PRM-72-8

ATTACHMENT

CITIZENS' OVERSIGHT

Position White Paper by Citizens' Oversight

A New Strategy: Storing Spent Nuclear Fuel Waste

Featuring HELMS Storage:

"Hardened Extended-life Local Monitored Surface" Storage

and

"Dual-Wall Canisters" (DWC)

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ABSTRACT

Ray Lutz and Citizens Oversight negotiated the recent settlement agreement with Southern California Edison which established an action plan focused on moving the 3.6 million pounds of spent fuel nuclear waste from the site at San Onofre, only 35 yards from the ocean, to a safer place. Nationally, we need a better plan for dealing with spent nuclear fuel waste, and we should target safe storage for the next 1,000 years. The centerpiece is the "HELMS" Storage criteria, allowing graceful upgrade of the investment in dry storage to date and prudently balancing risks. It is our hope that environmentalists and the nuclear industry will recognize that they share a common agenda for the storage of this waste while minimizing impact to the environment and safety risks, now that the nuclear industry is in decline.

HELMS Storage is Hardened, Extended-life, Local, Monitored Surface Storage, and is a set of criteria against which any option may be measured. "Local, Surface" implies that waste should be moved away from water resources and dense populations in the vicinity of the original location of the waste, but stored locally or regionally, probably within state or among state consortia, on the surface. Hardened, Extended-life implies the facilities are terrorist-hardened facilities with extended-life cask designs. Monitored means 7/24 electronic monitoring of all measurable attributes. For "Extended-life," we suggest the Dual-Wall Canister design (DWC) which provides a sacrificial outer shell pressurized with inert gas enclosing the existing "thin" canisters in use in the US., so the internal cask will not suffer corrosion degradation. The DWC outer shell can be monitored for leaks by detecting the pressure inside the outer shell, rather than relying on difficult and occasional robotic inspection technologies which probably will not be effective in detecting microscopic cracks. The outer shell of the DWC should be added to any thin canisters within a few years after the spent fuel has cooled for 20 years.

This paper provides the context and compares with other alternatives.

Finally, the paper defines a set of steps – on a conceptual level – phase-in the HELMS Storage + DWC proposal by the industry under the watchful eye of oversight groups. This white paper does not attempt to quantify costs or exact implementation details. However, we believe there will be cost benefits to the proposals while still improving safety. We appreciate your review and notice of any technical errors and omissions so those can be repaired.

This plan is focused on commercial nuclear spent fuel and does not attempt to create a comprehensive plan for defense waste, however the same concepts can be employed in that segment as well perhaps with some modification, and is mentioned briefly.

INTRODUCTION

THE NUCLEAR EXPERIMENT

"Atoms for Peace" was our attempt to harness the destructive power of the atomic bomb for peaceful purposes. That experiment, which never would have occurred in the free market without extensive investment, promotion, and risk protection by the federal government, is now over. We know now that nuclear accidents do happen, with three major disasters so far, and it remains costly – commercial nuclear plants are financial disasters. They can't compete with other sources, and it's getting worse.

We now have an eternal "gift" from that experiment: the US. nuclear industry alone generates up to 2,300 tons of highly toxic spent fuel each year, and we have 76,430 tons to deal with so far.[1] By the time we get all nuclear plants to close, we'll have much more, perhaps 120,000 tons of high-level nuclear waste at sites all around the country and a complete failure of the promise that this waste would be safely and effectively dealt with. Given the sort of casks we will be discussing below, we are talking about approximately 10,000 casks.

WASTE CONFIDENCE? Not at all.

The Nuclear Regulatory Commission (NRC) has the responsibility for the safety of nuclear materials used in a commercial context. It has conducted "Waste Confidence" proceedings over the years, based on the notion that as a matter of policy, it ''would not continue to license reactors if it did not have reasonable confidence that the wastes can and will in due course be disposed of safely."[2] The original plan was primarily focused on a deep geologic repository – Yucca Mountain (YM) – which was to be licensed and open for business by January 31, 1998. Nearly 20 years later and no geologic repository is open. YM is far from viable[3], and nothing is on the horizon.

In 2014, the NRC changed the name of the report to "Continued Storage Of Spent Nuclear Fuel,"[4] now stating that the waste could be left where it was generated: at the power plants all around the country, *indefinitely,* And, in canisters only designed for temporary use, that is they were designed to last only until the promised repository opened. Those "thin" canisters have a 10 to 20 year warranty, and the manufacturer says they are designed for 60 years or perhaps 100 or 120 if you are lucky, wild guesses at best, and the NRC licenses them for 40 years with possible renewal of another 40. The places where we find the short-term storage installations (each called an "Independent Spent Fuel Storage Installation" or "ISFSI")[5] – at some 70 sites near 104 reactors all around the country, are hardly optimal for nuclear waste storage. **This default solution is simply not acceptable.**

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1 Nuclear Energy Institute, https://www.nei.org/Knowledge-Center/Nuclear-Statistics/On-Site-Storage-of-Nuclear-Waste Here, "ton" indicates metric ton, equal to 1000 kilograms, or approximately 2204 pounds, whereas the conventional ton is 2000 pounds, so the metric ton includes about 10% more mass.

2 BRC Report, Page 25.

3 This will be more fully explained later in this report. The primary fact is that the spent fuel must cool for many decades before it is ready to place in a geologic repository, even if it were available today.

4 NRC "Continued Storage Of Spent Nuclear Fuel" (2014) https://www.nrc.gov/docs/ML1417/ML14177A474.pdf

5 NRC License requirements for ISFSIs is provided in 10 CFR Part 72.

The problem becomes even more pressing as nuclear plants are retired and we transition to a sustainable renewable energy infrastructure.

Local communities have no say over their safety concerns as long as the NRC claims the risk is “low.” This is due to the concept of federal preemption, where no community can set higher safety standards nor block anything due to safety concerns. If the NRC says it’s safe, then you can’t ever mention safety as a concern. Yet the NRC is primarily focused on licensing nuclear power plants, which are a many times more risky than an ISFSI, so anything you do in an ISFSI is safe on their yardstick, and there is no discrimination among various options.

THIN TEMPORARY CANISTERS NEAR WATER RESOURCES IS ANOTHER BLUNDER

The ISFSI designs we use in this country surround the thin canisters with a thick concrete overpack, or place them in below-ground vaults. But the strength of these overpacks is largely an illusion, because the thin canisters are exposed to outside air flowing into and out of vents and over the surface of the (very hot) canisters to cool them. This cooling must continue for many decades before they will be cool enough to seal into a repository like YM. Once any portion of the canister surface cools below about 70°C (158°F), corrosion and cracking may start within a couple of years[6], and the radiation boundary can be compromised within about another ten years, which then may release radioactive particles and allow moist oxygenated air to enter, and with that, even more damage may occur.

The default solution currently embraced by the industry is to leave this toxic waste near the closed nuclear plant, usually only yards from important water resources, where nuclear waste definitely does not belong. And, since the power is destined for use by major cities, the plants are also near those populations. By regulation, the ISFSI related to the plant has to be located within the exclusion zone of the plant and thus these rules do not encourage prudent placement of the ISFSI away from those populations and the water, rising sea levels, tsunami risks, or flooding, and coastal storms.

The waste problem is still not solved, and it is getting more expensive the more we look into our options. It is almost never included in the economic analysis of nuclear power.

Thus, we suggest that we must plan to deal with the waste based by accepting the realities of the present rather than gambling that we will have better solutions in the near or distant future.

6 The factual basis for this point will be made later in the document.

HELMS Proposal

Our proposal, which uses the acronym **HELMS,** is in essence a set of criteria to which any proposal can be measured rather than a specific detailed plan, but we do have some specific technical design recommendations and changes to NRC regulations and operating philosophy, and this should also inform DOE strategy development in their quest to manage our nuclear waste.

(Our proposal will be defined at this point in this document prior to setting the stage in the Technical Context section. Readers who are new to the field may wish to read the Technical Context first.)

HELMS simply means:

Hardened – to resist (terrorist) attacks such as by truck bomb, airplane strikes, etc.
Extended-life – meaning a design life of 1,000 years, and we suggest dual-wall canister design.
Local – meaning located in-state or within regional consortia of states.
Monitored – each canister is outfitted with a standard electronic monitoring package.
Surface – need to store on the surface for cooling for at least the next 200 to 300 years.

Starting with the second part of the acronym:

Local, Monitored Surface (LMS) Storage

Spent fuel from nuclear sites is thermally hot for many decades and will require extended cooling on the surface. Surface storage facilitates monitoring and it is obviously retrievable, so it fulfills the requirements of Monitored Retrievable Storage[7] (MRS), the form of surface storage envisioned by the Nuclear Waste Act along with YM. Unless some very novel disposal approaches are created, surface storage is an unavoidable requirement.

Local – Probably In-State

Where we site these facilities will impact transportation requirements. “Local” implies that although the waste will likely be moved from the exclusion area of the (closed) nuclear plant to a location away from the water resource and out of harms way, it will not moved all the way across the country. There is a common-sense fairness to the idea that each state should be responsible for its own waste, and even better, within the service area of the population that gained the benefit of the power generated.

Keeping the waste in or near the state of origin mitigates “not in my state” (NIMS) legal action that may result otherwise. We use the term “Local” because it may still be reasonable to site a facility in common with a number or adjacent states where the transportation is still limited to the local area. The limitation of the transportation of the waste is important to reduce the overall risk while still allowing consolidation to a relatively remote area away from the most densely populated areas near where the nuclear plants are typically sited.

7 According to Part 72.3, Monitored Retrievable Storage Installation or MRS means a complex designed, constructed, and operated by DOE for the receipt, transfer, handling, packaging, possession, safeguarding, and storage of spent nuclear fuel aged for at least one year, solidified high-level radioactive waste resulting from civilian nuclear activities, and solid reactor-related GTCC waste, pending shipment to a HLW repository or other disposal.

Some states with nuclear power plants may have difficulty finding a safe location for waste storage. Some power plants straddle the borders between two states. Many supply power to more than one state. Although easier than siting a deep geologic repository, surface storage siting is still not a trivial endeavor.

Characteristic	Surface Storage	Deep Geologic Repository
Siting Difficulty	Much Easier	Very difficult, requires extensive geologic characterization
Containment	Fully Contained	Problematic, relies on geology to contain
Ground water	Not Impacted	Will Permeate or flood
Cooling	Passive	>200 years of Active Ventilation
Transportation	Local	Remote, Risky
NIMBY	Local Responsibility	Severe
Monitorable	Yes	No plans disclosed
Maintainable	Yes	Only that the design must allow retrieval in the first 200 years.

Comparison of Surface vs. Deep Geologic Siting

Compared with a deep geologic repository, finding a technically suitable site for surface storage is immensely easier. Surface dry storage facilities do not rely heavily upon predicting the geology of the underlying rock or predicting changes over immense time periods. With that said, nothing is truly easy when it comes to dealing with nuclear waste.

Consent-Based

We agree with the conclusions of the BRC Report regarding the need to find communities that consent to host the facility and the monetary benefit it can bring.[8] The trouble with this general statement is it flies in the face of all the rest of the nuclear energy legal structure, where the federal government – in the form of the NRC – is solely responsible for all safety concerns, making it impossible for states to object to the siting of a nuclear plant, for example, for safety reasons. So consent is almost an unknown concept in this industry. Thus, if communities consent to accept the waste, they must have a say if they want to institute higher safety standards. Consent may be easier to come by if the facility is more robust in terms of its design – as we recommend here – to mitigate the risk which is otherwise a factor in that decision-making process.

Extended Life

This proposal targets an extended design life of 1,000 years. Yet, the storage is still "interim" because it is anticipated that eventually a deep geologic repository will be developed, or perhaps some other

8 BRC Report, Page 47

approach will be available in the future. But the proposal is not predicated upon a repository. We must consider that a HELMS facility is permanent in the human time scale, and that a number of HELMS facilities – perhaps a dozen or more around the country – will exist for multiple human generations.

The 1,000 year goal is likely NOT feasible without some monitoring and replacing part of the system on regular intervals. The design should provide graceful degradation such that if maintenance ceases due to an absence of administrative control, then it will remain safe for an extended period and only slowly release significant toxicity into the environment.

Dual-Wall Canister (DWC)

For sake of description, we propose a specific mechanism for obtaining the Extended-life criterion. But we must also emphasize that the HELMS proposal does not rely on the adoption of this specific proposal as long as the extended-life criterion is satisfied.

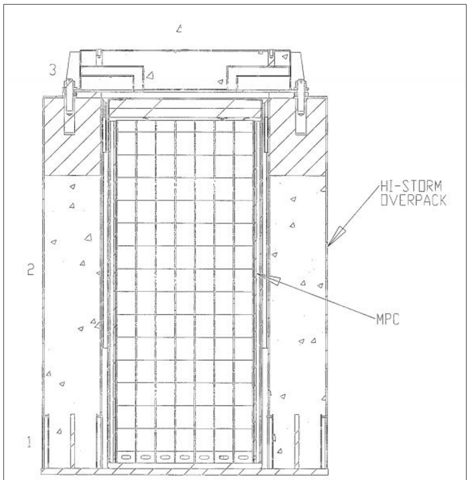
The Dual Wall Canister (DWC) proposal provides encapsulation of each of the relatively thin canisters (1/2” to 5/8” thick) used today within an additional sealed and pressurized container, to form a dual-wall canister system. The DWC outer shell should be similar in design to the (3” thick) container proposed for YM, but we propose a “gas gap” between the internal canister and the outer shell, filled with dry pressurized helium, thereby creating a dry inert environment for the internal canister, eliminating oxygen and the corrosive effects of moisture. The pressure of the helium should be about the same as what is currently used inside the canister (perhaps about 50 psi). Any leak to the outside environment could be easily detected just by sensing the gas pressure (described in more detail below).

The DWC outer shell is exposed to the environment and thus to moisture, oxidation and ultimately, corrosion and cracking. As a result, it is sacrificial and will deteriorate over time while protecting the interior canister from deterioration. When they finally crack or corrode through the wall, no release of radioactive particles will occur, and the relatively unharmed interior canister can be removed and inserted into a new DWC outer shell. Thus, with periodic replacement of the outer shell, the DWC system meets the extended-life criterion.

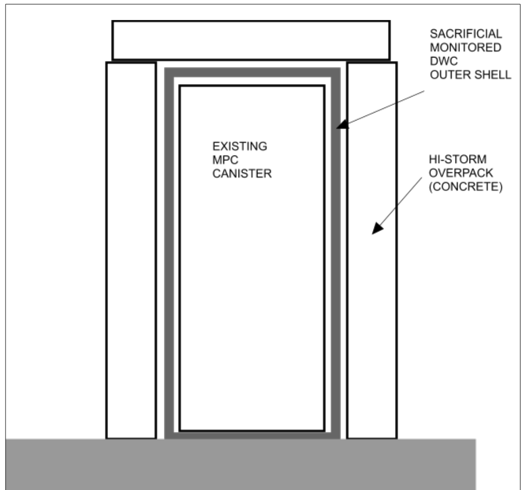
This two-layer approach is analogous to the double-hull design mandated in US. waters after the Exxon-Valdez disaster of 1989.[9] There, the inside and outside steel plating is about 15mm thick (0.59”) with a gap of about 2 meters between the two hulls. Thus, in an accident, if the outside hull is breached, it is hoped that the two meter gap will keep the inside hull from being breached as well. The difference in the two cases is that the risk to the outer hull in the oil tanker is mainly due to accident, while in the case of spent fuel canisters, we are mainly concerned about corrosion and deterioration over a very long period of time.

9 “Limitations of Double Hulls” https://friendsofwildsalmon.ca/images/uploads/resources/Limitations_of_Double_Hulls.pdf

The detailed discussion of exactly how to upgrade to the DWC is deferred to designers in the various firms offering their dry storage solutions to the industry. However, we offer the following conceptual proposal to allow discussion of the implications of such a configuration.



CURRENT: Holtec HI-STORM above ground system w/o DWC



PROPOSED: DWC outer shell added to Holtec HI-STORM above ground casks

Above-ground systems can add the DWC outer shell fairly easily by removing the upper lid of the overpack, removing the canister into a Transfer Cast, then introducing the DWC outer shell into the existing concrete overpack (if there is sufficient space) or within a new concrete overpack with sufficient space, and then replacing the canister into the DWC outer shell, adding the upper lid to the outer shell, and then the overpack lid. We anticipate that there may be a need to replace the concrete anyway, as it will degrade over time due to the radiation it is absorbing.

Similarly, the DWC outer shell can be introduced into an underground system such as the Holtec UMAX system. As mentioned, the cavities should be designed up front to be of sufficient size to accommodate the interior canister PLUS the outer shell.

The DWC outer shell can be is added after the interior canister has cooled sufficiently but not below the temperature where cracks may initiate (70 to 80°C – about 20 years of cooling for the coolest part of the canister.) The process is envisioned as follows: a) remove the top cap from the cavity, b) remove the interior canister from the cavity, c) insert the DWC outer shell in the cavity, d) replace the canister into the outer shell, e) bolt (or weld) on the DWC outer shell lid, e) pressurize the DWC outer shell with dry helium, and f) close the top cap. The DWC is used similar to the manner in which a transportation or transfer cask is used today.

In either case, some thought will need be put to the design so the concrete vaults are compatible with the additional of the DWC outer shell to the design.

Other desired attributes of the DWC:

- **Sacrificial**
  The purpose of the DWC outer shell is to provide longevity to the expected life of the overall container, and allow the outer shell to deteriorate without affecting the interior canister, and then replace it when it fails. It is not necessary, therefore, to constantly visually inspect the DWC because the outer shell can fail without the entire system failing, as the interior canister is protected from the corrosive environment until the outer shell fails.

  However, there are other aging effects that will come into play, such as vibration, irradiation[10], stress from pressure points of the enormous weight, as well as residual contamination. But without DWC encapsulation, deterioration will occur much more rapidly.

- **Easy to Test**
  Considering a dry canister system without the DWC outer shell, the canister must be carefully inspected visually or through other detection mechanisms (eddy current, ultrasound, etc.) to anticipate failure. The hope is that prior to failure, those inspection protocols will indeed detect cracking or other failure mechanisms, and allow the radiation containment boundary to be replaced. In contrast, with the DWC, there is no need to anticipate failure through difficult inspection protocols. The outer shell is simply allowed to fail. Failure can be easily detected by a loss of pressure inside the DWC outer shell. At that point, we still have plenty of time to react, as the interior canister can withstand exposure for many years.

- **Easy to Replace**
  Repairing a thin canister amounts to replacing it. The top must be first cut off, then all the individual fuel assemblies must be removed from the old canister and placed in a new canister. This requires a “hot cell” (chamber pressurized with dry helium) or fuel pool. This process is not clearly specified in NRC and industry documents and officials usually say it is “under study.”

  In contrast, the DWC outer shell can be easily replaced. To do so, the top is removed from the DWC outer shell, and the interior canister is removed and then inserted into a new DWC outer shell. Since this process does not open the interior canister at all, there is no need for a hot-cell

10 Radiation embrittlement may be a factor. See the recent NRC MAPS aging management document on the subject: Regarding Stainless Steel, 3.2.2.9 Radiation Embrittlement:

> Embrittlement of metals may occur under exposure to neutron radiation. Depending on the neutron fluence, radiation can cause changes in stainless steel mechanical properties, such as loss of ductility, fracture toughness, and resistance to cracking (Was et al., 2006). Cracking has been observed in boiling-water reactor oxygenated water at fluences above 2 to 5 × 10**20 n/cm2 [1.3 to 3.2 × 10**21 n/in**2] (Was et al., 2006). Gamble (2006) found that neutron fluence levels greater than 1 × 10**20 n/cm**2 [6.5 × 10**20 n/in**2] are required to produce measurable degradation of the mechanical properties. Caskey et al. (1990) also indicates that neutron fluence levels of up to 2 × 10**21 n/cm**2 [1.3 × 10**22 n/in**2] were not found to enhance SCC susceptibility
> As discussed in Section 3.2.1.9 of this report, the maximum potential accumulated neutron fluence on DSS components after 100 years was calculated to be 2.63 × 10**16 n/cm**2 [1.70 × 10**17 n/in**2]. This fluence level is four orders of magnitude below the level that would degrade the mechanical properties of stainless steels. As such, radiation embrittlement of stainless steel exposed to any environment is not credible.

or fuel pool. The interior canister can be thoroughly inspected as it is moved to the new DWC outer shell.

- **Confinement Barrier**
  The DWC outer shell as envisioned here is intended primarily as a corrosion barrier and as a secondary confinement barrier, not as a neutron or gamma radiation shield, although it would provide some shielding. Uranium and radioactive isotopes are physically held inside the fuel rod cladding (if they are not compromised) and confined inside the sealed internal canisters. Alpha and beta particles are stopped by the cladding and the interior canister. The surrounding concrete overpack (or below-ground concrete vault) would still exist to absorb the neutron and gamma radiation. When transported or handled, additional shielding would be necessary is it is today.

- **Logical Unit Option**
  If fully integrated into the design of a dry storage system, the DWC could be handled in much the same way as the internal thin canister is today, with the DWC outer shell and the internal canister forming a logical unit, to be placed inside the transfer or transportation overpacks. This would require substantial change to transportation procedures and other existing licenses and thus is not easily feasible at this juncture. (The canisters used in Chernobyl adopted the Logical Unit option, see details below.)

- **Component Option**
  The more likely approach would use the DWC outer shell only in the storage configuration, and when moved, continue to use the thin interior canister inside the existing and unmodified transfer and transportation overpacks for shielding and structural support. This scenario implies that sealing and pressurizing the DWC system is performed at the storage location, once the lid is closed and secured to the top.

- **Seals may be used**
  If the lid of the DWC outer shell is bolted to the outer canister shell, this would likely require the use of seals which would need to be replaced periodically, or the lid could be sealed with a hermetic weld. Any required maintenance of a seal does not open the interior canister, and does not require the use of a hot-cell or fuel pool. However, the DWC would need to be purged of air and repressurized using helium *in situ*. Redundant seals are not required.

Monitored

Although the term “monitored” is mentioned as an assumed attribute of dry storage systems, the BRC Report admits that “Many current dry cask systems lack instrumentation to measure key parameters such as gas pressure, the release of volatile fission products, and moisture.” Yet decision makers, such as Robert List, Nevada Governor (1979-1983) expresses the common assumption, that canisters in YM

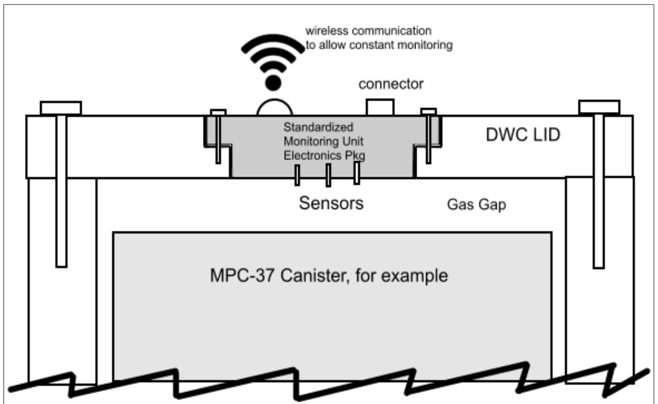
will be monitored to the extent that “they’ll know exactly what is going on.”[11] In our review of the current dry storage systems, the only mandated monitoring is to perform a manual check of ventilation vents to verify they are not blocked. Very minimal indeed. But more may be the case even though it may not be mandated.

We are not aware of any DOE or NRC documentation that requires electronic monitoring, recommended standards for monitoring, nor any review of the electronic strategy.[12] Real-time monitoring is a key shortcoming in the dry-storage system in use nationwide. Occasional inspections of one or two canisters once every twenty years with nifty robots is wholly insufficient.

The only specific requirements for monitoring appear to be in Part 72.122 h (4)

> 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.

Standard Monitoring Module



Electronic Monitoring Strategy

The DWC should be outfitted with replaceable standardized electronic monitoring module to allow constant real-time monitoring of conditions inside the outer shell, such as pressure, temperature, humidity, gamma radiation intensity, neutron flux, etc, as well as capture the ID of the canister and relay those data to a central monitoring facility. A monitoring module requires the penetration of the outer shell, certainly less problematic than it is to penetrate the hermetically sealed internal canister. Standardizing this module will allow various vendors to compete on price and functionality.

The same monitoring module can be retrofitted into the design of the transfer and transportation casks so as to constantly track the location of each spent fuel canister by ID.

One caveat to the glamorous idea of such monitoring is that any gizmo added will likely also fail and may reduce the over-all life, which is of importance in an institutional failure scenario. The design of a

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11 Robert List, Nevada Governor – “The thing is I think way too often overlooked is that this material is not just going to be stuffed in and covered up with dirt and forgotten, the idea is, it is going to be monitored, and it's going to be retrievable. And by being monitored, they'll know exactly what is going on with it, it's not going to be just a hope and a prayer that nothing happens.” 39:34 https://www.youtube.com/watch?v=c0emnrflYKE “Subversive Doubt: The Story of Yucca Mountain Nuclear Repository”

12 Note to NRC or DOE: Please provide any additional information on the electronic monitoring strategy as it is not impossible that it exists and we are not aware of it.

monitoring module is not a trivial matter, but at least in the near term when we do not have very much experience with the degradation of the canisters, such monitoring is viewed as well worth the trouble, and provides the public with the assurance that the industry is employing the latest technologies in the storage of these extremely toxic materials.

Detecting through-wall cracks

The DWC outer shell is to be pressurized with an inert gas, such as helium. If a through-wall crack occurs or if any of the seals are compromised, then this can be detected by sensing the pressure drop. Such pressure sensors are to be part of the Monitor Module. Failure of the DWC outer shell is an expected event, and does not compromise the ultimate containment boundary.

Detecting MPC Canister through-wall cracks

After testing the DWC outer shell for leaks by pressurization, integrity of the contained canister can be tested with pressure tests. The test would include a purge of gas inside the outer shell, pulling a vacuum. If the vacuum does not hold, then the contained canister may be leaking. Even if the contained canister has minute cracks, encapsulation will eliminate the threat that canister failure may result in radiation release.

Hardened

The “Hardened” attribute relates to resisting malicious attack. Current ISFSI installations are far from acceptable in this attribute.

There are two elements which are envisioned for this attribute:

1. An enclosing building or bunker. This can provide several functions:
    1. Limiting release of radiation in the event of any accident on site, and thus providing another layer of defense in depth,
    2. Enclosing all storage system operations, such as loading, replacing DWC outer shells, and maintaining the system, and
    3. Securing the facility and reducing vulnerability to simple malicious attacks.
2. Covering the facility with earth, rock or other material to further provide immunity to surface blasts.

One of the important obvious aspects of a deep geologic repository is resistance to many attack scenarios with even some “bunker buster” munitions (but these are always advancing, so this may be only a temporary fact). To provide similar resistance in a surface facility would require the addition of a bunker concept. Most “bunker buster” explosives do not penetrate more than about 60 meters deep (about 200 ft.), and much less if the material above the bunker is hard rock. For example, provision for spacing and additional footings for intermediate supporting walls may allow a structure to be added

over the ISFSI to provide additional resistance to attacks and may be useful as a tertiary radiation boundary and to block access should institutional control be lost.

There's a problem with making it "too" secure, namely that the weight of the protection itself, when it eventually fails, it may then crush the casks and cause a release or a criticality event.

The point is that at this juncture, we need to concentrate on simplicity, getting the waste to the right location, while maintaining accessibility. We should allow time and knowledge acquisition to work for us, for scientists to continue to evaluate risks and benefits, while the waste is still accessible, monitored, and protected.

Summary of HELMS

The HELMS proposal requires three changes to the current status quo:

1. The use of a sacrificial DWC outer shell over the current thin canisters to extend the design life to 1,000 years, including electronic monitoring to allow the detection of through-wall cracks,
2. Siting surface storage installations locally, near the nuclear plant (or cluster of plants) of origin but away from the water resource, high population densities, known fault lines, tsunami risk, sea level rise, etc. that is frequently present at the plant site, and
3. Improved hardening of the ISFSI site including a bunker or building surrounding the facility, or at least providing footings and locations where bunker walls can be added to the base structure.

Action Plan

We recommend the following actions:

- Each state, or local group of states, should determine its/their own spent fuel storage plan, probably with a consolidated site chosen in-state or among a few adjacent states, or to continue to store the spent fuel at shut-down sites indefinitely using a prudent, 1000-year design basis.
- NRC should review the design of spent fuel ISFSI canisters to resolve the discontinuity between the thin canisters and the current approval of ISFSIs to remain on site indefinitely. We recommend the adoption of the DWC design, with the features we have mentioned. ISFSI owners should be required to upgrade to DWC with monitoring after the canister has cooled to a temperature of deliquescence (about 70°C – 158°F). As the temperature on the surface of the canister is not uniform, we estimate that DWC should be used after about 20 years of fuel assembly cooling, and probably before 30 years of cooling.
- We recommend a moratorium on any movement of spent fuel to local ISFSIs until a top-to-bottom review is performed and a strategy at each site is determined.

- ISFSI vendors should determine an upgrade path so as to provide a dual-wall design, such as with the DWC upgrade for any existing or future ISFSI installations, and all CIS (Consolidated Interim Storage) installations.
- A standard specification for an electronic monitoring module which can be used with a DWC, in terms of mechanical dimensions, sensing capability, and wired and wireless communication should be defined. Such a monitoring module should be able to sense pressure, temperature, radiation flux, canister ID and any other standard metric that is feasible, and interface with the HELMS facility using electronic communication (wireless or wired). The module must be easily replaceable in the event of failure and include triple sensing redundancy to allow the module to detect internal failure. Such a standard specification will allow the module to be made by competing vendors and result in optimization of functionality and reduced cost.
- The Congress should act to provide
  1. Nuclear Waste Fund (NWF) money to allow the HELMS compliant CIS facilities to be built, and restart the collection from ratepayers who are still receiving power from nuclear plants. It is a matter of fairness to charge those customers who are using nuclear energy today rather than putting on the back of future generations.
  2. That CIS or MRS facilities must not be predicated on the approval of Yucca Mountain.
  3. Consenting local communities must be able to have a larger say in what level of safety they require, even if it exceeds the NRC safety levels.

Funding and Ownership

It is our position that HELMS compliant storage installations should be funded by the NWF with monies originally collected from ratepayers, and contributions from operating plants should be restarted. (Collections were, we believe, inappropriately aborted in 2014[13].) The installations should be owned and operated by the federal government. With this said, HELMS storage is not a deep geologic repository and so it is not considered “disposal,” but is an interim solution for the next 1,000 years, the first 1/150th of the minimum time we are concerned with (assuming the waste reaches the same toxicity as the original ore after 150,000 years.)

13 E&E News, “U.S. ends fee collections with $31B on hand and no disposal option in sight” (May 16 ,2014) https://www.eenews.net/stories/1059999730

TECHNICAL CONTEXT

With the HELMS proposal in mind, and with the DWC proposal to attain the Extended-life attribute, we now turn to further define the context of the proposal.

There is little dispute regarding most of the facts that define the problem. We refer readers to the "Report to the Secretary of Energy by the Blue Ribbon Commission on America's Nuclear Future," published in January, 2012 ("BRC Report"), primarily Chapter 3, "Technical and Historical Background"[14] for anyone who is not already acquainted with that background[15]. The BRC Report also includes definitions of many acronyms in use in the field.

With that as a basis, we consider some key points to build the context for the HELMS proposal. The following passages are noteworthy, with our comments following:

- "The approach laid out under the 1987 Amendments to the Nuclear Waste Policy Act (NWPA) —which tied the entire U.S. high-level waste management program to the fate of the YM site— has not worked to produce a timely solution for dealing with the nation's most hazardous radioactive materials."[16]
    - **No Repository**
      Indeed, the original plan was to have a permanent "deep geologic repository" open and accepting waste by January 31, 1998. This plan failed to open any respository. This failure points out a fundamental mismatch between legal and political policy vs. scientific inquiry and engineering development. The concept that we can reliably predict what will happen 10,000 to one million years in the future, as was mandated by the YM project definition, is clearly untrue.

      Plate tectonics, the overarching theory behind all earthquake predictions was only accepted after the 1964 9.2 magnitude Alaska earthquake[17], only just over 50 years ago. To now be able to say with any certainty what will happen even 1,000 years in the future is no more than a wild guess, let alone 10,000 or a million years. Thus, designing a geologic waste repository is very difficult indeed. Politics should not trump science, and thus, this is not just a political problem of "Not In My Back Yard" (NIMBY), but also there are honest concerns about the design of such a repository, and most particularly at YM.
    - **Plan B is now Plan A**
      Certainly, unless we figure an inexpensive way to detoxify the waste – and this is quite unlikely in the near term – then a deep geologic repository is one way to deal with the

14 "Report to the Secretary of Energy by the Blue Ribbon Commission on America's Nuclear Future" (BRC Report) https://energy.gov/sites/prod/files/2013/04/f0/brc_finalreport_jan2012.pdf

15 Also recommended is the book, "Too Hot to Touch -- The Problem of High-Level Nuclear Waste" Cambridge University Press (2013) William Alley and Rosemarie Alley See: http://copswiki.org/Common/M1792

16 BRC Report, Executive Summary, page vi

17 https://en.wikipedia.org/wiki/1964_Alaska_earthquake

problem. But finding sites for such a repository and then developing it is a very difficult technical and political challenge, and given the recent history of YM, we plan now that it will not be available. As a nation, our “Plan B” needs to be good enough to be considered effectively “permanent” rather than a temporary or interim fix. And that means storage on the surface for an extended period of time, probably 100 to 300 years, before it can be moved, and we recommend a design goal of 1,000 years, with the ability to persist safely without any maintenance for 300 years.

- **The BRC Report says that after the Fukushima disaster...**
  “...Americans became newly aware of the presence of tens of thousands of tons[18] of spent fuel at more than 70 nuclear power plant sites around this country—and of the fact that the United States currently has no physical capacity to do anything with this spent fuel other than to continue to leave it at the sites where it was first generated.”[19]

  - **Terrorism now perceived as a reality**
    The issue was further compounded by the post-9/11 perception that spent nuclear fuel at these sites represents more more than 70 terrorist targets, which could result in a nuclear dirty bomb without any need to obtain or handle nuclear materials by terrorists, and could potentially be activated with simple truck-bomb or hi-jacked plane scenarios. This is not science fiction, it is reality.

- **Wet (pool) storage**
  “Nuclear fuel will remain in a commercial power reactor for about four to six years, after which it can no longer efficiently produce energy and is considered used or spent. The spent fuel that has been removed from a reactor is thermally hot and emits a great deal of radiation; upon removal from the reactor, each spent fuel assembly emits enough to deliver a fatal radiation dose in minutes to someone in the immediate vicinity who is not adequately shielded. To keep the fuel cool and to protect workers from the radiation, the spent fuel is transferred to a deep, water-filled pool where it is placed in a metal rack. Typically, spent fuel is kept in the pool for at least five years, although spent fuel at many U.S. reactor sites has been in pool storage for several decades. Approximately 50,000 metric tons of commercial spent fuel are currently stored in pools in the United States.”[20]

  - **Spent Fuel Pool Risk Varies**
    There are two main configurations of spent fuel pools, those used in the General Electric Mark I design as used in Fukushima[21], with the fuel pools approximately three-stories up in the building, and the more recent designs with the pool at grade level. The grade-level design does not pose as great a risk, however, all spent fuel pools require active cooling and

18 Actually 76,430 metric tons and increasing
19 BRC Report, Executive Summary, Page vii
20 BRC Report, page 10
21 https://en.wikipedia.org/wiki/GE_BWR

thus if no other factors exist, passive dry storage is preferable. The NRC regards both as being "safe." But we must also state very clearly that placing spent fuel dry storage only yards from the ocean (such as at San Onofre) should never happen.

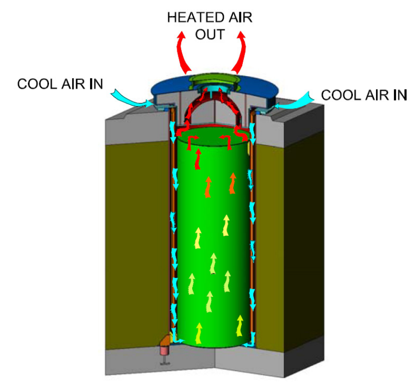
The primary radiological disaster at Fukushima was due to the full melt-down of three reactor cores. The fuel pools were damaged and were in a precarious situation to be sure. But the spent fuel in the pools represented a far greater risk in terms of the total amount of nuclear material. The most precarious fuel pool was in the Unit 4 reactor building, and it was all removed as of Dec, 2014[22]. Other fuel pools still have hundreds of fuel assemblies[23]. The dry storage canisters on site were not harmed, but they were of a thick-wall design with bolted lids, bolted to the floor of the dry storage building, far different from what we use in the U.S.[24]

- **Dry (cask) storage introduced when pools became full to overflowing**
  "After the fuel has cooled sufficiently in wet storage, it may be transferred to dry storage. Dry storage systems take many forms but generally consist of a fuel storage grid placed within a steel inner container and a concrete and steel outer container. The amount of commercial spent fuel stored in dry casks in the United States totals about 15,000 metric tons."[25]
  - **Pools Full, Risky**
    Operating plants initially increased the capacity of the spent fuel pools simply by re-racking them to much higher density. Now the density is frequently the same or nearly the same as in the reactor core. Boron separators and borated water absorbs neutrons to avoid a critical nuclear reaction in the pools.
  - **Dry Storage**
    In desperation, plant owners started storing spent fuel in dry canisters in an inert gas, usually helium. The industry has built a fleet of ISFSIs, otherwise known as "dry storage" around the country at operating nuclear plants to allow the plants to continue to generate waste while not having any place to ultimately move it. Analysts concluded that passive dry storage is generally safer than the overflowing spent fuel pools.[26] However, this analysis

22 https://www.japantimes.co.jp/news/2014/12/20/national/all-spent-fuel-removed-from-reactor-4-pool-at-fukushima-no-1-tepco-says
23 https://www.japantimes.co.jp/news/2017/01/27/national/fukushima-reactor-3-fuel-removal-pool-postponed
24 https://www.ncbi.nlm.nih.gov/books/NBK373721/ – The casks are steel, equipped with an inner and outer bolted closures that can be removed for inspection, and bolted to the foundation of the cask storage building, which is located at a low elevation close to the quay . Nine casks containing a total of 408 fuel assemblies were in storage on March 11, 2011. The building lost power and was inundated with sea water, sand, and debris by the tsunami, and the doors and louvers ventilating the building were damaged. However, the casks were not damaged or displaced, and air flows were not significantly obstructed (TEPCO, 2012a, p. 300). Inspection of the cask interiors in March through May 2013 revealed that there was no leakage of seawater into or helium out of the casks, and there was no damage to the fuel bundles or baskets within the casks (Tateiwa, 2015; Wataru, 2014).
25 BRC Report, page 11 (as of 2012)
26 Alvarez, Robert, "Spent Nuclear Fuel Pools in the U.S. – Reducing the Deadly Risks of Storage" (May 2011) – https://www.nrc.gov/docs/ML1209/ML120970249.pdf

does not apply, in our view, to ISFSI installations extremely close to salty water resources where they will be subjected to accelerated deterioration.

- **Thin, Single Layer Canisters**
  The Multi-Purpose Canister (MPC), was conceptualized by the U.S. Department of Energy (DOE) as a single versatile package equally suitable for on-site storage, transport, and permanent disposal in a future repository.[27] The MPC systems used predominantly in the U.S. are a component system with relatively thin (1/2" to 5/8") welded stainless steel internal canisters, surrounded by an additional structural support and shielding element, such as concrete – when stored at a fixed site – or surrounded by transportation overpacks, which use lead and sometimes water, surrounded by a steel jacket – when transported. The original concept by the DOE assumed that MPCs would be stored for no more than about 20 to 40 years at any plant site.



Atmospheric air flows right over the canisters, shown in the below-ground Holtec UMAX ISFSI design

- **Water Resource at Risk**
  As the plants close and are decommissioned, the spent fuel remains at those sites and moving it away from the water resource is likely appropriate.

  Due to NRC licensing restrictions, ISFSIs are within the exclusion areas[28] of each power plant, which places it in very close proximity to a large water resource in almost all cases, except for the Palo Verde site near Phoenix, AZ, which is the only nuclear plant in the world which does not rely on a water resource for cooling[29].

  Thus, moving the waste away from this water resource can decrease the risk that any accident will contaminate and ruin that resource virtually forever. The temporary increased risk of transportation is easily offset by the reduced risk at a location away from such water resources over a much longer period of time.

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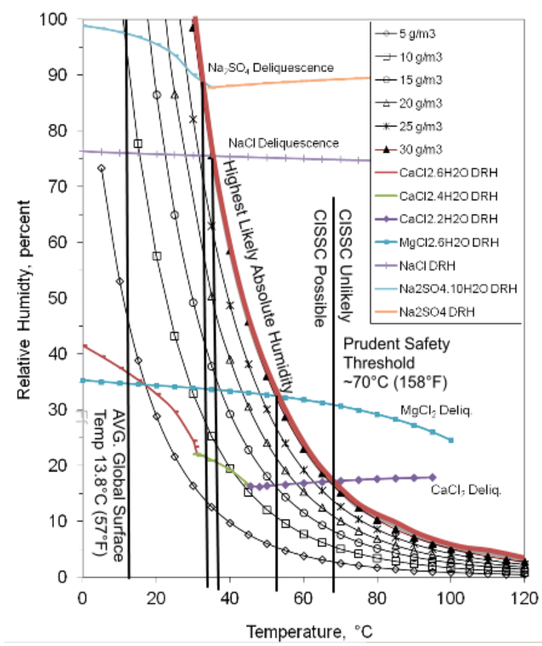
27 https://holtecinternational.com/productsandservices/wasteandfuelmanagement/dry-cask-and-storage-transport/multi-purpose-canisters/

28 "Exclusion area" is defined in 10 CFR part 100, which unfortunately defines the exclusion area in terms of dosages rather than hard distances. Technical Information Document 14844 (http://www.nucleartourist.com/events/TID-18444.pdf) provides some sample calculations for various reactor sizes. For example, for a 1000 MWth Reactor, they calculate the exclusion area should be 0.67 mi (3537 ft, 1.078 km), low population zone, 10.3mi, and population center distance of 13.7mi. Unfortunately, many plants have been licensed with FAR SMALLER footprints, such as San Onofre which has a minimal exclusion area, but still has a super freeway, rail, and publicly accessible beach area within it.

29 https://en.wikipedia.org/wiki/Palo_Verde_Nuclear_Generating_Station – "The Palo Verde Generating Station is located in the Arizona desert, and is the only large nuclear power plant in the world that is not located near a large body of water. The power plant evaporates the water from the treated sewage from several nearby cities and towns to provide the cooling of the steam that it produces."

Also within this consideration is the concern about sea level rise due to climate change. Most on-site ISFSIs are within a few dozen feet of the high water mark and will be easily inundated by the expected rise of sea level. For example, the ISFSI at San Onofre is expected to be fully surrounded by Pacific Ocean water by the end of the century, according to documents submitted by Southern California Edison to the California Coastal Commission.[30]

- **Salty Air Results in Corrosion**
  Furthermore, siting waste storage facilities near salty ocean waters exposes the thin metal containers to the corrosive saltwater air and will reduce the life of storage containers.



Deliquescence of Chloride Salts (NUREG/CR-7170) (annotated by Ray Lutz)

The reality of Chloride-Induced Stress Corrosion Cracking (CISCC) was not fully recognized for more than a decade after MPCs started being used. The 2007 NRC Probability Risk Assessment for Dry Storage[31] stated that no corrosion would occur at all. The issue was recognized and more fully understood by the NRC starting in 2010, and work continues to deal with this issue.[32]

The canisters are not immune from corrosion and over extended periods of time, WILL corrode and deteriorate. The question is not IF, it is WHEN. According to test data it appears that at temperatures greater than about 70°C (158°F) that any salt that may collect on the surface will not dissolve into the water, known as deliquescence[33]. Once the surface temperature of the canisters drops below that figure,

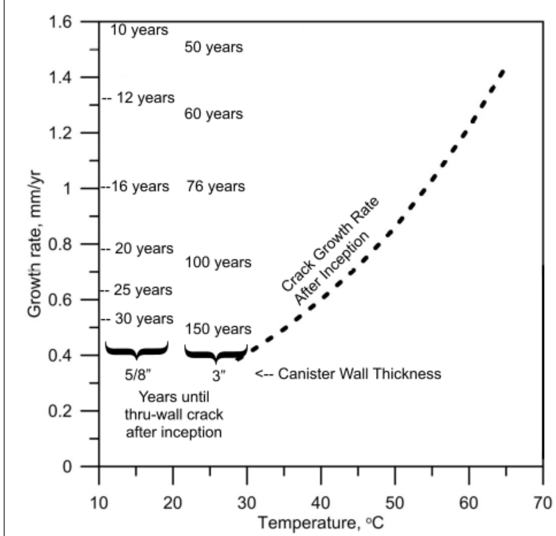
30 RSAR-8095 Attachment 6a - SONGS Spent Fuel. Storage: Offsite and Onsite Location Alternatives (Page 19) http://www.copswiki.org/w/pub/Common/M1756/RSAR-8095_Attachment_6a.pdf

31 NUREG-1864, "A Pilot Probabilistic Risk Assessment Of a Dry Cask Storage System At a Nuclear Power Plant" https://www.nrc.gov/docs/ML0713/ML071340012.pdf (2007) – We note this has not been updated subsequent to the recognition of the CISCC issue, and includes many disturbingly optimistic assumptions and no treatment of terrorist threats. On Corrosion, the entirety of its attention to this issue is as follows: "The MPC, which acts as the confinement boundary for the HI-STORM dry cask storage system, is constructed entirely from austenitic stainless steel Types 304, 316, 304L, or316L. All of these stainless steel grades are corrosion resistant in high-humidity and industrial environments. Therefore, coastal and industrial atmospheres should have no effect on the confinement ability of the MPC (Reference 51). The MPC is drained, dried, and filled with helium. Helium is an inert gas; it does not react with the fuel cladding or the internal structures of the MPC." Also noted is the fact that degradation of the cask considered the CASTOR V/21 cask which are rarely used in the US.

32 Lombard, Mark, "Chloride-Induced Stress Corrosion Cracking (CISCC) Regulatory Issue Resolution Protocol (RIRP) Closure Meeting" (April 28, 2016) – https://www.nrc.gov/docs/ML1611/ML16113A160.pdf

33 NUREG/CR-7170 – "Assessment of Stress Corrosion Cracking Susceptibility for Austenitic Stainless Steels Exposed to Atmospheric Chloride and Non-Chloride Salts" – https://www.nrc.gov/docs/ML1405/ML14051A417.pdf (Page 3-51)

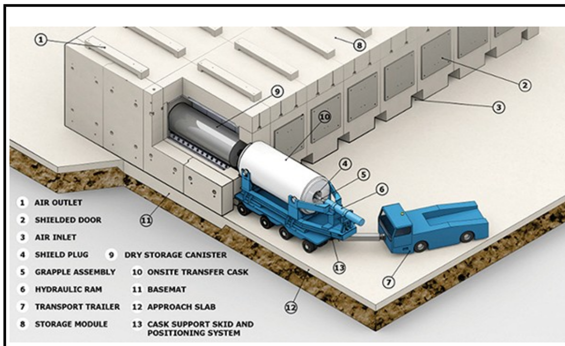
CISCC is possible, and in test scenarios, "the time to SCC initiation is between 32 and 128 weeks." Thus, in less than 2.5 years and as quickly as just over half a year, CISCC may start on any canisters with surface temperatures less than 70°C, and crack development is faster the higher the temperature. It appears that through-wall cracks could develop in the 5/8" canisters in as little as about 12 years, as a worst-case minimum, but it may take 30 years or more for any crack to develop to compromise the boundary (See adjacent figure)[34].



Crack growth rate after inception by temperature

We will assert here that the NRC Regulatory Issue Resolution Protocol (RIRP) investigation into the CISCC issue should not yet be closed because we believe additional steps should be taken. At this point, the only action taken is adding administrative controls and improving aging management. We believe the design of the casks must be improved. Our suggestion of the DWC design is an example of a feasible design change that can more appropriately solve this issue.

- **Spent Fuel Still Hot**
  The BRC Report mentions that the spent fuel is "thermally hot." The maximum expected temperature of fuel cladding has been estimated to be 400°C [752°F] at the beginning of storage. This cladding temperature is expected to decrease to around 266°C [510°F] after 20 years and to approximately 127°C [261°F] after 60 years.[35] The cladding is around the fuel rods, and that is inside the canister, but the surface will exhibit similar temperatures. It's not safe to approach the canister unless it is inside another overpack, but if you could, it is too hot to touch even after 60 years.



Areva (Now Transnuclear) Horizontal NUHOMS ISFSI system

- **Dry Storage Types in the U.S.**
  In the common dry storage configurations in the U.S., there are two major vendors, Areva (now TransNuclear) and Holtec. These storage designs feature concrete surrounding the canisters to absorb radiation. However, atmospheric air freely circulates through openings and then over the canisters to cool them off, and that air is subject to gamma and neutron radiation, and depending on the intensity of that radiation, may become slightly

34 Figure from slide of 4/21/2015 meeting – https://www.nrc.gov/docs/ML1514/ML15146A115.pdf
35 NRC NUREG-2214 Managing Aging Process In Storage (draft) Adams Accessor ML17289A237, Page 3-14

radioactive. Any release of radioactivity would be carried into the atmosphere without restriction. The concrete that surrounds the canisters is needed to absorb the gamma radiation and neutron flux from the radioactive material and will break down over time and therefore eventually will have to be replaced.

- **Airborne Radioactive Release Danger**
  One risk from dry storage is an airborne release caused by an extremely hot fire, that spreads over hundreds or even thousands of square miles. Such a release could be caused by terrorist attack, warfare strike, or industrial accident. Sure, these are not daily events, but we need to plan for the worst case. Dry storage facilities should be in remote locations generally away from dense populations.

- **"Spent Fuel" is extremely dangerous**
  A U.S. Nuclear Regulatory fact sheet states that after 10 years in a cooling pool, the surface radioactivity of a spent fuel assembly is still about 10,000 rem/hour. To understand the danger that poses to health, consider that a 500-rem dose delivered to a whole person in a single exposure is fatal. Close proximity to a single 10-year-old spent fuel assembly would deliver a fatal whole-body radiation dose in about three minutes.[36] After about 150,000 years the spent fuel will be no more hazardous than the parent ore, so any geologic repository should be designed for that period of time.[37] But we must admit, planning to safely store the waste for even 1,000 years is a big challenge.

- **Shallow Defense**
  The nuclear industry usually prides itself by respecting the philosophy of "Defense-in-depth" by providing layers of defense and providing recovery of failures at many levels.

  This philosophy is not well respected in the case of spent fuel, as the spent fuel is encapsulated only two times, once by the cladding of the fuel pellets, and once by a thin canister. However, the cladding of fuel pellets is already cracked in many cases (perhaps about 15% of the time at many nuclear plants). In any accident that deforms the canister itself, and since the zirconium cladding is pyrophoric (flammable)[38], it may start to burn, and pouring water on it will split the water into oxygen and hydrogen, only making matters worse. So really the cladding can't be counted as a defense layer in any conservative analysis. And the "cans" used around individual damaged fuel assemblies do not fully isolate the spent fuel because they have drains in the bottom (to allow the water to drain out when the canisters are loaded from the fuel pool). And so, they don't provide an isolation boundary either. That leaves only one layer – the thin canister – which if cracked or

36 http://www.psr.org/environment-and-health/environmental-health-policy-institute/responses/the-growing-problem-of-spent-nuclear-fuel.html

37 John Deutch and Ernest J. Moniz, et al., Massachusetts Institute of Technology Report, The Future of Nuclear Power: An Interdisciplinary MIT Study, 2003, 180 pages, (April 16, 2011). http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf page 161

38 Review of Zirconium-Zircaloy Pyrophoricity -- https://www.osti.gov/scitech/servlets/purl/5791423

compromised, and if isotopes exist in in the gas inside the canister, radioactivity can escape directly into the circulating cooling air[39].

In fact, the NRC regulations doe not mandate any "defense in depth." The only mention of containment boundary is § 72.122 Overall requirements. (h) 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.
>
> (2) For underwater storage of spent fuel, (not relevant).
>
> (3) Ventilation systems and off-gas systems must be provided where necessary to ensure the confinement of airborne radioactive particulate materials during normal or off-normal conditions.
>
> (4) 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.
>
> (5) 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.

We note the following deficiencies:

- "Canning" used to confine a single spent fuel assembly inside a dry canister have drains on the bottom to allow the water to drain out, and thus they do not provide a radiological confinement boundary.
- Dry cask storage systems used in the U.S. are vented to the outside air, and thus they are all in noncompliance with 72.122(h)(3) (above).

39 However, if a crack were to occur in a canister and it the cladding was not compromised, then there may not be much of any release, particularly if the cracks are microscopic.

- Constant monitoring is required for wet storage, but only periodic monitoring is required for dry spent fuel systems. We disagree that this is an appropriate level of monitoring given that electronic monitoring is feasible on 7/24 basis.
- The short-duration of the license is not realistic and results in designs that are insufficient for “indefinite” storage now allowed by other NRC regulations. The sentence “The package must be designed to confine the high-level radioactive waste for the duration of the license.” is the crux of the problem. The short 20-year license means that dry storage systems will be designed only for that extent, and perhaps only two or three times longer. 40 to 60 years is not “indefinitely.” HELMS is proposed to fix this deficiency in the regulations.

○ **No easy way to deal with cracked canisters**
If these stainless steel canisters are subjected to the outside air, especially if next to the ocean, they will suffer stress corrosion cracking.

> In a sheltered environment, deliquescence of airborne salts below the dew point also could generate an aqueous electrolyte initiating general corrosion. These salts may be chloride rich and originate from marine environments, deicing salts, and condensed water from cooling towers, as well as a range of other nonchloride-rich species originating from industrial, agricultural, and commercial activities. Studies have shown that $MgCl_2$, a component of sea salt with a low deliquescence relative humidity, would deliquesce below 52°C [126°F] under realistic absolute humidities in nature (He et al., 2014).[40]

If a canister becomes compromised due to cracking, the industry has very few actions defined. Apparently, the way to solve this is to replace the canister, and to do that, it needs to be placed in either a spent fuel pool or in a “hot cell”, which is a chamber which can be filled with helium to provide a dry inert environment (without moisture or oxygen), and use remote controlled robotics to cut open the canister, remove the fuel assemblies, and then place them in a new canister, and weld it shut, and pressurize it with helium. This step is so difficult, it should be avoided by design. The HELMS proposal avoids this problem.

Holtec Proposed Consolidated site in New Mexico between Carlsbad and Hobbs could hold waste from all plants storing canisters vertically in underground vaults

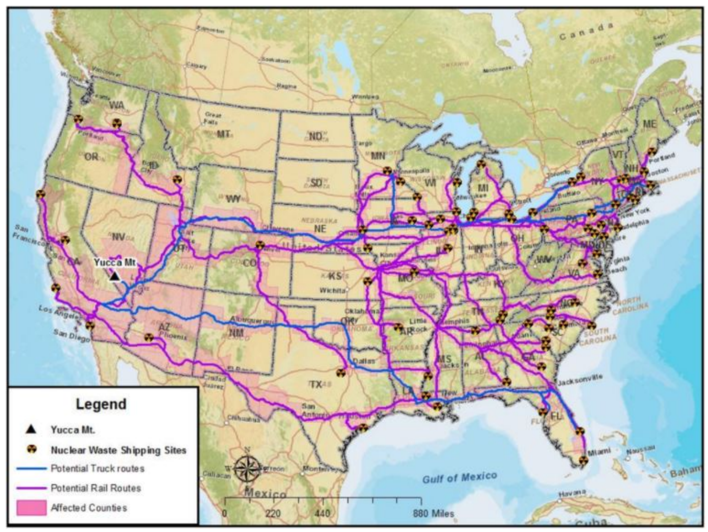
○ **Consolidated Storage**
The BRC Report proposes that an interim solution is to build one or more large “Consolidated Interim

40 NRC NUREG-2214 “Managing Aging Process In Storage” (draft) Adams ML17289A237, page 3-8 – our own analysis suggests the threshold temperature should be conservatively set to 70°C

Storage" (CIS) sites[41] designed to operate on the order of 100 years while a permanent geologic repository can be developed. Consolidation can reduce costs of administrative control and security by avoiding duplication. However, they propose the same lousy design similar to what we have now at the local ISFSIs. (It is our position any CIS facilities must comply with the HELMS plan.) Fully consolidated waste means a lot of transportation, which will be covered below.

- **Transportation**
  "Because of the residual hazard it poses, spent fuel must be shipped in containers or casks that shield and contain the radioactivity and dissipate the heat. In the United States, spent fuel has typically been transported via truck or rail; other nations also use ships for spent fuel transport."[42]

  - **Limit Transportation, Limit Risk**
    There is obviously increased risk during handling and transportation compared with not transporting the waste at all, if the two sites (source and destination) have similar risk profiles. The increased risk is due to three factors: human error, in handling the waste containers during transportation; design error, the possibility that the containers do not perform as expected; and terrorist risk, which might be higher if the transportation route is either more accessible to such attack, or if the route exposes dense populations.



Proposed Transportation Routes to YM

  - **High Consolidation Means High Transportation Risk**
    Either a single geologic repository or a single large CIS facility includes the concept that spent fuel would be transported <u>across the country</u> to those consolidated sites, resulting in transportation over very large distances and then requiring a second move to a permanent repository, if and when that ever happens. Residents are rightly concerned about this possibility exacerbated by the fact that rail transportation routes typically run right through the middle of cities. We must say, however, that it is probably quite reasonable to transport spent fuel out of California (and any locations west of the Rocky Mountain range, approximately 104° longitude – approximately along the extension of the Montana-North Dakota border) to locations east of that same line to reduce risk due seismic factors. We do

41 BRC Report, Page 35
42 BRC Report, Page 11

not subscribe to the theory that we can adequately predict seismic risk using the very short history of seismology.[43]

- **No Real Transportation Experience**
  Even though the BRC Report and other documents[44] make it sound like transportation in the United States is routine and has a long history, we have **NO experience** transporting full-sized dry storage canisters containing commercial spent fuel in the US[45]. France and other countries have transported spent fuel but we must remember that France is a much smaller country and has no routes even close to an East-coast to YM route, and there are differences in the types of fuel and canisters being used.

  In December 2016, Oak Ridge National Laboratories started a project to research the concerns regarding transportation.[46] The study and most planning is still around a large transportation campaign to a central site rather than to more local consolidation centers.

- **Rail or Ship Transportation raises fewest issues**
  Rail is said to be the safest approach for transporting spent fuel nuclear waste on land as it avoids most traffic incidents, but those same rails typically go right through the center of many towns and major cities. Ocean-going ships have been designed to accommodate spent fuel in dry cask storage containers and that approach may reduce popular push-back on spent fuel transport. However, transportation by ship likely means we will have much more handling as the canisters are loaded and unloaded, and then transported over land to the final destination, and we have no experience with transporting full-size commercial spent fuel canisters that way.

- **"Local" Siting Important**
  Thus, since transportation is a risky endeavor, it should be minimized while also balancing the need to move the waste from the site of origin and the associated water resource and high population density. In our proposal, we refer to this as "Local" siting, which may usually equate to "within the state of origin," or among a consortia of nearby states. There is something inherently fair about that concept. Each state that benefited from the power generated by the nuclear plant should also bear the burden of the waste. Since transportation does add risk, why transport very hot spent fuel long distances just to store it on the surface to cool for decades anyway? It makes no sense, but prudent local relocation does.

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43 Lutz, R, "A Prudent View of Earthquake Risks, Nuclear Plants and Nuclear Waste Along the California Coast" http://copswiki.org/Common/M1731

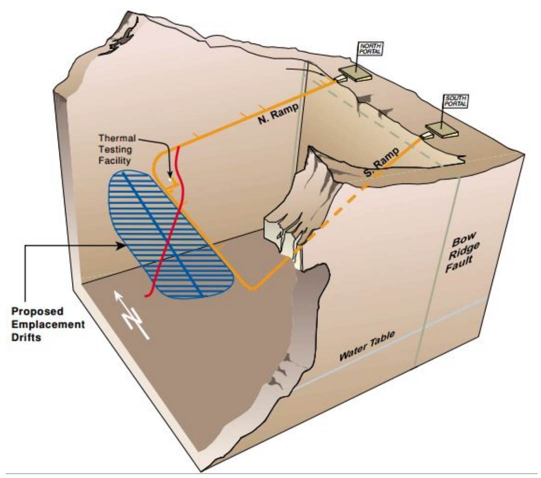
44 Kevin J. Connolly, Oak Ridge National Laboratory & Ronald B. Pope, Argonne National Laboratory, "A Historical Review of Safe Transport of Nuclear Spent Fuel" – FCRD-NFST-2016-000474, Rev. 1 (Aug 31, 2016) – https://www.energy.gov/sites/prod/files/2017/03/f34/Enhanced%20safety%20record%20report%20-%20final%20public%20release_0.pdf

45 Based on an answer to my question at the NRC DSFM REG CON 2017 meeting on Nov 1, 2017.

46 https://www.ornl.gov/division/rnsd/projects/spent-nuclear-fuel-transportation – This project was started in December 2016 and has no published papers on their web site disclosing any results.

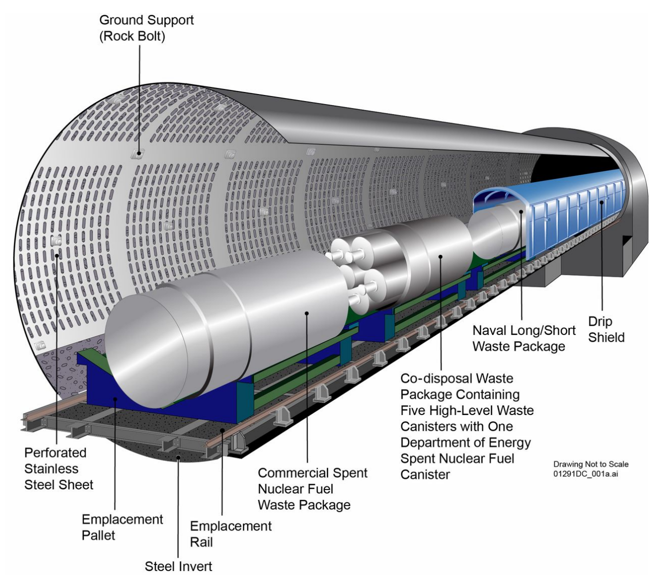
Where exactly should the sites be? That question is beyond the scope of this paper, but some work should be done to look at possible sites generally away from dense populations, water resources, and other concerns, while being mindful of environmental justice issues.

- **Deep Geologic Repository**
  "While several options for disposing of spent fuel and high-level nuclear waste have been considered in the United States and elsewhere, international scientific consensus clearly endorses the conclusion that deep geological disposal is the most promising and accepted method currently available for safely isolating spent fuel and high-level radioactive wastes from the environment for very long periods of time."[47]



Overall diagram of YM as currently proposed

  - **Interim Storage a Reality**
    While the statement in the above paragraph is no doubt true, we believe there are a number of reasons why we must have a better interim solution which can get us through the next few centuries with a design goal of 1,000 years, as follows:
  - **Siting Very difficult**
    Siting and developing a deep geologic repository is a more difficult technical and political challenge than anticipated. There are many unknowns over a long period of time in a geologic repository and it would be very difficult to deal with any significant unanticipated events.



YM Emplacement Tunnel As Designed

  - **Very few**
    Very few deep geologic repository sites will be developed, if any. Our experience so far is only with YM, and it was perhaps the finalist not because it is an optimal location from a geologic standpoint but because it is near the national atomic weapons testing area, and the planners at the time figured that politically, it would be accepted by Nevada.

47 Massachusetts Institute of Technology, *The Future of the Nuclear Fuel Cycle: An Interdisciplinary MIT Study*, Cambridge, MA, 2011, p. 59 (Referenced by the BRC Report, Page 29, Footnote 52.

- **YM Not Viable**

  There are many red flags about the YM site: It is not really "deep" in that it is in a mountain above the saturated zone rather than being deep in the crust. It is not in a highly stable geologic rock formation. It is near cinder cones and has a number of faults running through it. There is recognition that it will be permeated by water. You may hear that "it is the most studied place on earth" from a geologic standpoint, but that only means that we now know how much we really don't know about the situation and any notion that it is the best place for such a repository has been refuted, particularly when mated with the design philosophy, which relies on the geologic formation for isolation.

- **Science Must Guide Law, not the reverse**

  It is tempting for lawmakers to throw science under the bus and just pass a law saying the YM site will be used no matter what, and then say that "any scientific conclusions to the contrary are now moot" which is exactly what the DOE administrator said in the early 2000s in a recorded interview.[48] We must base our actions regarding this highly toxic waste on science and prudent planning rather than passing an overriding law in desperation while ignoring those real concerns at the site. In our view, science does not support YM.

- **Spent Fuel Too Hot Anyway**

  There are two approaches to the use of YM, one where the mountain is allowed to get very hot, and another where the temperature is kept below 100°C, so the water will not be boiled out of the rock and its characteristics changed dramatically. It will apparently be necessary to actively ventilate and cool the mountain for up to 200 years before it can be sealed. If that is the case the "deep geologic" part of the proposal is far from real. The air circulated over the waste effectively places it on the surface, or the spent fuel must stay on the surface for a long time (> 60 years) as well to be "aged"[49] which is to say they must cool off.

  Thus, even if we had YM open and ready for business, waste canisters from plants are far too hot, from a thermal perspective, to place in the repository under the cool-mountain scenario.

- **Too Hot for Humans**

  If hot waste is placed into the mountain, then it will be all but impossible to work in that environment without being roasted. We are told that it will be fully automated and there will be no reason for humans to have to enter it. This is the same sort of broken optimism that got us painted into the corner to begin with. Our conclusion is that a geologic repository is premature until at least several hundred years of cooling has been completed.

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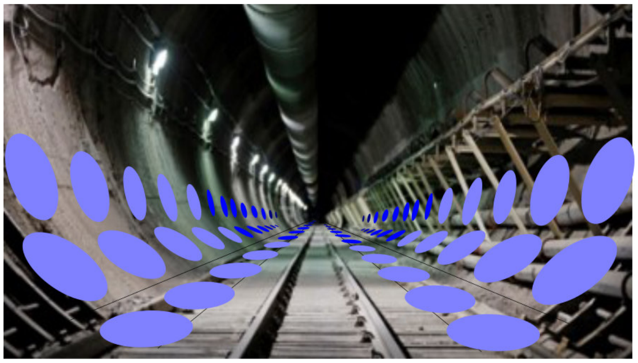
48 https://www.youtube.com/watch?v=c0emnrflYKE "Subversive Doubt: The Story of Yucca Mountain Nuclear Repository" 36:52 Quote by Edward F. Sproat III, Director, Office of Civilian Radioactive Waste Management, U.S. Dept of Energy – "Whether of not Yucca Mountain is an appropriate site for a repository, it is a moot point because back in 2002, the Department of Energy recommended to the president, the president accepted, and both houses of Congress approved Yucca Mountain as the site for the national high level waste repository."

49 NRC Yucca Mountain Report, section 2.1.1.2.3.5.3 "Aging Overpack and Shielded Transfer Casks" page 2-96

- **Design of a Repository should be compatible with Surface Storage**
  We believe it is a mistake for the canisters used at any geologic repository to be a completely different design from that used on the surface. The design proposed for YM was developed prior to learning what works best on the surface (and we believe we are still learning what works best on the surface). YM proposes canisters that are much smaller (only 24 PWR fuel assemblies vs. 37 in Holtec UMAX system), where the canisters are placed in a horizontal orientation and rolled down long tunnels with no means to pull out just one errant cask or deal with any issue down that tunnel, and do not use a double-wall design as proposed in HELMS.

  We suggest it is probably best to rethink the YM design to make it compatible with surface storage, i.e. a HELMS surface installation moved underground. If we assume nearly vertical, UMAX style emplacement with three tiers on both sides of the main tunnel, and since the main tunnel is about 5 mi (8.0 km) long, there is room for about 10,000 casks (about 120,000 tons heavy metal waste). That's about how much waste we expect if we prudently shut down the remaining nuclear plants and avoid building any new ones.

  YM-HELM Concept – Radial HELM storage in the YM main tunnel so each cask can be monitored, serviced and replaced, to accommodate 120,000 tons heavy metal waste (roughly 10,000 casks). Each blue circle represents the lid of a below-grade cavity where the cask is interred.

  With that said, we believe this decision can be set aside for the next one or two hundred years and focus on the reasonable proposal of HELMS on the surface.

Loss of Administrative Control

One of the important considerations and the rationale for either the geologic repository or the 1,000 year design criteria we endorse is the potential loss of administrative control and an extended "dark age" when the human culture may lose its technological prowess, or just a loss of funding, industry bankruptcies, and total lack of attention. Such a retreat implies that all inspections, maintenance, and aging management protocols will cease. Optimally, nuclear installations should then persist in a safe state without releasing radiation into the environment for as long as possible, to hopefully allow the human culture to re-establish technological capability and attention to the waste.

DISCUSSION

With the HELMS proposal presented and factual context in hand, there are a number of other important points which deserve treatment.

Two Phases of Spent Fuel Storage

We can define two phases in the storage regimen:

Phase 1 – Hot Storage: Single wall canister storage is appropriate when no part of the canister is below the deliquescence threshold. This is the hot phase, and the single thin walled canisters are important to allow cooling of relatively hot fuel assemblies, and

Phase 2 – Extended life storage: The DWC outer shell should be added when the heat load of the canister has decreased enough to allow the use of the DWC outer shell, and when the coolest location on the surface may dip below the deliquescence threshold.

To get a rough estimate for the two phases requires that we review the estimate of the temperature profile along the surface of a canister, and how it changes over time. The adjacent illustration shows the temperature distribution as it varies along vertical axis of a canister which is stored in the vertical orientation.[50]

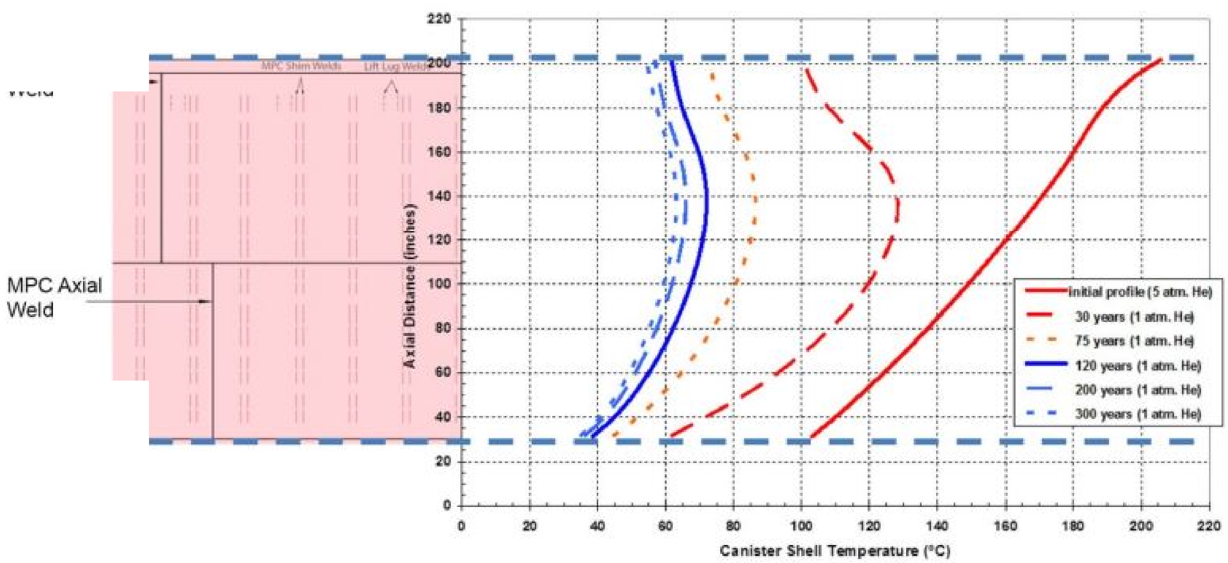


Figure 5.4. Axial Temperature Distribution at the Canister Shell Surface for Projected Decay Heat Decrease Over Time in Vertical Storage

50 "NDE to Manage Atmospheric SCC in Canisters for Dry Storage of Spent Fuel: An Assessment" -- https://www.nrc.gov/docs/ML1327/ML13276A196.pdf

We can note that the temperature varies substantially (100°C differential) at first and then the differential decreases as time passes. What we are interested in is actually the minimum temperature because once that goes below 70°C, CISCC may initiate. It is clear from this chart that the minimum drops below 70°C before 30 years of cooling have passed. To get a better idea of when the minimum might occur, the same reference provides a set of curves of the temperature of a given “typical” spent fuel canister in a vertical orientation, and on this illustration, we have attempted to estimate the minimum temperature (provided by the prior illustration), and then define the two phases.

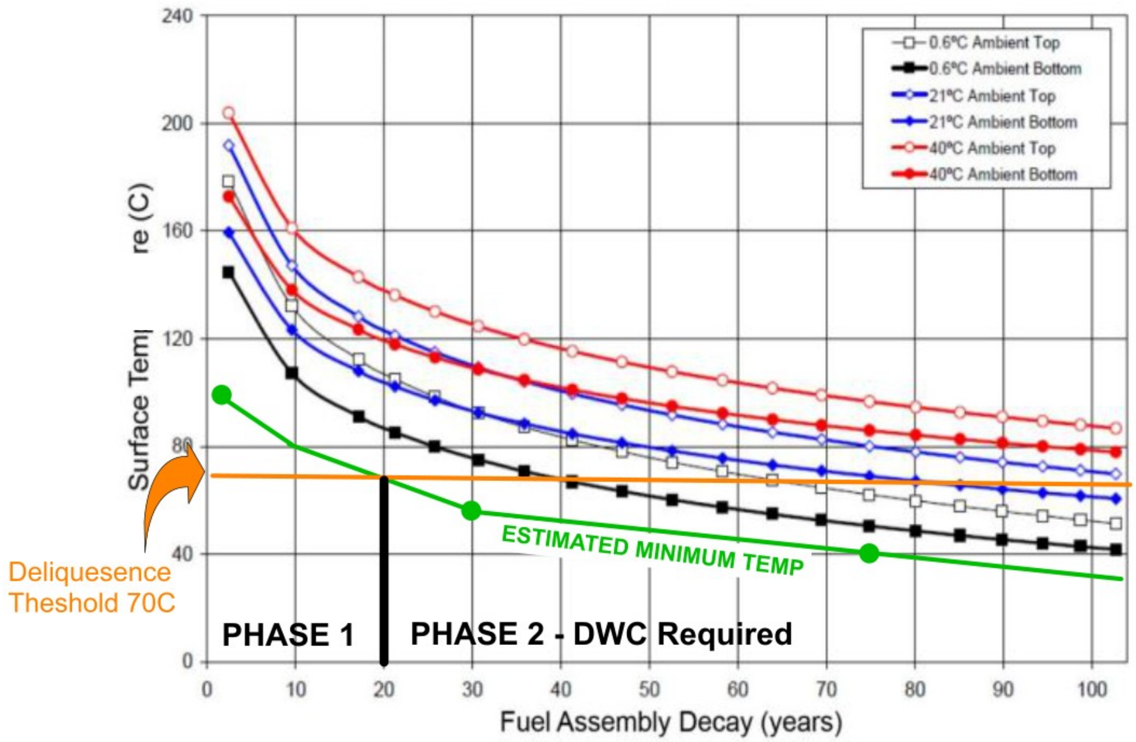


Figure 5.6. Calculated Temperature Estimations for Canisters with an Initial Heat Loading of 24 kW Under Different Ambient Conditions (Gordon et al. 2006). Copyright 2006, Electric Power Research Institute; used with permission.

Minimum temperature curve added by comparing with the axial (vertical) temperature profile, which provides T(min) of 100C at T=0, 60C at T=30y and T=40C at T=75y and sketching in the curve using similar curvature. Deliquescence threshold of 70C provides likely need to upgrade canister when fuel assemblies have cooled for about 20y. Additional estimate by R. Lutz.
Primary data from “NDE to Manage Atmospheric SCC in Canisters for Dry Storage of Spent Fuel: An Assessment”

Remarkably, the data in the first illustration does not actually match any of the data points in this second set of curves, so those key data points of the minimum temperature have been added to this illustration. We believe the reason the minimum curve must be added is because the very bottom of the canister is hotter than it is slightly up from the bottom, due to the air flow. Also, the deliquescence threshold of 70°C is shown. From these data, Phase 1 ends after about 20 years of cooling, and as soon

as the overall heat load of the canister can endure the DWC outer shell, it should be added to configure the canister for the long term. This estimate represents a best guess as to the time when the public should expect DWC to be used, so provide a basis for long-term storage.

HELMS does not assume a geologic repository will soon open

The use of thin, temporary canisters was based on the expectation that the spent fuel would be moved to a geologic repository within the limited service life of those canisters. This expectation is now known to be without merit, both from the likely life of these canisters in corrosive environments, and the likelihood of a repository, which is currently not on the horizon.

The more recent suggestion that these same canisters alone (without the DWC outer shell) can be stored “indefinitely” at a Consolidated Interim Storage (CIS) facility is also unreasonable. Faced with the temporary nature of the thin canister solution, communities who are asked to consent to such CIS facilities require that a geologic repository is also available or at least predicted to be available. Indeed, that may cause some to link approval of YM to laws allowing CIS to be developed, even if approval and use of YM may not be supported by scientific inquiry or honest reason.

Even if YM was approved and open, it would not be feasible to accept such hot canisters in the facility. Use of the existing thin canisters without using an improved storage technology, is unreasonable and imprudent. Therefore, it is essential that improved storage technology is used, such as the HELMS Storage recommendation and DWC.

HELMS: an essential and prudent step to secure commercial nuclear waste

The Waste Bottleneck stopped some new plants and thus reduced the overall waste problem.
As the world came to recognize the danger of nuclear power after witnessing periodic devastating meltdown accidents and other close calls, communities wished to block the threat of new nuclear plants. However, the principle of federal preemption eliminated raising safety concerns as a means to block new plants and close those that were already in operation. Some states – starting with California – passed moratoria to block new nuclear plants based on economic concerns unless a permanent solution to the waste problem was established.[51]

So if no permanent repository site was approved, the moratoria would in turn stop new plants from being built. Although we believe that the YM repository was appropriately discontinued. Regardless of the rationale, there is now a build-up of waste around the country. The world now recognizes that one of the fatal weaknesses in nuclear energy is the production of long-lasting and highly toxic waste, and that there is no means at hand to easily and cheaply dispose of it.

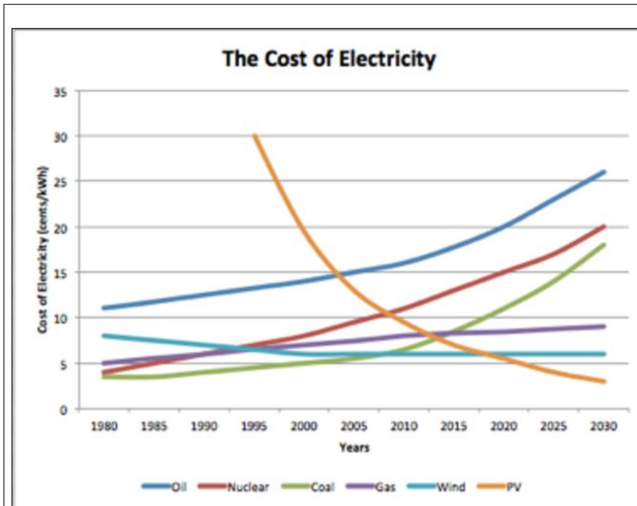
51 BRC Report, Page 25

Since operating nuclear plants generates new waste, blocking new plants and expediting shut down of any operating plants becomes the top priority to reduce the overall amount of toxic radioactive waste that needs to be dealt with.

Thus, we are faced with a difficult decision. Do we work to provide a safe way to store the waste for the long term, albeit in HELMS facilities, because that might encourage the industry to build new plants?

We believe we have moved past this quagmire due to the economics of electricity sources and the rapid decline in the cost of electricity from solar photovoltaic (SPV) systems and other renewable sources.[52]

We believe this is a trend that will be impossible for nuclear and other large-scale power plants to compete with.



Nuclear Power cannot survive the rapid decrease in cost of electricity from PV Solar, and nuclear cost shown here does not include the cost for dealing with the waste.

SPV is a good match to free-market-based optimization because many manufacturers compete in the fabrication of SPV cells, and since many millions are built each year, there is a great impetus and opportunity to improve them. The open free market cannot be easily controlled or rigged by utility monopolies to reduce this competitive advantage and thus to preserve their existing investment in fossil and nuclear plants.

In contrast, nuclear plants and other large-scale plants are NOT a good fit for market-based optimization because there are too few vendors and the design and life cycle of the plants is far too long. Experts agree we are still using nuclear plant designs that are obsolete and many – like the Mark I design in Fukushima – are downright dangerous. In the very near future, nuclear plants will be even more economically nonviable. It matters not what sort of newfangled "modular" designs may be contemplated, this difference in optimization will never allow the more complex and dangerous nuclear plants to compete.

Thus, it is now time to shift gears and embrace prudent storage of the existing commercial nuclear waste, and allow these severe market forces to limit the future generation of waste.

Thick vs. Thin Canister Debate

Much has been said of late about the inadequacy of the thin canisters for use on an extended basis at ISFSIs around the country. We agree with this concern as the thin canisters were designed for short-

52 Chart and data from Zoltan Kiss, "Trends In The Cost Of Energy" https://seekingalpha.com/article/1324411-trends-in-the-cost-of-energy (2013)

term use only, and now we are aware that they will corrode and crack over time. The industry has responded with administrative workarounds – make them work anyway, using even more administrative controls, in the form of aging management[53] and detailed robotic inspections[54] perhaps using ultrasound or eddy-current imaging[55]. These steps might work to squeeze every year of life out of the thin canisters, but it assumes the aging management and inspections are indeed feasible, performed correctly, and the reports honestly prepared. The simple fact remains that the design of these thin canisters is insufficient for the purpose for which they are now being applied – indefinite storage – and ignores the concern of loss of administrative control.

The HELMS criteria itself actually takes no position on the technology used to obtain the criteria of "hardened" and "extended life." Thus, it is open to any proposals that may come forward that can be judged against each other. Our proposal of using an additional DWC outer shell with inert gas protecting the thin enclosed canister, we believe is one viable approach.

However, some have advocated very strongly that we require the so-called "thick" casks, pointing to the CASTOR design, as an example, made of ductile cast iron instead of stainless steel. It is much thicker, with walls about 10" thick or more. Typically, these are stored in buildings without requiring the concrete overpacks or transfer casks, and they may be directly transported. Additional shielding is not required because shielding is integrated into the cask. These casks are not licensed for use in the U.S., and were originally designed for a different use-case, to be reused as spent fuel was sent to be reprocessed.[56] That said, just because they are not licensed does not mean the design elements cannot be adopted. These do have some very good design features, but we must caution that every design change comes with a trade-off of some sort, and so no design is perfect.

GNS CASTOR cask uses thick single-wall design that provide both containment and shielding

Direct Comparison Can Be Inappropriate

Sometimes, the thin canisters (1/2" to 5/8") are compared directly (i.e. without the overpack associated with the thin canisters) with the thicker casks to demonstrate how thin and inadequate they are. But, this is an incorrect comparison, because the thin canisters are part of a *component system* and are always transported and stored with some other additional overpack or enclosure, either concrete, steel

53 NRC NUREG-2214 "Managing Aging Process In Storage" (draft) Adams ML17289A237

54 https://www.epri.com/#/pages/product/000000003002008234/ "Dry Canister Storage System Inspection and Robotic Delivery System Development"

55 NDE to Manage Atmospheric SCC in Canisters for Dry Storage of Spent Fuel: An Assessment -- https://www.nrc.gov/docs/ML1327/ML13276A196.pdf

56 http://www.npolicy.org/article.php?aid=395&rtid=2 – "U.S. Government policy turned against reprocessing after India, in 1974, used the first plutonium recovered by its U.S.-assisted reprocessing program to make a nuclear explosion. Reprocessing makes plutonium accessible to would-be nuclear-weapon makers – national or sub-national – because it eliminates the protection provided by the lethal gamma radiation emitted by the fission products with which the plutonium is mixed in spent fuel."

with lead (for example the Holtec HI-STAR 190), or sometimes steel with lead and water (Holtec HI-TRAC transfer cask). The overpack would need to be included to make a fair comparison with regard to radioactive shielding.

On the other hand, the comparison DOES have merit because the thin canisters ARE exposed directly to the environment and the air, and are more likely to develop through-wall cracks (due to their thinness). So if any cracks should develop, radioactive particles could escape.

The thicker casks look more robust, but size is not everything. Cast iron, even the most ductile is much more brittle than stainless steel and there is a lot to learn how these options react to neutron bombardment over many decades or centuries. The thick casks typically have cavities bored into the cast iron filled with polymer to provide neutron shielding as the ductile cast iron is inadequate in that regard.

Also, the thicker casks have a bolted lid with a seal which degrades over time and must be replaced. The hermetically sealed thin canisters have no seals to replace. As a result, thick casks require periodic maintenance which may require a hot cell to avoid any entry of oxygenated air.

No need to inspect fuel assemblies inside the interior canister

We reject the notion that there is a great need to inspect the contents of the canister once it is sealed. If you ever do that, then it will likely require a hot-cell as the cask is completely open. It is better to view the canister as a unit that is never to be opened unless there is no other option. Yet inspection is still possible and likely will occur often enough for the industry to get an idea of the degradation processes inside. Opening a welded canister is not impossible, probably by cutting the lid off in a hot cell with remotely controlled equipment.

Heat Load Differences

The other downside of the “thick” cask alternative is the reduction in heat dissipation, since the thicker walls will reduce the transmission of heat, and therefore, those casks will not be able to enclose the very hot fuel assemblies thin canisters commonly allow. This is probably the most important reason the U.S. industry adopted the thin canisters, as they were eager to move extremely hot spent fuel out of fuel pools into canisters that could transfer a lot of heat to the environment.

The DWC design suggested here adds another layer and gas-gap, therefore, it does reduce the transmission of heat. However, we are suggesting using the outer shell only after the interior canister has substantially cooled and after the heat load of the canister can be effective dissipated through the DWC.

Thin Component Canister Systems are the defacto Standard in the U.S.

The design of dry storage systems is a balancing of many trade-offs. Most decisions in this industry were made to solve the near-term problem with cost and expediency in mind, rather than a well-thought out integrated system. The fact remains that the industry has already adopted the thin canisters and replacing the investment in these canisters will be a very difficult sell.

The DWC proposal essentially embraces this fact, thereby minimizing handling while improving the design to extend the overall life of the system. These canisters should be compatible with any future geologic repository. There was an assumption in the design of YM that the fuel assemblies would be removed from the canisters and placed in smaller YM-compliant canisters. This additional handling is a mistake in our view. The only handling should be replacement of any deteriorated DWC outer shells.

Since almost all spent fuel in the U.S. is in the thinner canisters (which are combined with other shielding elements), we are hopeful that providing an upgrade path in the form of the DWC design will provide most of the advantages of the thick cask systems, and provide a few other benefits not available with the single-wall design.

So for these reasons, we suggest that those pushing for the thick cast-iron casks should endorse the DWC we are proposing, so that the sacrificial outer shell can serve as the warning that the interior canister may now start to corrode, and will eliminate the severe requirement that inspections of the canisters detect minute cracks before they become through-wall holes. The DWC design provides an upgrade path for existing thin-wall canisters and can be readily adopted on a gradual basis, most particularly as new locally consolidated HELMS compliant facilities are built somewhat away from the risk factors that exist at the nuclear plant sites.

But it is fair to say that either choice is allowed under the HELMS criteria. If the industry decides that the single-wall casks can provide the 1,000 year design life and 300 year passive life, then there is no reason to quibble.

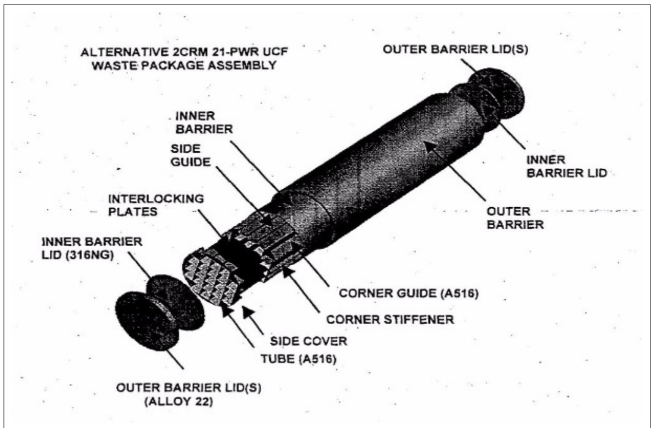
The upgrade path

We suggest the following upgrade path from the status quo:

- Any new ISFSI installations – and most importantly, any Consolidated Interim Storage site – should be designed with sufficient space between the internal canister and the outer concrete and or steel shielding cask, so as to accommodate a DWC outer shell and thereby HELMS compliant in that regard.
- Older ISFSI installations which are designed to be above-ground, should phase-in a larger overpack, if insufficient space exists around the interior canister, and then add the DWC outer shell to the older canisters and then replace the concrete overpack as these cool to below 70°C and Stress Corrosion Cracking may start. This may be after the fuel has cooled for about 20 years (including spent fuel pool cooling).
- Older ISFSI installations which are designed with below-ground vaults should review the applicability of the dual-wall design provided by adding the DWC outer shell and if necessary, using lower capacity canisters, and then add the DWC outer shell as soon as they cool to 70°C. Otherwise, we hope sufficient forethought will be given to any new below-ground ISFSI installations so they will have the capacity for the DWC design.

Comparison with Yucca Mountain

We should note that the cask design at Yucca Mountain (YM) uses a single-wall canister using two layers of different types of steel alloys bonded together, which together is about the same thickness as what we envision for the DWC outer shell (3”). The two layers in the YM design has no gas-gap to facilitate monitoring for cracks of the outer cask. They also added one more partial layer, in the form of a titanium (and costly) “drip shield” to avoid moisture induced corrosion. We believe there would have been more merit in a slightly different design by enclosing the drip shield as an enclosed outer shell, like the DWC design.



Canister design conceptualized for use at Yucca Mountain

According to Farmer et al of the Lawrence Livermore Laboratory regarding the waste package proposed for YM[57], “The waste package outer barrier (WPOB) is to be made of Alloy 22 (UNS N06022), while the underlying structural support is to be made of 316NG or 316L (UNS S31603). Alloy 22 is a high-performance nickel-based alloy with substantial amounts of chromium (21%), molybdenum (13%) and tungsten (3%). This particular material contains palladium (0.12-0.25%) to enhance resistance to hydrogen induced cracking.”

Stress Corrosion Cracking

Farmer continues, “There are several modes of failure that could lead to premature breach of the waste package. One of the most threatening is stress corrosion cracking (SCC). Initiation and propagation of SCC can occur at relatively low stress intensity factors. After initiation, through-wall penetration is essentially instantaneous when compared to the 10,000-year time scale of importance to the high-level waste repository at Yucca Mountain.”[58] (This issue has already been fully described in this paper.)

The paper by Farmer goes on to say there are a number of strategies to reduce the probability that such cracking will occur, but there is no way to prevent all risk of such cracking. Other than this factor, they claim that general corrosion will not consume the container for 10,000 years.[59]

We submit that the YM storage container and its associated drip-shield is not optimal. The drip shield provides incomplete encapsulation and is built into the storage cavities rather than being part of the cask itself. There is no means to monitor and detect leakage of the canisters at YM and no way to do much of anything if a breach does occur. The drip shield was a very costly attempt to reduce the flow of water over the canisters but can’t stop inundation from below.

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57 Farmer, et al, Lawrence Livermore Laboratory, (2000) “Modeling and Mitigation of Stress Corrosion Cracking in Closure Welds of High-Level Waste Container for Yucca Mountain” https://digital.library.unt.edu/ark:/67531/metadc733541/m2/1/high_res_d/791472.pdf

58 *Ibid*

59 *Ibid*, Figure 14, Page 10

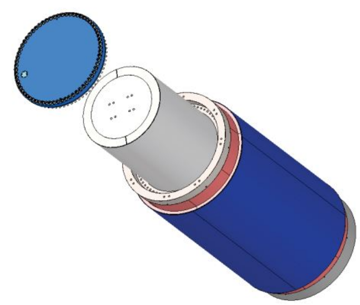
We believe that the DWC design should be compatible with any future geologic repository, so that no repackaging would be necessary, and if any were to be done, it would be restricted to replacing the DWC outer shell.

Comparison with HOSS

The HOSS proposal – Hardened On-Site Storage – has been discussed recently and is similar to HELMS in that surface storage is used. But, in contrast with the "On-Site" of HOSS, HELMS includes the notion of "Local" to imply that an on-site location may be fine in a few instances (such as at Palo Verde nuclear plant in Arizona, as there is no associated body of water next to it), but in general, some local transportation will likely be appropriate, so as to move it away from the water resource associated with the nuclear plant, away from dense populations, and consolidate the waste on a regional basis. For those plants in California – which we now know are in a very seismically active area – moving these off the moving Pacific plate and onto the more stationary North American Plate is advisable to reduce seismic risk. Although no place is safe from seismic risk, 90% of earthquakes occur on the "Ring of Fire" around the Pacific Ocean, and 81% of the largest earthquakes occur there. All of California is considered "very" or "extremely" hazardous.

Comparison with Humboldt Bay Nuclear Plant ISFSI

Humboldt Bay Nuclear Plant was very small and during decommissioning, had the need to store only five multipurpose canisters, and one canister with Greater Than Class-C Waste. PG&E selected the underground Holtec UMAX design, but modified the design not just to accommodate the "thin" canisters, but also to include the Holtec HI-STAR transportation overpack (without the impact limiters installed, see illustration.)



HI-STAR 190 Transportation Cask showing enclosed MPC canister

This is VERY similar to the DWC design because it includes two containment boundaries, and the gap between the overpack and the canister is purged of oxygenated air and replaced with purified helium. The outer shell at Humboldt is the HI-STAR transportation overpack and so it does provide extensive radiation shielding intended for transportation. That shielding is redundant in the storage configuration because the underground UMAX facility also provides sufficient radiation shielding, but more shielding never hurts. The Holtec HI-STAR 190, similar to the units at Humboldt, has walls that are a total of 15.25" thick, including nine inches of lead encapsulated in steel[60]. Other overpacks include concrete and sometimes water encapsulated in a steel jacket. The units

60 The HI-STAR 190 Transportation cask has an inside diameter of 76" and outside diameter of 106.5", providing an overall wall thickness of 15.25". The walls have an inside steel layer and an outside steel layer, providing structural support, while containing approximately 9" of lead, which is a gamma radiation absorber. Table 1.1.1, page 1.1-4 "Safety Analysis Report, HI-STAR 190 Package", NRC Adams Accessor number ML17166A448

at Humboldt can be removed from the ISFSI and (in theory) transported directly after installing the impact limiters.

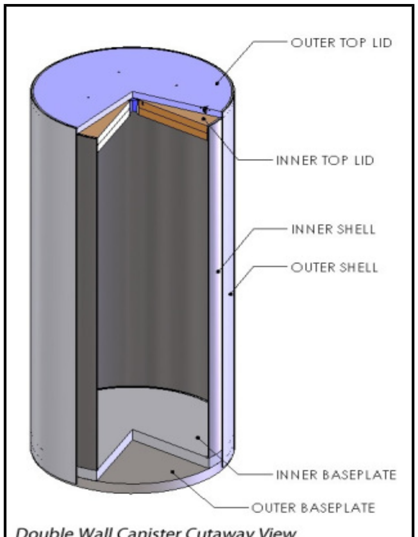
Although the implementation of the Humboldt Bay ISFSI does NOT provide the monitoring features we recommend for the DWC design, we appreciate the effort of PG&E to anticipate the need for the two-layer design. It may be feasible to back-fit monitoring to this configuration by adding the standard monitoring module to the lid.

Comparison with Chernobyl Cask Design

The design of canisters used for storage at the Chernobyl plant use a two-layer canister[61] similar to the DWC design except that they do not have the ability to remove the outer enclosing layer and replace it when it becomes compromised, since the two layers are "bonded" and in substantial contact, with no intervening gas gap.

> "The system consists of an enclosure vessel comprising two welded canisters that form two separate confinement areas to prevent the spread of radioactive materials, an internal basket and fuel tubes. It is designed for the horizontal placement of each canister inside the individual compartments of a concrete storage module."[62]

The new Holtec UMAX type installation recently approved for use for Chernobyl waste will also include a two-layer canister.[63] The Holtec Patent on the design used for the Chernobyl[64] mentions the first pressure vessel (the interior canister) and an outer pressure vessel, but there is no mention of a gas-gap nor or any facility to detect leaks in the outer shell, and it says they are in "substantial contact" between the two confinement systems. It is important for U.S. NRC regulators to be mindful of the fact that other international regulations apparently are more robust, and so the HELMS proposal is perfectly reasonable in comparison.



Double-Wall Canister as approved for Chernobyl.

The Holtec patent document describes the fact that the outer shell is bonded to the inner shell:

> In other words, the interface between the inner shell 10 and the outer shell 20 is substantially free of gaps/voids and are in conformal contact. This can be achieved through an explosive joining, a cladding process, a roller bonding process and/or a mechanical compression process that bonds the inner shell

61 https://holtecinternational.com/2015/08/03/the-chernobyl-defueling-project-worlds-largest-makes-major-strides/
62 http://www.world-nuclear-news.org/WR-Holtec-delivers-first-dry-storage-canisters-to-Chernobyl-site-27111501.html
63 "In addition to leading the world in size, the ISF-2 project has bestowed new technologies to the nuclear industry that includes the first double wall canister design (now adopted by other users)" – https://holtecinternational.com/2017/08/03/chernobyls-spent-nuclear-fuel-storage-facility-worlds-largest-enters-the-post-construction-integrated-testing-phase/
64 https://www.google.com/patents/US20160372224 Holtec Patent on Double-Wall Canister.

10 to the outer shell 20. The continuous surface contact at the interface between the inner shell 10 and the outer shell 20 reduces the resistance to the trans mission of heat through the inner and outer shells 10, 20 to a negligible value. Thus, heat emanating from the SNF loaded within the cavity 30 can efficiently and effectively be conducted outward through the shells 10, 20 where it is removed from the outer surface 22 of the outer shell via convection.

Comparison with Holtec UMAX system with metal liner

The underground Holtec UMAX system, like that installed at San Onofre, does include a metal cavity liner. This may appear to provide another layer of defense, but it is almost useless because it is not sealed, cannot be easily replaced, is not pressurized to detect leaks and to isolate the canister from the corrosive outside air; nor is there any integrated and standardized monitoring package. Thus, it does not – in itself – provide the attributes of the DWC design, and therefore, we see a need to add the DWC outer shell to the UMAX system, which unfortunately may require slightly larger cavities. Modifications to the current UMAX system design may provide some of the advantages of the DWC design by pressurizing the cavity between the metal liner and the enclosed MPC canister with helium once the canister cools to the point that the lid can be sealed, and outfitting the lid with the standard monitoring unit. In any case, the UMAX system as it stands is insufficient after about 20 years of cooling.

Comparison with Maine-Yankee Failed canister enclosure

We understand that the Maine-Yankee plant has a failed canister overpack on hand which exhibits some of the characteristics we are suggesting in the DWC outer shell so as to provide a double-wall canister. The image of this component (adjacent) provides a concept which would likely be quite similar to what we have envisioned in this recommendation, albeit with the note that the Failed Canister Overpack does not provide the monitoring features we are recommending.

Failed Canister Overpack at the Maine-Yankee nuclear plant.

HELMS for Hanford

Since HELMS is really a set of criteria rather than a final design, it may help us find a better solution for the Hanford, WA site, even though this question is out of the intended scope of our attention. Nevertheless, this question can be entertained as follows.

Much of the waste at Hanford is in the form of liquid waste in tanks, some 149 single-shell tanks (SSTs) and a few dozen double-wall tanks. The SSTs are all unfit for use and decades past their design

life.[65] Sum of capacity of all tanks at Hanford is 206,000 cubic meters[66]. Assuming a DWC system similar in size to the Holtec MPC-37 plus the DWC outer shell, we end up needing about 15,000 casks. If placed 16 feet on center, 122 units on a side, this would consume an area of about 75 acres – easily sited at Hanford. The benefit to using many smaller casks rather than huge tanks is that a) they can be produced in a factory setting with tighter tolerances and quality assurance, b) they can be more easily replaced if there are any leaks, and c) even if one is completely breached, it is not nearly as large a catastrophe as a large tank. That said, this is a much different problem because liquid waste will more easily leak out of a canister system when compared with spent fuel, which is solid in form. And, some of the tanks were filled with grout to absorb the liquid and getting it out is a problem of its own, and in some cases the waste is vitrified into a solid.

Bottom line is that we believe HELMS and DWC design could be appropriately applied to the Hanford site with positive results, at least for some of the waste there.

Conclusion

We hope that the nuclear industry and community concerned with nuclear spent fuel will consider our recommendations in this document, and start to make some changes in the planning, most particularly for any new ISFSI installations or CIS proposals.

We appreciate feedback and comments from the community as we progress this plan for national implementation. Please email the author.

About the Author

Ray Lutz, MSEE, has been involved in nuclear decommissioning and spent fuel issues most particularly regarding the shut down and decommissioning of the San Onofre nuclear plant, and has served in the role as intervenor at CPUC and NRC proceedings, among other endeavors.

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65 http://www.ecy.wa.gov/programs/nwp/sections/tankwaste/closure/pages/tank_leak_FAQ.html
66 Appendix D: Waste Inventories – https://energy.gov/sites/prod/files/EIS-0391-FEIS-Volume2_AppD-G-2012.pdf