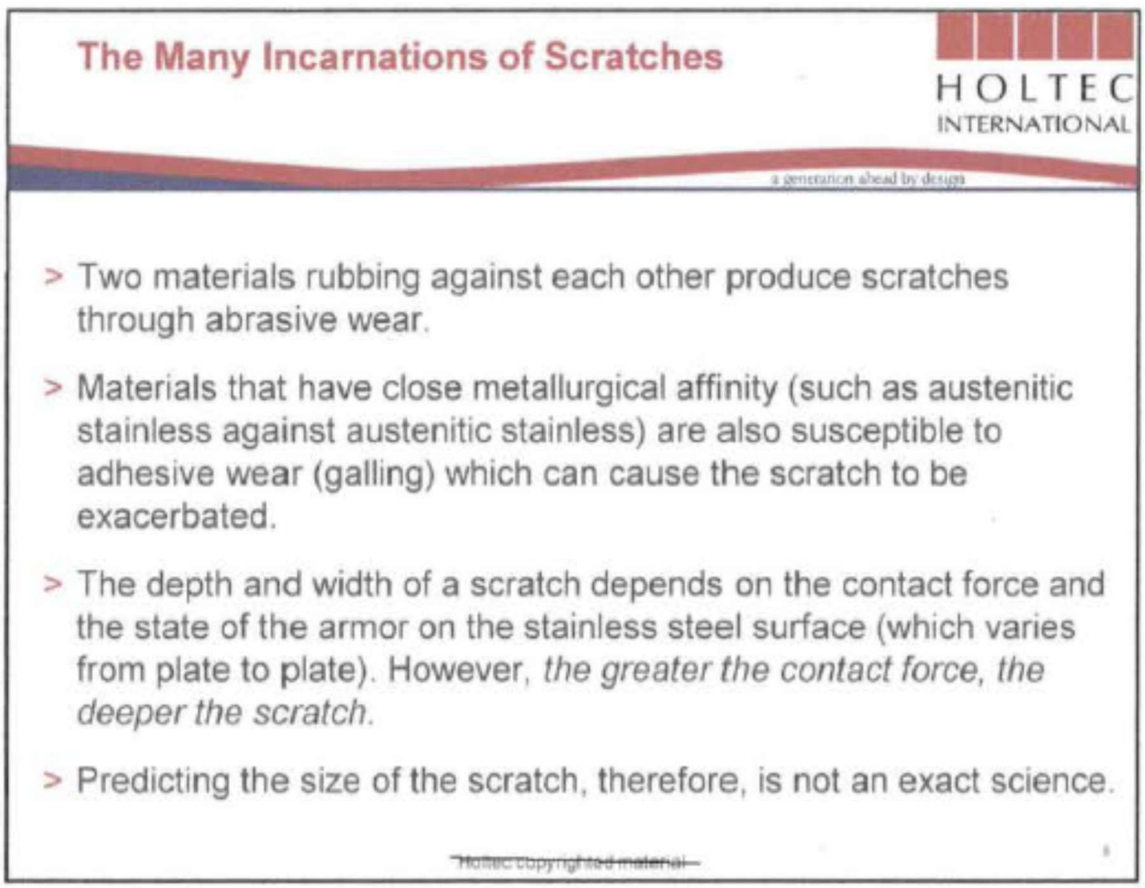
> "The very tight and tortuous morphology of CISCC cracking means that through-wall cracking provides a flow path with a high flow resistance. This means that a leak would be relatively slow and unlikely to release particulates from within the canister. However, the tight morphology also makes direct visual identification of CISCC cracking difficult without high magnification."[46]

Inspecting one, maybe two, canister(s) every ten, maybe twenty, years seems quite unlikely to find cracking before it progresses through-wall unless the selection of the one, maybe two, canister(s) very fortunately picked the worst-case, most susceptible canister(s).

According to an industry consultant,[47] the factors governing CISCC – the purported primary cause of through-wall cracking – are either "somewhat known" or "poorly known."



And Holtec conceded that all surface flaws are not alike and predicting the size of a flaw is "not an exact science":[48]



Thus, the crystal balls used to determine which one, maybe two, canister(s) to inspect every ten, maybe twenty, years are more like bowling balls. Picking canisters by drawing slips of paper from a hardhat seems as likely to identify the most vulnerable canister, or two, as the alleged scientific process.

While one, maybe two, canister(s) get inspected every ten, maybe twenty, years at each ISFSIs, there are dozens of ISFSIs scattered across the United States. Results from these few and infrequent inspections are compiled by the Institute of Nuclear Power Operations (INPO) for use by INPO members in either confirming their initial picks were spot-on or making adjustments to the scope and/or frequency of spot checks:

> "The ISFSI Aging Management INPO Database (ISFSI AMID) compiles industry experience to be leveraged using learning aging management principles to improve inspections throughout the industry. Inspection and monitoring results should be submitted to the ISFSI AMID."[49]

But not everyone is an INPO member. For example, during my tour of the Indian Point site on July 27, 2022, I was informed that Holtec is <u>not</u> an INPO member. Whatever value is provided by the ISFSI AMID is diminished by lack of access to its information.

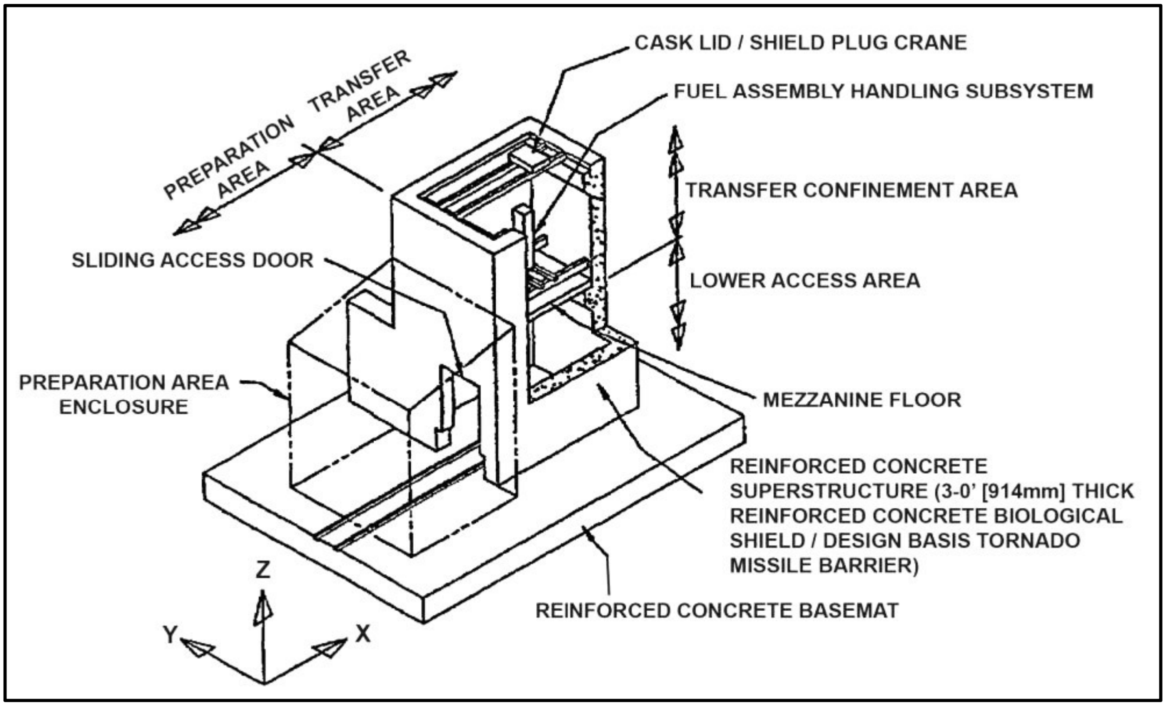
If the guess, or rather the scientifically-informed selection, of the most vulnerable canister is correct and the inspection every ten, maybe twenty, years frequent enough to identify a crack before it breaches the canister's integrity, the "fix" poses a challenge:

> "Repair of a through-wall flaw may require removal of a canister from its overpack. It may not be possible to move the canister back to a spent fuel pool, or seal the canister in an oversized container, and it may be necessary to temporarily relocate the canister to a hot-cell or to a larger overpack to allow access to 100% of the canister surface."[50]

The NRC's Generic Environmental Impact Statement (GEIS) for long term ISFSI storage assumed that each and every ISFSI site across the country would build a dry transfer system (DTS) to accommodate the repackaging of spent fuel assemblies from a degraded canister into a pristine canister fresh out of its shrink-wrap.[51] The NRC's GEIS did mention a slight drawback to this DTS assumption:

> "**Although there are no dry transfer systems (DTSs) at U.S. nuclear power plant sites today**, the potential need for a DTS, or facility with equivalent capability, to enable retrieval of spent fuel from dry casks for inspection or repackaging will increase as the duration and quantity of fuel in dry storage increases. A DTS would enhance management of spent fuel inspection and repackaging at all ISFSI sites and provide additional flexibility at all dry storage sites by enabling repackaging without the need to return the spent fuel to a pool. A DTS would also help reduce risks associated with unplanned events or unforeseen conditions and facilitate storage reconfiguration to meet future storage, transport, or disposal requirements."[52] [**boldfacing** added for emphasis]

So, ISFSIs exist across the land because the geological repository that was required under the Nuclear Waste Policy Act – a federal law – to be available by January 1998 will be aided by dry transfer systems assumed in 2014 to be available but still unavailable by 2023. While a dry transfer system does not exist anywhere in the United States, at least a drawing of a dry transfer system exists:[53]



The ISFSI canister inspection scheme seems contrary to decades of nuclear power safety experience. Typically, inspection and testing efforts are initially broad. Once years of inspection and testing results demonstrate where problems occur and where they don't, inspection and testing efforts are scaled back to focus on the areas of known problems. In other words, operating experience differentiates between muscle and fat allowing properly informed decisions on where to avoid cutting muscle.

The ISFSI canister inspection scheme employs a different tactic by inspecting one, maybe two, canisters every ten, maybe twenty, years. When inspection results or "surprises" reveal the deficiencies in this "inspection-lite" approach, the scope and frequency will be broadened to belatedly provide the necessary protection of public health and safety.

Spent Fuel Assemblies Will be Able to be Removed When that Time Comes

COMFORTS

Scientists at the Idaho National Engineering and Environmental Laboratory (INEEL) examined and tested spent fuel rods that had been in a dry storage cask at the Surry nuclear plant in Virginia for over 14 years. The cask's fuel basket components, welds, fuel cladding surfaces, etc. were examined. Fuel rods from one spent fuel assembly were removed and shipped to the Argonne National Laboratory[54] for mechanical examination and both non-destructive and destructive testing. The researchers reported that the "examination and testing indicate the concrete storage pad, CASTOR V/21 cask, and cask contents exhibited sounds structural and seal integrity and that long-term storage had not caused detectable degradation of spent fuel classing or the release of gaseous fission products."[55]

Scientists at the Oak Ridge National Laboratory (ORNL) tested spent fuel rods from the HB Robinson nuclear plant in South Carolina to evaluate the mechanical behavior under storage and transportation conditions. Static testing included applying force on the fuel rods to bend them until they broke for comparison to the physical strength of pristine cladding. The testing also included applying lesser force on the fuel rods to bend them back and forth to simulate vibrations experienced during transportation. One of the dynamic tests reached 13,000,000 cycles before being stopped. The researchers conceded that "The results of this study are particular to the specific fuel tested. The results are not intended to be generically applicable and may not be inclusive of all cladding types and fuel burnup levels."[56]

The INEEL and ORNL research supplements actual experience packaging spent fuel assemblies decades ago for transport to facilities at Morris, Illinois and West Valley, New York for reprocessing, and then repackaging and transport back to nuclear plants when reprocessing in this country was curtailed.

CONCERNS

Spent fuel assemblies have been onsite in dry storage systems at several nuclear plants for decades and will likely remain in onsite dry storage systems at these and many other nuclear plants for several decades into the future. At some point, the canisters will be removed from the dry storage systems and either transported offsite or repackaged into other canisters for transport offsite. I asked representatives at the San Onofre nuclear plant if there was a regulatory requirement for the canisters in their ISFSI to be inspected before being transported offsite. Their answer was yes, and no:[57]

There are three (3) transportation CoCs associated with SONGS dry storage canisters. Whether a canister contains high burnup fuel (HBF) may influence whether a pre-shipment inspection is required. Storage of HBF within the 24PT1 canister is not authorized.

Canister Model (Stores)	Certificate of Compliance (CoC)	Canister inspection/integrity verification requirement for non-HBF?	Canister inspection/integrity verification requirement for HBF?
NUHOMS 24PT1 (Unit 1 Fuel)	71-9255	No	N/A
NUHOMS 24PT4 (Units 2/3 Fuel)	71-9302	Yes	Yes
Holtec MPC-37 (Units 2/3 Fuel)	71-9373	No	Yes

A SCE representative stated the company "would likely inspect canisters prior to offsite transportation, even if not required by the CoC."[58] I have no reason to doubt that this company would voluntarily inspect every canister before loading them up and shipping them out. Their representatives were very candid and forthcoming during our meeting. But considering that canisters may never ever have been inspected even once during their decades of onsite storage, the NRC should not leave it up to the owner's discretion.

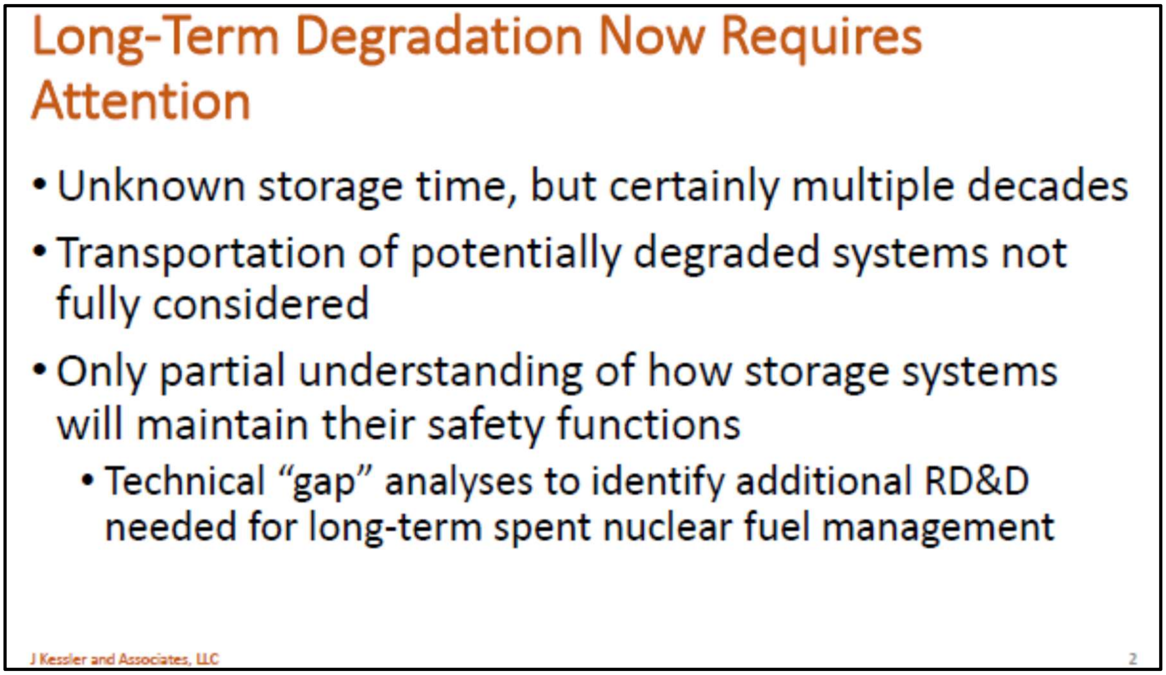
Spent fuel assemblies literally fell apart when moved after years of storage in a spent fuel pool:

> "A spent fuel assembly being moved in the spent fuel pool at GPU Nuclear Corp's Oyster Creek fell apart and 41 fuel rods dropped about seven feet into the spent fuel rack, June 15. … The assembly failed as it was being lowered into a new location in the pool. Preliminary reports indicate the bottom plate of the 7x7 assembly separated from the tie rods. The upper tie plate and eight tie rods – which are a special type of fuel rod – were suspended in the pool June 15. … The assembly was loaded into Oyster Creek's reactor in April 1973 and was put in the spent fuel pool seven years later. … GPUN was re-positioning the assembly in preparation for its eventual transfer to an on-site, interim, above-ground dry cask storage facility."[59]

Will canisters fall apart when moved after significantly longer years of unmonitored storage in an ISFSI?

Time (and gravity) will tell.

Until then, an industry consultant pointed out that moving potentially degraded systems has not been fully considered:[60]



Maybe "degraded systems not fully considered" plus "partial understanding of how storage systems will maintain their safety functions" plus uninspected canisters pre-shipment equals "adequate protection of public health and safety." Maybe not.

Maybe a drawing of a degraded system being transported exists.

Turning Concerns into Comforts

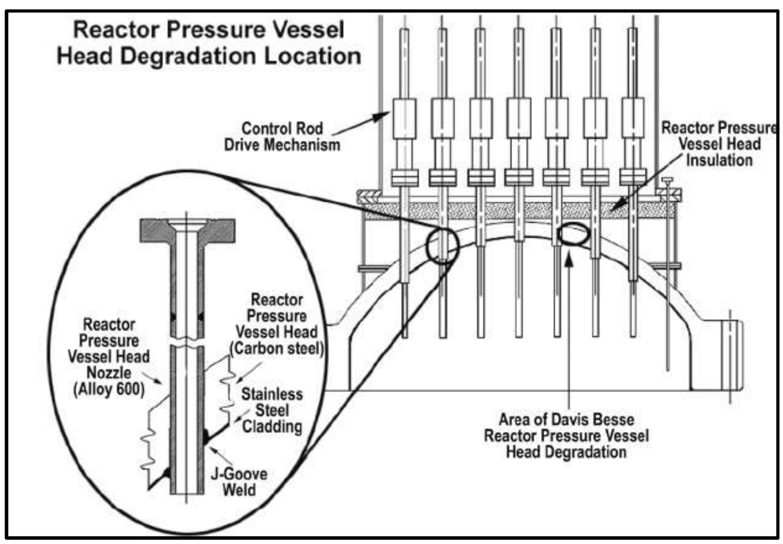
Finding degradation before it compromises integrity of spent fuel storage canisters is essential for ISFSI safety. Intact canisters protect against degradation of spent fuel rods during storage from overheating and corrosion damage.

The challenge is to implement a Goldilocks dry storage inspection program – one with a scope and frequency that is neither too much nor too little but just right.

Inspecting every loaded canister every year would be too much. Workers must get close to the canisters when conducting the inspections. While the concrete housing the canisters lessens the radiation dose to workers, it does not eliminate the exposures. Inspecting canisters more often than necessary results in needless radiation doses to workers. Worker doses for cask inspections at Calvert Cliffs (Maryland) and Diablo Canyon (California) were 40 millirem and 48 millirem respectively.[61]

Inspecting one, maybe two, canisters every ten, maybe twenty, years would be too little, particularly when the selection of the scant canister(s) to be infrequently inspected excludes consideration of pre-existing surface flaws that can promote chloride-induced stress corrosion cracking. That scheme is eerily similar to the misdirected inspection program that nearly led to disaster at Davis-Besse.[†]

For years, the smart money had workers inspecting the J-Groove Weld on the inner surface of the reactor pressure vessel heads of pressurized water reactors. This weld is where the nozzles penetrated the heads to allow the control rod drive mechanisms (CRDM) located outside the reactor vessels to manipulate the control rods within them. The J-Groove Weld was considered to be the most vulnerable location for cracks to form – if the J-Groove Weld was found to be okay, the entire rest of the CRDM nozzle was "known" to be okay, too.



Somebody forget to tell the parts about this secret. So, the uninformed CRDM nozzle cracked, not at the J-Groove Weld where they were supposed to crack but in the vertical section passing through the reactor

[†] Based on the NRC's Accident Sequence Precursor Program calculation that the delta core damage probability from conditions at Davis-Besse was $6x10^{-3}$ – closer to meltdown than any other event or condition since the March 1979 meltdown at Three Mile Island Unit 2. See ADAMS ML050520021.

pressure vessel head. Cracking at that location leaked borated water from the vessel onto the vessel head. Evaporation left behind boric acid crystals that ate through the six-inch thick carbon steel vessel head. Only the quarter-inch thick stainless steel liner prevented a loss of coolant accident at Davis-Besse.

The second easiest way to overlook a problem is to look in the wrong places for it. The easiest way is to not even looking at all.

The canister inspection program should take into account pre-existing surface flaws when selecting the most susceptible ones to monitor for degradation. Instead of picking one, maybe two, canisters to inspect, a reasonable subset (say 10-15 percent) of the loaded canisters should be periodically inspected. If accumulated inspection results show that certain canisters are less susceptible to degradation, that knowledge can be used to responsibly reduce the scope of canisters inspected.

Unless all loaded canisters are inspected frequently, there exists a very credible possibility that a canister's degradation will go unnoticed resulting in its integrity being lost. Consequently, evaluations must be performed of the consequences of a breached canister on (a) the cooling performance of the loaded canister and (b) the corrosive degradation from the non-inerted canister atmosphere. The results from these evaluations would complement the limited scope inspection program if they showed that radioactivity releases from a breached canister would pose little hazard to workers and the public for X months.

If the nuclear industry remains divided into the "haves" and "have nots" – i.e., those who have access to the dry storage inspection information in INPO's AMID and those who lack such access – then the NRC must compensate for this information vacuum by providing fuller information to all ISFSI owners so that all safety decisions are made with all available information. If ignorance is bliss, dry cask storage performance bliss must be eliminated.

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