Reviews, Inputs and Backup Materials: 1 Sept draft report on dry cask options at San Onofre

Subject: FIRST ITEM FOR REVIEW PDF: "Frank von Hippel to David Victor, 18 Sept 11:44AM"
Date: Wednesday, October 8, 2014 at 7:19:45 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

From: "Frank N. von Hippel" <[redacted]
Date: Thursday, September 18, 2014 at 11:44 AM
To: "David G. Victor" <[redacted]
Subject: Re: long term storage of nuclear waste

Dear David,
Good to hear from you!
A few reactions which are not definitive answers but may provide you with some additional questions at the least:
p. 2: Re Castor casks, The first casks in the U.S. (at Surrey in Virgina) were Castor casks. They are more robust with regard to attack. I don't know whether they have been licensed for transport. (I am surprised at how much of your report is devoted to the Castor cask. I guess there are advocates on your committee.)
Re: Licensing period. The NRC has recently extended some existing casks to 60 years. I don't know whether that means that new casks can now be licensed for 60 years from the beginning.
p. 3:Re defense in depth. Some (Gordon Thompson is the lead technical person who works with US NGOs on this [redacted] argue that casks should be protected from direct attack. Germany has casks in thick-walled buildings and, at one plant, Neckarwestheim, in tunnels. I guess the new Holtec design has this feature.
p. 4. Re: recycling. Only two country of the 31 with nuclear power reactors systematically recycle spent fuel: France and the Netherlands (one 500-MWe reactor).
Japan is trying but failing. China, India and Russia have R&D on breeder reactors. The UK has been reprocessing but is quitting. France, Russia and the UK have had customers but all those customers have decided not to renew except for the Netherlands.
p. 5. Castor casks sit inside in Germany and outside in the US.
It is not clear that any current US cask would be accepted in a repository. The DoE put out design specifications for triple-purpose casks (storage, transport and disposal). The effort was cancelled but it might be interesting to compare those specifications with those of the casks that US utilities have been buying.
The primary reason that US utilities have gone with thin stainless canisters with reinforced concrete shielding is cost. They cost roughly half as much as Castors.
I don't think that the overpack can be given much credit for preventing corrosion. They may protect from direct rain and snow but not from humidity and leakage -- or salt at an oceanside site. Once again, Castor is licensed for use at Surry.
p. 8: I too am concerned what "periodic inspection" would involve. Do you pull the canister out? If so, you can't get close to it because of the thin walls. You would have to put it in a spent fuel pool, which would presumably be unavailable (or see below).
p. 9: I don't think that monitoring for temperature and radiation around the concrete overpack would be that useful. Measuring radiation would put you pretty late in the game if there were radioactive leakage. However, the canisters are filled with helium and are often equipped with valves through which you could measure the helium pressure.
p. 12: I would like to see a description of how canisters are inspected and repaired without incurring unacceptable radiation doses.
p. 13: The NRC, in its Generic Environmental Impact Statement for Continued Storage of Spent Nuclear Fuel shows a design for a way to repack a cask in a small shield building without a pool.
p. 14: A sample Surry cask was transported from Virginia to Idaho National Lab for external and internal inspection.
p. 15: "the temperature at which HBF faces cladding failures is dramatically higher than for non HBF." I think that you may be confused. The temperature that HBF reaches in a canister is higher.

I suspect that a Castor cask could be welded shut if desired.
p. 16: Degraded HBF will have the same temperature as non-degraded HBF.
Best regards,
Frank

On Sep 18, 2014, at 10:51 AM, David G. Victor wrote:

Dear Frank

I hope this note finds you well. It has been much too long since our paths have crossed. But I continue to be engaged with various activities at Princeton—most recently, advising (with Denise Mauzerall) three of your students who are doing dissertations on energy issues in China. And I keep working on issues related to climate—including a major role in the last IPCC report, about which the attached essays from Science last summer may be of interest.

Today I write on something totally different. As a resident in southern California, I have been tapped by the co-owners of the San Onofre nuclear generating station (SONGS) to chair a community engagement panel (CEP). The CEP, modeled in part on a similar panel at Maine Yankee, has engaged the variety of communities around the SONGS plant to help provide feedback and spread information about the decommissioning process. This year, the first year of this CEP, we are highly focused on providing input to various regulatory filings and strategic choices that Edison (the majority owner) is making with regard to decommissioning. Some of the most vocal members of the community have focused, in particular, on questions about storage of spent fuel. Everybody wants it off site, which is understandable but not practical given the gridlock with Yucca mountain. (However, in early 2015 the CEP will be revisiting this issue and exploring what might be done, if anything, to pursue consolidated interim storage and other options.) That unpleasant reality has focused minds on long-term cask storage. Edison is making some key decisions on that matter this fall when it chooses a vendor for its casks.

Lots of questions have been raised about this choice and the long-term strategy. And, frankly, for non-experts it has been hard to get reliable answers in plain English along with a sense of how the storage options will evolve over 50+ years and how the industry and regulators will assure stewardship of these casks. Through the CEP we saw many of the same questions coming up and the lack of a focus on the discussion of debate. So earlier this summer I got folks to agree on 7 critical questions and then I led a research project to find the answers. The results of that research project are attached in draft form.

I write to see if you would be willing to read the attached and offer your views. I don't need a detailed technical review (but if you have pointers to materials or areas where I have erred through commission or omission that feedback would be welcome). But a big picture read would be helpful.

My plan is, over the next 2 weeks, to revise this memo and then release it more widely as part of the CEP process.

We have a team of four members of the CEP who are also centrally involved in this process—Gene Stone (whom you may know), Ted Quinn (past president of the ANS), Bill Parker (physics professor at UC Irvine) and me. The rest of the CEP, 18 members in total, are regularly briefed on our work.

I am also sending a review copy to EPRI, NEI, and David Lochbaum at UCS. I've also been in detailed communication with the NRC on this and testified at NRC in July on related issues. I think Gene (and a colleague of his, Donna Gilmore, who is a particularly well informed member of the community and quite active on these issues) have also shared a copy with Marvin Resnikoff.

I'd welcome your counsel—either informally or, if you prefer, a review that I release publicly. What I care about most is getting the story accurate, properly balanced, and written in plain English. I am sure that not everyone will agree with the final text, but the idea is to have one document that fairly represents the literature and helps inform the public accurately about what is happening and what they should pay attention to as the casking process unfolds.

all best

David

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David G Victor
Professor & Director, Laboratory on International Law & Regulation
School of International Relations & Pacific Studies, UC San Diego
[redacted]
<CEP memo on casks and safety, DRAFT, 1 Sep.pdf><Victor et al, IPCC Berlin.pdf>

Subject: SECOND ITEM: "Dave Lochbaum to David Victor, 18 Sept 10:54AM, plus attachment"
Date: Wednesday, October 8, 2014 at 7:19:44 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

From: Dave Lochbaum <[redacted]
Date: Thursday, September 18, 2014 at 10:54 AM
To: "David G. Victor" <[redacted] Chris Thompson <[redacted]
Subject: RE: email introduction

Dear Dr. Victor:

Thank you for the opportunity to review and comment on the draft memo about dry storage at San Onofre. My comments are embedded in the attached file. If I can clarify these comments or if a more formal response would help your work, please let me know.

None of my comments involves a recommendation/finding that is off-the-mark or suggests a key recommendation/finding is missing. Some of my comments suggest a minor expansion of the recommended effort, but these are more tweaks than wholesale revisions.

I think the tone and content of the memo are spot on. It is often tempting to explain why a product was selected or a pathway chosen by describing its many virtues. When decisions aren't as clearly black and white, as in this matter, a memo like the one you've drafted is invaluable. It broadens the decision-making rationale by also explaining why alternatives are less attractive.

The CEP is helping both the public and the company. I sincerely appreciate the time and effort you are applying to this outcome. If I can assist your efforts in any way, I will do so if I'm able.

Thanks,
Dave Lochbaum
Director, Nuclear Safety Project
Union of Concerned Scientists
[redacted]

From: David G. Victor [redacted]
Sent: Thursday, September 18, 2014 10:02 AM
To: Dave Lochbaum; [redacted]
Subject: Re: email introduction

Dear Dave

It was a pleasure to meet you via email last month and thanks for your offer to help with our evolving issues at SONGS. Today I write with such a request where your review and insight would be of special value.

As you know, I chair a community engagement panel (CEP) that has engaged the variety of communities around the SONGS plant to help provide feedback and spread information about the decommissioning process. This year, the first year of this CEP, we are highly focused on providing input to various regulatory filings and strategic choices that Edison is making with regard to decommissioning. Some of the most vocal members of the community have focused, in particular, on questions about storage of spent fuel. Everybody wants it off site, which is understandable but not practical given the gridlock with Yucca mountain. (However, in early 2015 the CEP will be revisiting this issue and exploring what might be done, if anything, to pursue consolidated interim storage and other options.) That unpleasant reality has focused minds on long-term cask storage. Edison is making some key decisions on that matter this fall when it chooses a vendor for its casks.

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I'd welcome your counsel—either informally or, if you prefer, a review that I release publicly. What I care about most is getting the story accurate, properly balanced, and written in plain English. I am sure that not everyone will agree with the final text, but the idea is to have one document that fairly represents the literature and helps inform the public accurately about what is happening and what they should pay attention to as the casking process unfolds.

all best

David

From: Dave Lochbaum <[redacted]
Date: Monday, August 25, 2014 at 9:08 AM
To: Chris Thompson <[redacted] "David G. Victor" <[redacted]
Subject: RE: email introduction

Dear Dr. Victor:

I had the opportunity to meet with Tom Palmisano and Chris Thompson last month after reviewing many documents about the decommissioning planned for San Onofre, including materials from the CEP workshops.

The CEP looks like it has and will continue to provide benefits to the community and to the company. If I can assist you or the CEP, please feel free to contact me by email or phone. The most reliable phone number for me is my mobile, [redacted]

Thanks,
David Lochbaum
Director, Nuclear Safety Project
Union of Concerned Scientists
[redacted]

From: [redacted]
Sent: Monday, August 25, 2014 12:01 PM
To: Dave Lochbaum; [redacted]
Subject: email introduction

Dav d V ctor, Dave Lochbaum,

Per prev ous conversat ons, ntroduc ng you v a ema . Not much more to say.

Best,

Chr s

Chr s Thompson
V ce Pres dent, Decomm ss on ng
Southern Ca forn a Ed son
[redacted]

To: Community Engagement Panel (CEP) for SONGS

From: David G. Victor, CEP Chairman

Re: Safety of long-term storage in casks

Date: 1 September 2014

DRAFT FOR REVIEW BY THE CEP DRY CASK REVIEW GROUP AND SELECTED EXTERNAL REVIEWERS

This is a DRAFT of a memo that I will eventually circulate to the CEP and the broader public about important questions that arise with long-term storage of spent fuel in casks. One outcome of the CEP's work on spent fuel management is the realization that spent fuel is likely to be stored on site at San Onofre for very long periods of time—most likely well beyond the 20-year period for initial licensing of dry casks. Thus many CEP members, along with the public, have urged us to pay attention to the long-term plan for management of those casks. Some CEP members have also raised specific questions about the procedures for inspecting and repairing casks if needed. The need for a long term strategy emerged as one of the central themes of a survey of CEP members that vice-chairman Tim Brown and I conducted over the last month. Mindful of that, he and I expect that the CEP will revisit these issues in early 2015 with a special focus on long-term management of spent fuel as well as what, if anything, the CEP can do to help Washington focus on its obligation to remove the spent fuel from sites such as San Onofre.

Until we revisit this topic, this memo offers answers to 7 questions that several CEP members have agreed should be answered because of their pivotal importance to a long-term management strategy. We have also benefitted from the input of Donna Gilmore, a particularly well informed member of the community who has been tracking these issues and helped us review these questions. I have also sought detailed input from Edison, which I attach to this memo. We have also benefitted from indirect input from the Nuclear Regulatory Commission (NRC) and other experts. I expect that this draft will be reviewed at NRC and other organizations and the facts I recount here may be adjusted as a result of that review.

This memo is designed to present factual information in plain English. In a few places, where readers may want more detail, I have added footnotes. Along the way, I also offer my assessment of the best strategic options for us in the San Onofre communities. This is my assessment as an independent person having now looked at a massive array of data and analysis with an eye to the best options for our situation.

I don't expect everyone to agree with everything I write below, and that's partly why I am releasing this memo in draft form. But I see three conclusions emerging from this work:

1. It has been very useful for us to pause and look more widely at the range of options—including European vendors of canisters not currently licensed in the United States. We have learned a lot. It is now time to move on. My assessment is that the SONGS co-owners are wise to be focusing on just the three vendors of stainless steel casks who have a significant presence in the US. I appreciate that some folks want SONGS to look at vendors from Europe who use a different technology with very thick iron walls rather than thinner stainless steel. Having looked at the totality of the evidence—in particular, a thick walled cask from a German company Castor—I don't see that option as viable for the long haul here in the US. Opting for that cask would put us alone in the U.S. industry and thus unable to benefit from lessons learned at other U.S. facilities. It would expose us to possibly long delays in initial regulatory approval and it would leave us vulnerable if Castor's manufacturer went bankrupt or otherwise decided not to continue investment in the U.S. market. My assessment is that safety with long-term storage comes from good design, "defense in depth," and working with technologies that many other peer companies use at the same time. As of June 2013—which was the last full inventory of US casks that I have seen—Castor had less than 1% of the U.S. market. In totality, the Castor option is possibly the most dangerous of the major options that have been discussed. Of the three cask vendors the best options are with Areva TN or Holtec—the two companies that dominate the U.S. market. These are exactly the two vendors that the SONGS co-owners are evaluating for final decision on cask vendor. (The third vendor, NAC, is not seriously being considered. They have only 16% of the US market.) **Recommendation**: before we move on, we should ask Edison for its final assessment of the Castor option, including an assessment of the possible regulatory delays and design problems that might arise from thick-walled ductile iron casks. We have a preliminary assessment from Edison attached as Appendix A, but we would benefit from Edison talking directly with Castor to resolve any remaining issues. A serious analysis of this option will require access to proprietary information and thus it would be inappropriate for the CEP to do that analysis—a task for which we are not qualified. But we should review what Edison has done at arm's length and quickly.
2. We in the communities around SONGS must look way beyond 20 years, which is the initial license period for casks by the Nuclear Regulatory Commission (NRC). When I began this research project I was concerned that, on the surface, it appears that NRC wasn't focused on this period beyond 20 years and that the whole process of setting 20-year time horizons was artificially short. What I have learned is that NRC's regulations in this area are only a small part of how the industry is facing this challenge and that NRC's approach is highly procedural. If we want to learn how long-term monitoring, repair (if necessary) and adjustment to new information will

actually occur we must look not just to NRC but also new procedures taking shape through the Nuclear Energy Institute (NEI), the Electric Power Research Institute (EPRI) and others. This memo outlines some of the key insights from that broader industry-wide program to manage aging materials, including casks. I call that program "defense in depth"—that is, layers of defense and monitoring so that the system, overall, is robust for the long term. Any long-term scheme like this involves uncertainties. Those uncertainties require management and new information along the way. My impression is that the industry is focusing on this task but has, so far, not conveyed to the public in a clear way exactly what "defense in depth" will mean in practice. Part of this lack of information simply reflects that the public has never asked for that information. Part of it reflects that the regulatory process is highly focused on cask licensing and license renewals—along with all the head-spinning technical details associated with those processes—rather than explaining in plain English the long-term strategy for management of spent fuel on site. **Recommendation**: We should meet with the two viable cask vendors and ask them what "defense in depth" means and how they, as vendors, will service these casks for the long haul. We need to ask these questions of the vendors themselves because it is clear that the vendors play a pivotal role in the regulatory and management process. At the same time, we should ask Edison to articulate over the coming year how "defense in depth" will work and how the industry is preparing for long-term management. When the CEP revisits this issue in early 2015 we should consider holding a workshop with NEI, EPRI, NRC, and national watchdog groups that are focused on this issue industry-wide. One of our roles in the CEP could be to help articulate in plain English how "defense in depth" will work at SONGS. That would help all of us focus on the elements of that strategy—including the uncertainties—that are really important. My assessment is that the uncertainties involved—such as long-term aging of the fuel inside the casks, integrity of cask walls, repairs of the walls and overpack if needed—are all completely manageable, do not require fundamentally new types of material and other sciences, and are within the realm of what good organizations know how to do already.

3. I remain convinced that the safest option for us is to get the fuel out of pools and into casks as soon as that's practical. In the pools all the fuel is sitting in two locations and is kept cool with active systems—pumps, circulating water, etc. In casks it is divided into more than 100 new independent containers—each designed to withstand massive shocks—and relies only on passive cooling. All else equal, decentralized passively managed systems are safer than centralized active schemes. **Recommendation**: while we should study the many options and continue to articulate views about the best strategies, we must also remain mindful that there are tradeoffs with delay. Demand for casks in the U.S. is surging and the SONGS plant needs to "get in line" to buy its casks; we need to participate centrally in the industry-wide aging management program. And delays come with the cost of leaving the fuel in pools for unnecessarily long periods of time.

Question 1: Why are U.S. utilities using thinner walled stainless steel casks rather than thicker walled ductile iron or forged steel?

For better or worse, the United States long ago decided to have a "once through" nuclear fuel cycle. We put fuel in reactors and burn it partly and then refuel the reactor with fresh fuel. The spent fuel is then cooled on site, put into casks, and as a final step sent to a permanent long-term repository. Of course, that last step hasn't happened yet. By contrast, Europe (and most of the rest of the world) recycles its fuel. In those countries, fuel is put into reactors and burned partly; then it is cooled in pools, put into casks and sent to reprocessing facilities where fresh fuel is fabricated in part from the old fuel. I won't get into the question of whether "once through" or "reprocessing" are better economically or in terms of safety, but the reality for us is that it leads to radically different strategies for casks.

In the American system, the cask is designed to be a permanent home for the fuel. We put fuel into the cask, seal it, and then keep it there forever. That strategy means that we in America want to select materials for the cask that have extremely long lifetime (usually stainless steel—more on that below) and we want to weld the whole thing shut so that it is hard for anyone to open the cask.[1] Europe, by contrast, puts a premium on casks that can be opened and re-used and that have monitors and other systems inside the cask that can be routinely inspected and repaired. European casks, as well, rely on bolted lids that can safely be opened and closed because the trip into the cask for spent fuel is a brief affair. Because the bolted lid relies on an O-ring and sealing between the lid and the cask, such designs also require more active monitoring to ensure that the O-ring keeps working as designed. Such risks of lid failure should be dramatically lower when the lid is sealed with a weld, although I have not yet seen a true "apples to apples" comparison of lid failure risks over the long term.

These fundamental differences make it very hard to compare European and American casks. One of the three vendors under consideration for SONGS casks (TN Areva) has a large European operation but uses slightly different casks in Europe than in the United States. So even within a single vendor there are important differences.

Because of the emphasis in Europe on fuel removal from casks, at least one vendor (Castor) uses very thick (about 14 inches) ductile iron walls. Iron may have some advantages over stainless steel in terms of integrity of the cask alone, but that is a hypothesis rather than anything proven. Thickness doesn't automatically mean safety, especially when it concerns long-term aging that might involve

[1] A small minority (11% by my calculation) of US casks have bolted lids. Most are welded shut and essentially all new cask designs envision welding.

[2] EPRI 2013, "Failure Modes and Effects Analysis (FMEA) of Welded Stainless Steel

embrittlement. The Department of Energy has raised serious concerns (so far unanswered to my knowledge, but a conversation between Edison and Castor's manufacturer can resolve this) about whether thick-walled casks have sufficient integrity. There are concerns about nodules in the iron, rusting and other aspects of aging. Some of these concerns appear to be much greater for thick walled casks because they are design to sit alone and exposed to the elements; by contrast, all the stainless steel options under consideration for SONGS would sit inside a concrete "overpack." What is clear, however, is that the thick walled casks have not taken off in the US—partly, perhaps, because it unclear whether such a cask would ever be accepted in a permanent fuel repository. The Castor cask has never been licensed in the US for transport or for permanent storage. The main U.S. facility that has about two dozen Castor casks has a site-specific license and thus little can be gleaned from that experience that might tell us about licensing of newer Castor designs at other sites such as SONGS. Absent a license for transport or permanent storage, if utilities bought these casks they would potentially need to move the fuel from the cask into a new, final storage cask—which is exactly the opposite of the "once through" fuel strategy and would expose workers to additional radiation hazards as the fuel is transferred. U.S. utilities know that so they don't purchase these casks—except for a small number used on an experimental basis. Even the utility that owns the two dozen Castor casks mentioned above hasn't bought any more of them.

All this creates a "chicken or egg" problem for Castor. It is imaginable that the U.S. industry might follow a radically different path and use thick-walled casks. But nobody wants to go first—in part because there are good technical reasons to use stainless steel with concrete overpacks. And the vendors know what the industry thinks so nobody makes a big investment in marketing and servicing these casks in the U.S. (Worse, the European vendors are about to face a severe crisis over their own since electricity demand in Europe is flat; few new reactors are being built; and some countries, notably Germany, are shutting all their reactors. That reality should make us worried about depending heavily on vendors whose financial lifeblood is in Europe unless they have other serious options elsewhere in the world.) This reality will not be altered by what we do at SONGS, and if we purchased Castor casks we might find ourselves stuck in the middle—neither chicken nor egg. That could mean that we would need to "repurchase" all of our casks when the time came to transporting the fuel off site or if some aging management problem arose that the vendor wasn't around to help us fix.

<u>For our purposes, what is crucial to know is that these thick walled casks have essentially zero market presence in the US.</u> In fact, the Castor design isn't currently licensed for use in the U.S. and thus even if SONGS were to purchase them there would be a period of uncertainty (and delay) in getting those casks into service. Edison's assessment is that would introduce 5-10 years in delay just for licensing. In email traffic with members of the CEP the NRC has said that its licensing process could run only 18-30 months, but I suspect that assessment is for licenses that use materials and procedures that are already familiar to the NRC. It is quite plausible that SONGS would suffer the much longer term estimate of a decade of delays in

light of all the uncertainties at NRC and the complete lack of operational experience with these casks in the U.S. along with the many questions that have been raised about whether thick walled ductile iron is viable. My assessment is that the safest options for the long haul require buying casks that lots of other utilities use provided that Edison and the communities have confidence that these casks are matched with "defense in depth." That assures us that we can learn from the real experience across the US industry and it assures us that we have lots of partners in case issues arise with casks over time. Even if the vendor of our casks were to go bankrupt, the large number of similar casks across the US industry would guarantee that other vendors would appear to help us manage these casks safely as they age.

I have asked Edison for their assessment of the potential for the Castor cask, which I attach as Annex A to this memo. It summarizes many of the issues raised above. There are still a few unturned stones—for example, the manufacturer's response to the concerns raised about ductile iron and the need for a fresh assessment of the likely delays in obtaining regulatory approval. But as soon as those concerns are resolved—which can be done through a direct meeting between Edison and the vendor—I would consider this matter resolved. I am mindful that there have been calls, as well, for a public meeting with the vendor but if the vendor is not a viable option I don't see the purpose in such a public event.

Question 2: What is the track record with cracking of stainless steel similar to that used in casks?

Stainless steel has been used extensively and for decades and thus the experts know a lot about how it ages under stress.

The Nuclear Regulatory Commission (NRC) has focused heavily on how aging materials might fail and has an active program in this area. However, when we look at information from this program we must remember that most of NRC's focus is on stainless steel in pipes, vessels and other uses in ACTIVE nuclear reactors. These pipes operate under extreme pressure (hundreds or thousands of pounds per square inch, psi) in direct contact with water; they are cycled between hot and cold, high pressure and low, and thus will experience a LOT more wear in those extreme flexing environments than the stainless steel that is relevant for casks. Within a cask the wall is dry; the pressure is low and constant and the temperature nearly constant.

What really matters, therefore, is an assessment of risks for stainless steel used in cask systems. In that regard, I have found it particularly helpful to review a massive recent (2013) EPRI study that looks at ways welded stainless casks could fail.[2] They look at a 120-year time horizon, and this study is part of a pair of studies along with

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[2] EPRI 2013, "Failure Modes and Effects Analysis (FMEA) of Welded Stainless Steel Canisters for Dry Cask Storage Systems." Online at epri.com

an ongoing EPRI program on materials aging in nuclear plants. This risk management approach is the right way to analysis risks across the whole system, but first let me comment on what I have learned about stainless steel itself.

In parallel with the EPRI study, NRC itself funded some research focused on one particular kind of failure—so-called stress corrosion cracking (SCC) due to chlorides and other materials deposited on the surface of the casks.[3] The NRC study includes a literature review—the most current one published, to my knowledge. Among the findings from the NRC study is that risks depend on the type of stainless steel, the filler material used in stainless welds, the ambient temperature and humidity, and a host of other factors. This is clearly an area of ongoing research, and at this stage it is very difficult to interpret what the NRC results mean for any operational spent fuel storage site.[4] The study reports fundamental results—for example, the rate of corrosion and cracking for a given temperature and exposure to corrosive salts—but was not designed to connect those results to real environmental exposures at real sites.[5] This helps to explain some confusion as some of these results have been used to argue that casks at SONGS will suffer corrosion cracking. When pressed on this point, the NRC itself has underscored that such results can't be used in isolation from knowledge about the actual environmental conditions at the plant as well as any mitigating measure that NRC would require if corrosion-prone conditions actually existed.[6] Such research tells us that we should be attentive to risks of stress corrosion cracking, as with an array of other risks, but doesn't tell us much about the specific level of risk.

Because it is unwise to pluck results out of studies that look at cracking under hypothetical conditions, here I will focus on the EPRI study because it is based on a full failure analysis through which the EPRI team looked at every mode that could lead to canister failure and then identify the relevant risks in each mode. They do that with an eye to every different configuration of welded lid stainless steel casks

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[3] NRC, "Assessment of Stress Corrosion Cracking Susceptibility for Austenitic Stainless Steels Exposed to Atmospheric Chloride and Non-Chloride Salts" NUREG/CR-7170 (2014)

[4] The same can be said for many other studies on corrosion in stainless steel, which tend to focus on other applications (notably piping) rather than the settings most germane to casks. For example, I am grateful to Donna Gilmore for pointing me to: R. Parrott et al 2010 "Chloride stress corrosion cracking in austenic stainless steel – recommendations for assessing risk, structural integrity and NDE based on practical cases and a review of literature," ES/MM/09/48 U.K. Health and Safety Laboratory.

[5] Looking across this research it is clear is that the industry and scientists are still learning about these casks. The first stainless cask was put into service in 1989 and only a few (3-5) cask systems have been through their first round of relicensing after the initial 20 year period.

[6] [cite here the email traffic between Mark Lombard, Donna, and Tom Palmisano from last week]

currently in service in the US. When we look at how the industry updates its procedures in light of information we should expect to see studies like the 2013 EPRI analysis adjusted periodically as new data comes in. That's crucial to a long-term plan that is adaptive to new information. What I see at EPRI and elsewhere is a big effort, delivering results, to do exactly that.[7]

The EPRI report is a complicated study, but let me highlight a few key observations and findings:

- While the license period is 20 years the typical useful service time for casks is probably more like 40-50 and could extend to 120 years;
- There are two trends that move in opposite directions. On the one hand, the risks of corrosion and damage to casks rises over time as environmental exposures accumulate and as materials age. On the other hand, the consequences of cask failure—in particular, cracking—decline over time because the half life of the materials that could most readily escape through a crack (gases) is relatively short. And the heat load on the cask also gradually declines over time.
- The dominant risks come from hazards OUTSIDE the casks, such as salt and biological corrosion. That insight suggests that the first line of monitoring should come from inspection of the outside of the casks on a regular basis (more on that below);
- Many of the cracking modes that have been the subject of concerns with stainless steel elsewhere in reactors—such as fatigue and the production of corrosive materials through "radiolysis"—are "non-credible" (see section EPRI report, section 4.2.6).
- The process of license renewals is producing substantial amounts of useful information about aging—for example, the license renewal for casks at Calvert Cliffs has provided much information about the impacts of fatigue. We should be happy that we in the SONGS communities are making cask purchase decisions and will be developing aging management programs later in the game. We will learn a lot from the others who precede us.
- There are three basic failure modes for cask walls that need attention (see section 4.3). Two of them are particularly unlikely. For the casks in our marine environment at SONGS the failure mode that seems to be of greatest concern is through-wall cracking that begins with corrosion on the surface from salt. That this problem exists does not mean that it can't be readily mitigated. Mitigating this problem requires periodic inspection of the canisters as well as monitoring of the composition and concentration of the deposits that accumulate on the surface of the canister. At this stage, it isn't clear to me what "periodic inspection" might really means in practice—nor

[7] Full disclosure: I am one of the independent directors on EPRI's Board of Directors. As with the other independent directors, one of my tasks is to hold EPRI accountable to its public mission as a non-profit research entity; these long-term aging programs are one of the areas where I have focused.

how much we can learn by looking at aging results at other sites versus the amount of real inspection that needs doing at SONGS itself. As fundamental knowledge rises the need for inspection may decline; as casks age the need for inspection may rise. More on that below.

- The best solutions to these problems come from monitoring and prevention. Particularly important will be the regular monitoring of temperatures and radiation around the concrete overpack as they can signal the conditions that would be pre-cursors to canister failure and also canister failure itself.
- A variety of expert studies reviewed and assessed in two EPRI studies shows that there is "no credible … pathway" to criticality of the fuel inside canisters. In the worst case analysis of an implausible scenario—substantial cracks in a cask followed by the intrusion of water sloshing around inside the cask—it is still impossible for the fuel to become critical (page 4-26). Results from an actual cask that has been allowed to leak slowly for 2 years show, as well, that intrusion of water and the formation of hydrogen gas can't reach explosive levels (section 4.4.3, page 4-25). I learn two things from this work. First, there is simply zero basis for the highly emotive statements that I have seen in the press and various other locations for the view that long-term storage of the fuel on site at SONGS has put "another Fukushima" or "another Chernobyl" in our backyard. We do the public a disservice with such emotive language since it creates images that are not in any way rooted in the technical assessment of the real risks. I would prefer the fuel gone, but the explosive consequences of highly concentrated critical fuel and accumulation of explosive hydrogen gas that were the root causes of Chernobyl and Fukushima has absolutely nothing in common with our situation here at SONGS. Second, we in the SONGS communities stand to learn a lot from the broader industry experience with aging casks provided that we actually use casks that are similar to the industry standard. Particularly important for us is the data coming from the other sites in the US that are further along and from the collective research and operational studies at EPRI, NEI, NRC and some of the national labs. I have been struck that this is one of many reasons for the "safety in numbers" logic when choosing a cask vendor.

As these casks age there may need to be a more active non-destructive evaluation (NDE) program for inspection that would evaluate casks on-site beyond just visual inspections. In addition to NDE there may need to be a more active modeling program to assess and predict corrosion and aging over time; in turn, those efforts could guide physical monitoring and NDE with greater precision. My sense is that the building blocks for all these efforts are in place, but it isn't clear how far along the industry and NRC are in developing such a strategic plan that would be adaptive to new information. We should ask the vendors and we should ask the experts, perhaps in the context of a workshop held in tandem with a CEP meeting when the CEP next looks closely at spent fuel. What is clear from the research is that this field encompasses a well-understood realm of chemistry and metallurgy and the relevant responses are within the realm of what industries that work with stainless steel already do.

Question 3: How would cracks be detected and addressed—especially since casks are stored in overpack and not readily monitored directly?

See answer to question 4.

Question 4: If a crack were detected in a cask, what is the timeline for removing fuel from the cask, replacing or repairing the cask and putting the fuel back into cask? Without an onsite spent fuel pool, how would this be done safely and efficiently?

I think questions 2 and 3 are two of the most important questions that the CEP has asked me to investigate. While this question 3 focuses narrowly on how we detect problems with the casks and question 4 focuses on the timeline for action after detection, both of these questions are central to a larger question of how the SONGS site will adopt what might be called "defense in depth." What are the layers of monitoring and defense that will help us detect and fix problems before they become serious, and how the site managers respond if such problems arise?

My read of the literature is that the industry has not articulated what "defense in depth" means in practice but that <u>there is a lot more going on in this realm than is immediately apparent.</u>

My impression is that defense in depth is unfolding on three fronts. First, the cask system is designed for layers of defense with the concrete overpack distinct from the cask that sits inside.[8] The collection of concrete overpacks are, in turn, surrounded by a berm at SONGS and layers of active defensive systems—a scheme described in more detail in a document from Edison attached as Appendix B.

Second, the NRC offers periodic oversight—in particular during the renewal of cask licenses after 20 years. I say "some" because it is not yet clear to me how aggressively NRC oversees this process, and with an array of license extensions in the near future—12 in the next six years alone—we will learn a lot more about how this process really works. I am comfortable with that approach because by the time that the existing casks at SONGS need relicensing (beginning about 2020) we will know a lot about what works and doesn't.[9] What is clear is that NRC has a set of

[8] And within the cask, depending on the design, there are multiple layers of defense as well. We should ask the cask vendors how each ofthese systems perform under different circumstances—for example, in an extreme seismic event how will the fuel racks inside the cask perform and will they protect the fuel and cladding against failure.

[9] The existing casks at SONGS are relatively young and are still in their first 20 year license period. According to NRC rules, the casks on site today will need to file for a renewal in 2021 and obtain it no later than 2023.

process-oriented regulations that guide license renewal.[10] Although the specific obligations are general—for example, licensees must that include, among many other things, "evaluate potential aging effects"—the renewal process includes extensive flowcharts and procedures aimed at the weakest links in the canister system. Overall, it is performance-oriented, as it should be, so there is flexibility for each site to develop its own plan. One striking aspect of the process is the idea of a "critical canister." Prior to license renewal the canister most likely to suffer damage—for example, the canister that has experienced the most extreme heat loads or exposure to corrosive salt—is subjected to particularly intense scrutiny. My read of the process is that that the canister must be pulled from the concrete overpack and inspected. If that canister is found wanting that perhaps others would be pulled as well and inspected until the NRC is satisfied that another 20 years extension is warranted. That means that the whole industry will be gaining information from many canister pulls associated with license renewals.

As more of these extensions are granted and the industry gains real experience of real hazards to the canister I assume that the "critical canister" concept will be adjusted—perhaps it is multiple canisters that should be pulled in some environments. In addition, the regulatory system is based on what NRC calls "Time Limited Aging Analysis Evaluation (TLAA) and an Aging Management Program (AMP) that can be tailored to individual canisters. Perhaps, at some sites, none need be pulled. It strikes me that this is the right kind of regulatory system—one that is adaptive to new information and is performance-oriented so that it can be adjusted to local circumstances and real world experience. The system is designed to avoid the need to open canisters and look inside—something that is quite difficult and probably should be avoided whenever possible since that process can add extra risk to workers. When I look across the totality of the NRC program it is also clear that the NRC is focused, as it should be, on places where there are still substantial uncertainties—it is risk averse where we know less and concentrated getting research done to narrow those uncertainties. For example, there are uncertainties about how fuel pellets swell over time and how they respond to water; there are uncertainties about when and how radioactive gases might be released from the pellets stored inside canisters.[11] This information and adjustment strategy strikes me as important not just because it can lead to better regulation but also because it is focused on ways to gain information that can be used across the industry. For example, there are periodic studies that do actually open canisters and look inside—many of those are cited in the NRC regulations (see p.20). Wherever possible, SONGS should be doing exactly what everyone else in the industry does—that maximizes the opportunity to learn from other plants and minimizes risk.

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[10] e.g., NUREG 1927 "Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance" (2011)
[11] see especially pages 2-3 of: *Annual Status Report: Activities Related to Extended Storage and Transportation*, USNRC, SECY-13-0057, dated May 31, 2013.

Third is a plan emerging in parallel from the Nuclear Energy Institute (NEI). This plan, known as "NEI 14-03," is expected to be released in final form for NRC review next month and approved by NRC before the end of the year.[12] What I know about it I glean from a 14 March presentation by the key person at NEI;[13] when the final version is released I will send around copies to the whole CEP. Some of the key points from NEI's work that are most germane for us in the SONGS communities include:

- To date, there have been three detailed inspections of actual canisters at actual coastal sites analogous to SONGS—none of them indicate any significant problems with chloride corrosion.
- The NEI approach will be based heavily on "toll gates"—that is, periodic checks on the performance of the casks that is an "extra layer of assessment" beyond what is done through regular checking and assessment (slide 13);
- The overall approach would make license renewals more streamlined (something that matters to the industry) and safety-focused (something that matters to the communities around these plants). I think we benefit from a licensing process that can focus like a laser on the parts of the system that might become vulnerable with aging—and then apply lessons from one site across the rest of the industry, including SONGS—rather than a system that is ad hoc and plodding.

At this stage I don't know if we can provide definitive answers to question #4. My impression is that the only defects that are likely to arise with long-term aging of the casks are minor defects on the surface of canisters and possibly with concrete overpacks. In the case of canister defects the repairs are rapid—a matter of days to clean and resurface an affected area or perhaps weeks to arrange a new weld. The NRC has stated that the industry has already proven that it has methods for identifying and repairing stainless steel cracks in difficult environments and has proven the ability to develop new methods as needed.[14] What's not clear to me is the strategy that would be followed in a worst case situation—where a cask started leaking for some highly unlikely reason. We should put that question to the vendors; I have already done this once, in a query to the vendor for the existing casks, and it is clear that there are several remedies that could be feasible.[15] My guess is that the most prompt response would involve putting the leaking cask into

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[12] Since this plan is not an official NRC activity I am not sure, as a legal matter, that NRC actually approves the plan. What is clear is that NRC and NEI both have a strong interest in each other agreeing on a common strategy.

[13] Cite here 14 March NEI aging plan. Possibly adjust main text if NEI supplies newer draft.

[14] Email replies from Mark Lombard (26 August 2014) in response to questions raised by Tom Palmisano and Ted Quinn and points made in a 25 August petition by Gene Stone and Donna Gilmore.

[15] Fact sheet from Areva (via Jim Madigan at Edison) in response to the questions posed on 23 August by David Victor; email detailed 25 August 2014.

a transport cask so that it is sealed from the environment. Then, the fuel might be moved in a "hot cell" or a pool—the industry has developed both technologies, although hot cells of adequate size do not currently exist "off the shelf" and a pool would not exist on site once the rest of SONGS is decommissioned. I don't see a need to have firm, final answers to these questions immediately but clearly these will be part of long-term "defense in depth." Having an on-site pool for such a remote contingency is probably quite impractical and would lead to an ISFSI that has a much larger footprint than the public favors---various comments from the public suggest to me that the public wants the footprint as small and secure as feasible. The transport cask option—or a similar arrangement with a spare overpack sleeve—might be the best one, but that could require pre-positioning such casks in the US for such contingencies, just as the industry shares other types of pre-positioned material. All of these are questions that are amendable to analysis using existing methods and probably require an industry-wide strategy.

For the concrete overpacks the timing of repairs is not critical assuming that defects are caught in time—which is what the NRC and NEI schemes would assure. According to Tom Palmisano at Edison, there is one documented case of a concrete overpack suffering minor external damage—something that was readily detected and repaired.[16] This type of activity doesn't strike me as rocket science and the industry is already adequately focused on the problem of concrete aging. In the worst case, an overpack could be replaced easily with the cask simply moved to the new overpack on the same pad.

Very far down the road at the end of the lifetime of the casks—which might be 50 to 100 years if not longer—then a temporary pool would need to be constructed on site to allow offloading of fuel and reloading of the new canisters. I don't see that contingency as material to our decisions today since the need for such a pool would be easy to anticipate with many years of advance notice.

After reviewing all these materials I see a "defense in depth" program that has physical, informational and strategic elements. The physical layers of defense start with the cask and the over-pack. The informational elements include monitoring the casks—especially temperature and radiation—as signs of failure, along with ongoing monitoring of corrosion and decay. The strategic elements, which are perhaps the most crucial for the long-term, are just taking shape—they include research on aging and industry-wide sharing of experiences. When I started this research project, frankly, not much of this was evident and that has created the false impression that less is going on in this domain than needed.

When I look across all the elements of "defense in depth" I draw three conclusions. First, the next time the CEP looks at spent fuel management we should ask Edison to articulate for us in plain English what "defense in depth" means for the SONGS site. The document at appendix B of this memo is an excellent start to helping us

[16] Cite Tom Palmisano statement at CEP meeting about Crystal River overpack

understand the procedures, but what exactly will be done, when and how? Answering this question really is a matter for the whole industry—vendors, utilities, NEI, EPRI, and the NRC along with the research community—in addition to Edison itself. As we grapple with these issues in the CEP we should be paying more attention to the broader industry-wide efforts.

Second, I have seen in the press much discussion of the need to wait to buy the "right" casks because this is an expensive purchase and we should "purchase them once." (I am paraphrasing comments from many officials.) I don't think this is the right way to think about the challenge. We have casks that are widely used in the industry that deploy the latest technology and are licensed by the NRC. Those are our options. Waiting doesn't change the laws of physics and chemistry that dictate how materials like stainless steel age. What's needed is the smartest cask decision today and then a smart aging and defense and depth scheme for the future.

Third, we should ask Edison to explore nominating SONGS to be one site where the industry does long-term aging research. Clearly that would be beneficial to the industry but it would also help assure us in the SONGS communities with the largest amount of real data on the real status of casks at this site. As a practical matter that might involve pulling additional canisters for surface inspections and more detailed monitoring of concrete overpacks. I don't know if the SONGS site would be a viable one for actual internal canister inspections since the site itself may not be an effective place to open canisters and moving canisters from SONGS to some research location may be impractical. But we should explore what might be done with research on the site, whether the costs could be reasonably recovered in the trust fund, and how this site might fit into the industry-wide aging management program.

Question 5: What is the internal pressure of a cask during storage, and how would leaks from helium over-pressure be detected? Are we safer with casks that have pressure monitors built in or with welded casks that do not contain those monitors?

The EPRI 2013 study cited above includes detailed information on cask designs. It appears to me that the internal pressures vary by design and are as high as 100 pounds per square inch (psi). Compared with many other uses for stainless steel in piping, where pressures rise to thousands of psi, these pressures strike me as quite modest. At SONGS the casks with the unit 1 fuel are pressured with Helium to 1.5 psi; the casks for units 2 & 3 fuel are 6.5 psi.[17]

The helium injected at pressure into the casks before they are sealed is extremely important as it helps keep the fuel cool and prevents contaminants, including water, from entering the cask. A helium leak would be detectable both through variations in temperature and also, in the extreme, release of radioactive materials. The EPRI

[17] Email from Jim Madigan to David Victor, 25 August 2014

2013 study makes it clear that one of the central issues in assessing the impacts of a cask failure is the rate at which helium escapes and is replaced by air or other contaminants. As air replaces the helium the temperature of the fuel rises and that raises the risk that the wrapping around the fuel (known as "cladding") that holds the fuel together will fail and a variety of other risks. These risks decline as the fuel ages and cools. These risks also vary with fuel type. The CEP has devoted considerable time and attention to HBF, and thus it is worth noting that the temperature at which HBF fuel faces cladding failures is dramatically higher than for non-HBF. This is a reminder that in some respects HBF may prove easier and safer to store than non-HBF fuel. It is also a reminder that the technology keeps improving. Newer fuels are essentially all HBF but they also have better cladding. Newer casks hold more fuel assemblies but they also have much better mechanisms for dissipating heat. (Holtec, for example, has now built a rack to hold the fuel inside the cask out of carbon nanotubes that probably has lower risks than older racks that are made from aluminum.)

How much equipment is needed on the cask itself to monitor pressure and safety? At first blush the right answer might be "as much as possible," and that is one reason that the Castor system might be attractive. My sense is that is not the correct answer for three reasons. First, we must remember that the Castor system has a removable, bolted lid—an application that makes sense in Europe but is probably unwise for extremely long-term storage that is envisioned here in the US. A lid with moveable bolts and O-rings needs more monitoring.

Second, with helium under pressure inside the casks and good monitoring of other parameters outside the cask we can gain essentially the same information—including early warning of failures.

Third, safety systems such as through-wall monitors bring risks of their own. In my professional life I do a lot of research on how real organizations manage complex systems. In that work, once of the books that has influenced me the most is Charles Perrow's *Normal Accidents*. Written by a sociologist, that book looks at why some complex systems are easier to manage safely than others and one of the central conclusions from his study is that sometimes active safety systems actually makes things less safe. When you drill a hole through the wall of a reactor vessel or a cask and install a sensor you get information about what's going on inside, but you also get a new failure point. Thus systems that are purely passive and welded shut are probably a lot safer than those that are bristling with through-wall sensors and can be opened and closed. I think that insight applies especially for systems that need to be safe for the very long haul and in environments where we don't know exactly how the sensors and lids would age.

Question 6: What is the track record with corrosion in concrete overpacks? How can corrosion be detected and addressed?

The concrete overpacks play a crucial role for "defense in depth" in the US system for storing spent fuel on site. They are the first line of defense. They provide physical protection for the canisters as well as radiation shielding and they help manage the heat flow away from the canisters as the fuel cools slowly over time. The fact that the overpack is physically distinct from the canister is probably a big advantage in the U.S. system for long term storage when compared, say, with the thick-walled European casks that are "all in one" systems with no overpack. If there is a problem with the concrete overpack then the canister can be moved to a new one.

As noted above, to my knowledge there is just one incident of a concrete overpack suffering material damage from aging. Since the most vulnerable to corrosion elements of the concrete overpack are directly visible I don't expect that any significant issues will arise with this, and if they do it is trivial task to remove a canister and put it in a new overpack. There may be some licensing issues with that if, for example, a new overpack would need to be built and that expanded the footprint of the "ISFSI" pad on which the casks are stored, but addressing those issues would be straightforward.

The CEP has already looked into the questions related to seismic and tsunami risks and found that the design of the current (Areva TN) system to be vastly beyond any plausible risk in that domain.[18] The underground Holtec system, which is the other leading contender for the SONGS contract, has similar performance.

Question 7: With fuel assemblies stored inside casks and not observable directly, how will we know if fuel assemblies—including HBF—degrade or damage with age? How will missing knowledge on this question be filled in and practices adjusted?

I think this question has been answered in the answers to questions 3 & 4. It is clear that the single most important indicator of fuel assembly integrity is temperature.

[18] This issue arose at the first CEP meeting in March 2014. On the CEP's behalf, CEP member Bill Parker researched it and reported back to the Panel on 22 May by email and also with a statement at our CEP meeting that same day.

Subject: for review pdf THIRD ITEM: "William Parker to David Victor, 2 September, 6:33pm"

Date: Wednesday, October 8, 2014 at 7:19:34 AM Pacific Daylight Time

From: David G. Victor

To: Steven Carlson

On 9/2/14, 6:33 PM, "William Parker" <[redacted] wrote:

> David,
>
> I continue to review your comprehensive review of issues generated by the choice of casks for the storage of the spend fuel at SONGS. There is much to digest in your review.
>
> But first a couple of minor comments.
>
> 1) The partial footnote #2 on page 4 should be deleted since the full footnote appears on page 6.
>
> 2) I suggest footnote #18 be limited to seismic risks, I did not address the risks of tsunami.
>
> Bill

Subject: for review pdf FOURTH ITEM: "Ted Quinn to David Victor, 1 Sept 12:18pm"
Date: Wednesday, October 8, 2014 at 7:19:33 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

From: Ted Quinn <[redacted]
Date: Monday, September 1, 2014 at 12:18 PM
To: "David G. Victor" <[redacted]
Cc: '[redacted] <[redacted]
Subject: review draft

Hi David

Hope you are doing well.

I reread the three attachments, based on the input from Mark Lombard at NRC last week and my knowledge of the Blue Ribbon panel and Yucca Mountain project. I don't have a lot of background on the specific cask vendors. I thought you covered that very well.

I think this is a very good white paper. I don't know to what extent the specific members of the public will want to vet this thru each paragraph but I don't want to underestimate them.

I think the most important statement on the Castor is in the third para on page 4, "Edison's assessment is that would introduce 5 – 10 years in delay just for licensing;"

Page 9 ---- last para. I believe DOE has a transfer cask program for transport. The DOE casks (funded under a line item of the Yucca Mountain (YM) Project) was to develop and license a DOE cask that would take transfer from any and all plant site casks ---- and DOE would do the transfer and then do the transport. I believe that element in the YM project was the least far along in the process when the program was put on hold by Senator Reid and the President.

Also on Page 8 and 9 the response to Question 4 should include what Mark Lombard stated – that industry has developed and performed repairs on stainless steel dry casks --- this is very important.

Page 10 EPRI on internal pressure variations. I believe one or more cask vendors would need to be checked on to provide data on this.

Page 12 – second para --- I believe there has been a case on concrete degradation and it has been repaired.

The two appendices look good --- -did Edison have any comments for you?

Sorry for the delay in getting these to you.

Best regards,

Ted

Subject: for review draft FIFTH ITEM: "Mark Lombard to Donna Gilmore, 28 August AT 5:10PM"
Date: Wednesday, October 8, 2014 at 7:17:50 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

From: <Lombard>, Mark <[redacted]
Date: Thursday, August 28, 2014 at 5:10 PM
To: Donna Gilmore <[redacted] Tom Palmisano <[redacted] Chris Thompson <[redacted] "David G. Victor" <[redacted]
Cc: '[redacted] <[redacted] Sepideh Khosrowjah for Florio <[redacted] "Dunn, Darrell" <[redacted] Kevin Barker - CEC <[redacted] Gene Stone <[redacted] CHAIRMAN Resource <[redacted] Mary Woolen <[redacted]
Subject: RE: Castor casks

Donna,

Respectfully, Darrell's presentation was based on the assumption that an environment is known to induce SCC in stainless steel dry storage system canisters. We don't know that such a specific environment exists at SONGS for their spent fuel storage systems. If we did have a known safety issue relative to the fuel in storage at any plant, we would move to put requirements in place to mitigate it.

Mark

From: Donna Gilmore [mailto[redacted]
Sent: Thursday, August 28, 2014 7:57 PM
To: Lombard, Mark; [redacted] David G. Victor
Cc: [redacted] Sepideh Khosrowjah for Florio; Dunn, Darrell; Kevin Barker - CEC; Gene Stone; CHAIRMAN Resource; Mary Woolen
Subject: RE: Castor casks

Mark,
After Darrell's presentations on stress corrosion cracking, how can you "believe" these stainless steel canisters are safe and how long do you believe they are safe for? Darrell Dunn's excellent presentations show they are susceptible to stress corrosion cracking. And the fact that none of the canisters can even be fully inspected, even on the outside, and you confirmed the EPRI statement that it is unknown what the current conditions are with all existing U.S. installed canisters, on what basis are you making that statement?

You also agreed with Al Csontos that no one can predict when the crack will start. And you know San Onofre had a pipe failure due to stress corrosion cracking, we have the marine environment to trigger this. And Darrell made it clear that once a crack has started it will go through wall faster due to the allowed heat load of the canisters.

Donna Gilmore
[redacted]

-------- Original message --------
From: "Lombard, Mark"
Date:08/28/2014 4:16 PM (GMT-08:00)
To: Donna Gilmore , Gene Stone , [redacted]
"David G. Victor"
Cc: [redacted] Sepideh Khosrowjah for Florio
Subject: RE: Castor casks

Donna,

Thank you for forwarding the information Tom Palmisano found. It is true that we have not done any work on ductile iron dry cask storage systems as none have been submitted for review since the Surry specific license was renewed in 2005. If someone does submit an application, we would conduct an appropriate safety and security review. I would like to reiterate that we have no information that suggests that stainless steel canisters are subject to potential material degradation issues at any U.S. spent fuel storage site. Hence, we believe that all stainless steel canistered systems we have approved to date are safe. We continue to conduct research on this topic and monitor information from sources around the world to make sure our information and regulatory position is up to date.

Thank you,

Mark

-----Original Message-----
From: Donna Gilmore [mailto [redacted]
Sent: Thursday, August 28, 2014 5:21 PM
To: Gene Stone; [redacted] David G. Victor
Cc: [redacted] Lombard, Mark; Sepideh Khosrowjah for Florio
Subject: Re: Castor casks

Yes, I've read that report. I spoke to NRC Division Director Mark Lombard about this and he said since no one has requested a license for the CASTOR in years the NRC has not done research on this. Mark said the NRC will only evaluate the ductile cast iron technology if a vendor requests a license, which of course doesn't happen unless they have a customer -- like you.

He also mentioned that the NRC has never turned down a licensing request and that the process would take about 18 to 30 months for either an new or amended license, depending on how complete the vendor application is.

This Sandia Labs report and some BAM reports regarding ductile cast iron casks are included as links below. Their conclusions both point to data showing embrittlement is not an issue. I've include links below and key paragraphs.

The NRC is only approving the NUHOMS and Holtec for the initial 20 years -- that's as much as they'll guarantee at this point. They have not addressed the aging management issues of these canisters, so it's up to you to make sure this is taken into consideration, so we make the best decision for California. From the public meeting that was held last night in Dana Point, it was clear the public is very concerned about this issue and doesn't want a decision to be rushed until the various dry cask options are considered. I urge you to allow the ductile cast iron vendor to make a technical presentation to

Edison management and the CEP.

Here are a few key paragraphs in the Sandia report. I think once you look at the report you should be more confident with the ductile cast iron. I've cc'd Mark Lombard, since I'm quoting him. I've also cc'd CEC and CPUC since this is a relevant and time sensitive issue for both of those agencies.

Sandia Abstract
The use of a fracture mechanics based design for the radioactive material transport (RAM) packagings has been the subject of extensive research for more than a decade. Sandia National Laboratories (SNL) has played an important role in the research and development of the application of this technology. Ductile iron has been internationally accepted as an exemplary material for the demonstration of a fracture mechanics based method of RAM packaging design and therefore is the subject of a large portion of the research discussed in this report. SNL's extensive research and development program, funded primarily by the U. S. Department of Energy's Ofice of Transportation, Energy Management & Analytical Services (EM-76) and in an auxiliary capacity, the ofice of Civilian Radioactive Waste Management, is summarized in this document along with a summary of the research conducted at other institutions throughout the world. In addition to the research and development work, code and standards development and regulatory positions are also discussed.

Sandia Page viii
The proposed use of ferritic materials for packaging containment has not been without controversy and critics. Ferritic materials, unlike austenitics, such as stainless steel, may exhibit a failure mode transition with &%. ieasing temperatures andor increasing loading rates from a ductile, high-energy failure mode to a brittle, low-energy fracture mode at below-yield stress levels. Regulators have thus been justifiably cautious regarding the use of ferritics for RAM package applications and have indicated that certification of such packages would require extensive confirmatory research and supporting data (although ferritic RAM packages for storage applications have been certified by the NRC). However, the general conclusion of the research reported herein is that appropriate engineering design methodologies exist which, when rigorously applied to RAM transport packaging conditions and environments, warrant the use of suitable ferritic materials for packaging containment. This report summarizes the Sandia work in support of that conclusion. The report also cites and references parallel research and conclusions of other institutions.

Sandia Page 53
The numerous studies cited show that DI [ductile iron] is a well characterized material that does have sufficient fracture toughness to produce a containment boundary for RAM packagings that will be safe from brittle fracture. All the drop tests discussed in this report were conducted using DI packagings and the studies indicate that even with drop tests exceeding the severity of those specified in 1 OCFR7 1 the DI packagings perform in an exemplary manner.

Fracture Mechanics Based Design for Radioactive Material Transport Packagings Historical Review, Sandia SAND98-0764 UC-804, April 1998
http://www.osti.gov/scitech/servlets/purl/654001

BAM Test Results for CASTOR containers
http://www.tes.bam.de/en/umschliessungen/behaelter_radioaktive_stoffe/behaelterpruefungen/index.htm#castor

GNS CASTOR Presentation, June 09-11, 2010, Varna, Bulgaria http://www.bulatom-bg.org/files/conferences/dokladi2010/Section%203/Report_Thomas.pdf

Donna Gilmore
[redacted]

----[redacted] wrote:
Donna & Gene,

As part of our continuing research into dry fuel storage options, I came across a 2013 report developed by consultants to the DOE which summarizes information about various dry fuel storage systems. I found the report interesting in the description of a variety of past and present systems. The CASTOR system is discussed starting on page 177. There were two CASTOR casks licensed for storage only in the US, the V21 (25 casks loaded at the Surry Plant) and the X33 (1 cask loaded at the Surry Plant). They are currently under site specific licenses, which means they are only licensed for that plant.

I thought you would find the report useful, if you haven't already seen it.

On page 179 they mention the NRC concern with the brittle nature of the nodular cask iron as a reason it was not licensed for transportation in this country. I've copied that section below for your reference.

Tom

Introduction
Contact:
GNS Gesellschaft für Nuklear-Service mbH
[redacted]
The GNS CASTOR® V/21 cask is a nodular cast iron shielded cask which has the capacity to store 21 PWR used nuclear fuel assemblies. It was designed for both storage and transport of used nuclear fuel, but has only been approved for storage in the U.S. The NRC had previously refused to approve nodular cask iron casks for transport in the U.S. because of brittle fracture concerns. However, the cask is in full compliance with IAEA standards for transportation.
Description
The cask body is formed by casting the sides and bottom in one piece of ductile cast iron in nodular graphite form. The nodular cast iron provides the gamma shielding, and the polyethylene rods inserted into two concentric rows of axial holes drilled into the side walls of the cask provide the neutron shielding. Heat removal is facilitated by circumferential fins on the cask surface. The cask inner cavity is plated with nickel. The cask inner cavity contains a borated stainless steel basket. The CASTOR® V/21 cask is closed with a multiple lid system consisting of both a primary and secondary lid machined from stainless steel, and multiple elastomer and metal seals for each lid.
Like all metal storage casks, the CASTOR® V/21 is loaded and unloaded in the used fuel pool of a reactor site.

http://curie.ornl.gov/system/files/documents/384/ENERGX_FINAL%20Report_9-20-13%20REV%202a3_0.pdf

Subject: for review pdf: "Donna Gilmore to David Victor, 22 Sept 7:35pm including attachment"
Date: Wednesday, October 8, 2014 at 7:19:31 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

On 9/22/14, 7:35 PM, "Donna Gilmore" <[redacted] wrote:

> David,
>
> Attached is more information on the stress corrosion cracking issues (more references and detailed explanations). I may also have additional comments for you, since apparently, it's not clear how some of my paper relates to your document.
>
> My paper is a separate document intended to be more than just answers to your seven questions. However, it addresses the seven questions in your paper. Since we had already spoken about your paper, I was confident I had the correct information to cover those issues.
>
> Hopefully, the attached document provides sufficient detail. I am also interested in knowing the references you are using to support your conclusion that the industry will have the ability to adequately inspect and repair these canisters and in a time frame that may be needed. The references I've provided in the attached point to how difficult it will be to adequately check for cracks.
>
> Also, there is no seismic rating for cracked canisters. That is another critical issue I recommend you include in your report.
>
> It's unclear what your definition of "defense in depth" is? Is that something you're asking them to define? Would you consider waiting until you have the answers to these critical issues before recommending a dry cask solution?
>
> Thanks,
>
> Donna
>
> ---- "David G. Victor" <[redacted] wrote:
>
> > Dear Donna
> > thanks for your notes and the updates on your version of the issues paper.
> > I am a bit puzzled as to what I do next, however. The plan, as I understood it, was that we would agree on the core questions, I would draft, and then folks would then comment on that draft‹identifying errors
> > in fact and analysis, disagreements over analysis and tone, etc. In the end, probably we wouldn¹t agree on everything‹and from your paper clearly

we don¹t‹but at least we would have a solid, core agreed base of facts
as
possible. That¹s what I thought we were doing, and I thought we were
doing that with the respect of working inside this small agreement and
getting to the point where we understood agreements and differences.
And
then, once we had done that, we would publish our results along with any
disagreements. Maybe I am too much of a wonk, but all I am trying to do
is get us focused on what¹s known and not known; and the only way that
can
be done practically is to write it down and subject it to intensively
peer
review. That¹s what we were doing, I thought. I am not trying to keep
anything away from the public‹quite the opposite. But what I am trying
to
do is help people understand, in plain English, a bunch of complex
things
and help them understand where people agree and where they disagree and
why.
So that is what I thought we were doing, but given your posting maybe we
are doing something different here?
So how do you want me to handle your 15 page single spaced document that
you have just circulated? Are there specific places where you think the
facts are incorrect, or are you satisfied with the reviews that
others‹Dave L and Frank vH‹have given?
Just as an illustration, your memo points to ³cracks within 30 years²
and
cites to a paper by Westinghouse (which concerns cracks in operational
piping‹my memo explains why that is almost certainly not relevant) and a
presentation by Darrel Dunn that summarizes some idealized crack
research.
(Your reference numbers 26 and 27). Does your 30 year number come from
slides 9 and 10 of that presentation? If so, I have spent a lot of
time
reading the original literature in this area and found that the cracking
dates on those slides are not relevant for spent fuel storage. These
dates are a combination of so-called U-bend studies on SCC under ideal
conditions (low temperature, high humidity, high salt) that can¹t be
applied directly to the analysis for spent fuel casks‹especially because
temperatures on the casks are much higher. The NRC, itself, has
explicitly NOT used the 30 year number as a hazard point for stainless
casks. Instead, what they are doing with these presentations is
triangulating around the issue by showing a variety of worst case
studies
while explicitly NOT connecting the circumstances that lead to such
outcomes to real world conditions on the surface of casks in the
presence
of chloride. Moreover, chloride deposition itself (e.g., as you cite
has
been observed at Diablo Canyon) is not the triggering factor‹it is a
combination of factors, of which low temperature is particularly
critical.
I am not a chemist, but I have now read that literature and talked with
many in the field and that conclusion comes squarely out of those

discussions. In my memo I offered an assessment of that literature and
also, therefore, pointed us all to the EPRI hazard analysis which takes
into account the multiplicity of factors that lead to SCC along with
real
world conditions when assessing the hazard. (And per the comments from
Frank and Dave L, I will put more emphasis on the areas where the EPRI
study did not yet do analysis‹such as materials defects at
manufacturing.)
That study points to radically different conclusions about much lower
risks of SCC than suggested in your paper and also tells us that
³defense
in depth² requires regulators and operators look at the whole range of
conditions actually present around the casks and also do regular
inspections. I have learned that NRC is evolving that direction (and I
will add more detail on that in the revision of my memo). I have also
come to the conclusion, exactly as you have that it is essential that
there be a long-term game plan for aging management. And my evaluation
of
that plan, similar to yours, is that part it must include proving up the
technologies that will be needed for surface repairs, onsite removal and
replacement of casks, etc. That hasn¹t been done but it could be; we
should recommend, as I do and as you do, that the industry develop those
technologies and best practices.
The above is just an illustration‹a place where your 15 page paper seems
to come to different conclusions than the memo I drafted on behalf of
our
group. My sense is that there are many others. For example, I sense
that
your comment on page 6 concerning transport canisters. Is that an area
where you believe that my memo is in error‹in suggesting transport casks
along with a variety of interim strategies in case a cask were found to
be
cracking?
So is it your view that my read of that literature is incorrect? Or is
your view that with the adjustments noted above (per Dave and Frank)
that
my assessment of the literature IS correct? And if there are errors,
specifically where are they?
Sorry to press you on this, but that is what we agreed we would do. And
we
agreed we would do it with drafts that are NOT part of the public domain
so that we can get the facts right as much as possible and then identify
areas where we disagree. Instead, I have learned that yesterday you
posted your document on your website as a new report. Everyone should
do
what they want to do, but if our goal here is to really zero in with the
benefit of many different perspectives and expertise on the facts then
making documents public domain along the way before we have all had a
chance to assess, debate and discuss is exactly the opposite of what I
thought we were trying to do.
So if there are specific areas where you think the memo is wrong in
fact,
analysis, omission and such please do let me know. It is clear to me
that

you and I will disagree on the overall recommendation (concerning cask
choice strategy) and that¹s fine. Disagreement is important for debate.
But what I need to do right now is something different‹which is to find
exactly where in the analysis the disagreements arise so that we can all
help the public that wants to be informed become as informed as
possible.
And so we can help them understand what¹s known and what¹s not known and
where we might do better, collectively, in managing these fuels as they
age.
all best
David
On 9/20/14, 3:21 PM, "Donna Gilmore" <[redacted] wrote:
>Here is a link to an updated version of the San Onofre Dry Cask Storage
>Issues paper. I've revised the first page for clarity and reformatted
>the references at the end. Please use this version.

> https://sanonofresafety.files.wordpress.com/2011/11/drycaskstorageissues
> 20

>14-09-20a.pdf
>
>Thanks,
>Donna
>
>---- Donna Gilmore <[redacted] wrote:
>> David,
>>
>> After we discussed your paper, I promised to send you references for
>>where I thought your facts differed from mine. Attached is a fully
>>referenced document I prepared on the San Onofre dry storage issues.
>>Thanks for sharing Lochbaum's and Frank's comments. I agree with most
>>of their comments. I don't agree with Lochbaum's conclusion that the
>>currently licensed casks are our best choice for San Onofre. I'm
hoping
>>once David read's my paper, he will agree.
>>
>> I listened to yesterday's NRC Commissioner's webcast on waste storage
>>and transportation. Dr. Macfarlane asked great questions that are
>>applicable to what we are facing at San Onofre. Mark Lombard, NRC
>>Director of SFST Division, provided answers to her questions. I've
>>included some of those in this paper.
>>
>> I agree with Lochbaum it's important to remove the fuel from the
pools.
>>However, living a few miles from this plant and learning about the
>>potential short-term problems with these canisters, I believe there is
>>time to select safer canisters. I was shocked to learn from the NRC
that
>>the steel/concrete canisters cannot even be adequately inspected on
the
>>outside and none have been. I've read some of Gordon's papers where
he
>>said the Castor type casks are better, but if the steel/concrete ones
>>can be shown to last 100 years, that they would be good enough. He
also
>>recommended the Castor casks for Diablo Canyon before they had

selected
>>the Holtec.
>>
>> When Tom Palmisano said he though the process would take 3 to 5 years
>>to receive approval from the NRC, I called Mark Lombard. He
personally
>>told me the 18 to 30 month time frame was more than adequate. With 30
>>month being the worse case. This assumes of course that the vendor
can
>>respond to all NRC concerns. And he said they've never denied a
license
>>application. Local citizens are willing to wait. The fuel needs to
>>cool in the pools anyway, so we're not talking about a significant
delay
>>here.
>>
>> Thanks,
>>
>> Donna Gilmore
[redacted]
>>[redacted]
>>
>> ---- "David G. Victor" <[redacted] wrote:
>> > Dear Colleagues
>> >
>> > Over the next 10 days or so I will revise my memo. If you have any
>>further comments on the piece please do let me know.
>> >
>> > Meanwhile, below please find comments from Frank von Hippel
>>(Princeton) and Dave Lochbaum (UCS). Both have provided us with
>>exceptionally helpful reviews (most of Dave¹s comments are embedded in
>>the pdf file, which I attach). They also point to new citations and
>>information about aging research.
>> >
>> > I am enormously grateful to both and have thanked them on our
behalf.
>> >
>> > It is clear that it will be very helpful to have a vendor event
with
>>Holtec and Areva and I very much look forward to that.
>> >
>> > all best
>> >
>> > David
>> >
>> >

To: David Victor
Fr: Donna Gilmore
Re: Stress corrosion cracking in stainless steel spent fuel storage canisters

Here is more in depth information on the stress corrosion cracking issues. The NRC does not plan to prepare documentation addressing stress corrosion cracking (SCC) guidelines until next year when they will publish a draft NUREG-1927. All we have are their slide presentations on some of these issues. However, I've found other documents that are relevant. In addition, I attended a number of NRC presentations on aging issues of the steel/concrete cask systems (July 14, 15 and August 5, 2014) and was able to ask questions and have numerous follow-up conversations with Darrell Dunn, Al Csontos and Mark Lombard.

If you think it would be helpful, I can ask Mark if he would allow Darrell to make a presentation to us on SCC. Here is the link to Darrell's August 5, 2014 SCC presentation on *Chloride-Induced Stress Corrosion Cracking Tests and Example Aging Management Program*, *https://sanonofresafety.files.wordpress.com/2013/06/8-5-14-scc-rirp-nrc-presentation.pdf*

In the August 5th meeting, the NRC questioned a number of EPRI's calculations, assumptions, and conclusions in their presentation. This was left unresolved at the end of the meeting. Here's a link to the meeting agenda. *http://pbadupws.nrc.gov/docs/ML1420/ML14206A735.pdf*

In Darrell Dunn's SCC presentation he said two of the three elements for stress corrosion cracking are known to be present in the canisters and EPRI concurs (see slides on page 2 of my paper). The third element is a corrosive environment. This requires chlorine salts in the air, a certain range of surface temperatures and humidity.

Since no canisters have or can adequately be inspected for cracks, they do not have actual data on existing canisters. In lieu of this, they did a number of experiments, evaluated stress corrosion cracking in similar material components at nuclear plants in marine environments, and initiated very limited inspections of exteriors of a few canisters in coastal environments, looking for tiny crevices (another initiator) and salts. They also took temperatures of some of the areas of the outside of the canisters. They were very limited in what they could reach. I discuss each of these areas below.

EXPERIMENTS

The experiments show the third element is present at a certain range of temperatures, humidity and salt levels. I agree with you this is experimental so is not confirmatory. However, the value of the data is to show that it can occur under certain conditions that may exist on canisters in marine environments. Therefore, at this point we cannot assume it will not happen on canisters. We should treat this as an indicator that it could, just as the NRC and others are doing.

> **Slide 8 Conclusions from NRC Sponsored SCC testing** (8/5/2014 presentation)
> • CISCC observed at temperatures up to 60^{o}C with absolute humidity values less than or equal to 30 g/m3
> • No observed CISCC at 25^{o}C is believed to be a result of salt solution draining from the specimens
> • CISCC observed with salt concentration of 0.1 g/m2 lower than previous reports
> • CISCC at 80^{o}C required absolute humidity values above 30 g/m3

SIMILAR COMPONENTS
The data regarding SCC on similar components should not be ignored. These real-life experiences provide additional data that adds to the picture and increases the probability this may occur on dry canisters. It also provides data on how long it takes crack to go through-wall. The fact that hotter canisters will have a faster rate of cracking is even more relevant.

The review of SCC of similar components shows cracks initiated and went through-wall faster than expected -- **11** to 33 years (Slide 2 from7/14/2014 presentation*). In Darrell's Slide 10 from 8/5/2014 presentation, he changed the number "11" to "16". I'm waiting for a response from him on why he changed the number. Al Csontos, said he didn't know and I should contact Darrell.*

Slide 9 (next page) of Darrell's 8/5/2014 presentation provides power plant operating experience with SCC of stainless steels. The worst case is the Koeberg plant in South African. This plant had a crack 15.5 mm deep (0.61") within 17 years. As shown on the slide, the NRC estimated crack growth rate for this is 0.91 mm/yr (0.03583"). If we had the same crack rate in a .50" canister, it would crack through-wall in 14 years after initiation. Crack initiation and crack growth rate have different variables, so must be evaluated separately.

> **Crack initiation:** Crack initiation in a spent fuel canister would likely take longer than in these cooler component, since initiation can only occur in a temperature range where salts can deposit (under 80°C to 85°C). At the August 8th meeting, I asked Darrell and Al how soon they thought a crack could initiate in a dry canister. They said 30 years. When I followed up later with Al, I asked if he could point me to the data to support that 30 year number, because I couldn't find any. If anything, it appears it could be sooner than 30 years given the data in Darrell's presentation and my discussions with him after the July 14th meeting. Al's response was "*if anyone could predict when a stress corrosion crack would initiate, they would probably win a Nobel Prize*". I followed up with Mark Lombard (Director of SFST Division). He concurred with Al's statement.
>
> **Crack growth rate:** Since the temperature of the Koeberg refueling water storage tank ranged from 7°C to 40°C (45°F to 104°F) and a spent fuel canister would likely be hotter, the through-wall crack rate would be faster for the canister. Darrell and Al said it would take 16 years, but provided no data for this number. This is another question I have for Darrell. Darrell said the hotter the canister, the faster the crack would go through-wall. Newer canisters are loading with much higher heat loads now, due to higher burnup spent fuel, more fuel assemblies per canister, and the industry's desire to unload the fuel faster out of the pools. All these factors work against our safety. We should recommend lower heat loads, less assemblies per canister, and longer cooling time for high burnup fuel.

The NRC said they plan to allow cracks under 75%, so that would mean 12 years after a crack initiates that the canister must be removed from service. Again, we need the data to support that number. ASME has no standards for spent fuel canister cracks, so the NRC is using ASME standards for other stainless steel components as a substitute. However, there is no seismic data for cracked canisters. We should ask the canister vendors for their seismic data on cracked canisters before allowing it to be acceptable to have any cracked canisters.

Of course, they can't inspect the canisters to see if there are cracks. And they have no way to repair them. Al and Mark both said they are optimistic there will eventual be a solution, but they had no data to support that optimism. Every method Al said the industry uses to repair other components will not work with spent fuel canisters -- even those in development. Do you have data to support their optimism? If not, what facts and references are you using to recommend canisters that cannot currently be inspected, repaired or replaced?

The current specifications for transport cask overpacks do not allow cracked canisters. I included references to this in my paper. For this and other reasons outlined in my paper, this is not an acceptable mitigation solution.

Slide 9 has an example of a San Onofre ¼" pipe that cracked all the way through within 30 years. This is an indicator San Onofre has the marine environment for stress corrosion cracks.

Power Plant Operating Experience with SCC of Stainless Steels

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

Plant	Distance to water, m	Body of water	Material/ Component	Thickness, or crack depth, mm	Time in Service, years	Est. Crack growth rate, m/s	Est. Crack growth rate, mm/yr
Koeberg	100	South Atlantic	304L/RWST	5.0 to 15.5	17	9.3×10^{-12} to 2.9×10^{-11}	0.29 to 0.91
Ohi	200	Wakasa Bay, Sea of Japan	304L/RWST	1.5 to 7.5	30	5.5×10^{-12} to 7.9×10^{-12}	0.17 to 0.25
St Lucie	800	Atlantic	304/RWST pipe	6.2	16	1.2×10^{-11}	0.39
Turkey Point	400	Biscayne Bay, Atlantic	304/pipe	3.7	33	3.6×10^{-12}	0.11
San Onofre	150	Pacific Ocean	304/pipe	3.4 to 6.2	25	4.3×10^{-12} to 7.8×10^{-12}	0.14 to 0.25

- CISCC growth rates of 0.11 to 0.91 mm/yr for components in service
  - Median rate of 9.6 x 10^{-12} m/s (0.30 mm/yr) reported by Kosaki (2008)
- Activation energy for CISCC propagation needs to be considered
  - 5.6 to 9.4 kcal/mol (23 to 39 kJ/mol) reported by Hayashibara et al. (2008)

August 5, 2014 NRC Public meeting with NEI on CISCC RIRP 9

INSPECTIONS

To determine if actual dry canisters can meet the environmental conditions, minimal inspections were done of a few canisters. In the SCC NRC meetings they stated they did not have test results for Diablo Canyon yet. However, I subsequently found an August 6, 2014 presentation with a photo showing the salts found on a Diablo Canyon canister. *FY14 DOE R&D in Support of the High Burnup Dry Storage Cask R&D Project*, William Boyle, NWTRB Meeting, August 6, 2014 (slide 12) *http://www.nwtrb.gov/meetings/2014/aug/boyle.pdf*

The details on the canisters tested for Diablo and others are in this 1/28/2014 EPRI presentation. The surprise here is the canister surface temperature ranges were low enough (well below 85°C) to provide the temperature range needed for crack initiation -- **after less than 3.5 years in service**. *Update on In-Service Inspections of Stainless Steel Dry Storage Canisters*, EPRI, Keith Waldrop, Senior Project Manager, Presented by John Kessler, Program Manager, NEI-NRC Meeting on Spent Fuel Dry Storage Cask Material Degradation January 28, 2014 Diablo *http://pbadupws.nrc.gov/docs/ML1405/ML14052A430.pdf*

Slide 18 Diablo Canyon Canister Inspection

Inspect 2 canisters

–Range from 2 to 3.5 years in service

–15 to 20 kW at time of loading

–Directly facing water (unobstructed) until recently

Follow similar process as Hope Creek

Slide 19 Diablo Canyon Canister Inspection

•Completed 1/16/14

•Preliminary results –Thermal

•Measured temperatures ranged from 49°C (120°F) to 118°C (245°F)

•Calculated temperatures ranged from 60°C (140°F) to 105°C (221°F)

•Lid - measured temperatures ranged from 87°C (188°F) to 97°C (207°F)

–Samples

•No results yet

•Comprehensive EPRI report will be published September 2014

AGING MANAGEMENT

The NRC plans to update NUREG-1927 mainly due to the need to have a management plan in place for stress corrosion cracking, concrete degradation and possibly other aging issues. They plan to have this available for public comment in early 2015 – not in time to meet Edison's preferred timeline.

Slide 11 Potential for SCC of Welded Stainless Steel DSCs

• Cl salts could be deposited by air flow from passive cooling

• Relative humidity increase as canister cools may lead to deliquescence of deposited Cl salts and CISCC

• Reactor operating experience indicates CISCC is a potential aging effect that requires management

Slide 16 suggests some methods to help detect cracks. However, they stated in the meeting there are no current methods to adequately inspect even the outside of the canisters. The NRC is giving the industry five years to develop inspection methods. However, the standards for what they need to inspect are low. And after reading technical reports about the challenges involved in inspecting for cracks – even in pipes, it became clear this may be impossible to do adequately.

Al Csontos was optimistic they would figure it out. However, he had no idea how they would do that. These are some of the suggestions that will require development.

Slide 16 Detection of Aging Effects (1/2)

- Qualified and demonstrated technique to detect evidence of localized corrosion and SCC:
  - – Remote visual inspection, e.g. EVT-1, VT-1, VT-3, or Eddy Current Testing (ET) may be appropriate
- Pending detection findings, sizing SCC would require volumetric methods

Rational for inspections within 25 years of initial loading was stated as follows: They would prefer 20 years after initial loading. However, they are allowing 5 years for the industry to develop the inspection technology. Once the technology is developed, all future inspects will be after the initial 20 years. Then every 5 years after that. And as it states, they only need to inspect one canister at each site. Is that acceptable to you? It isn't to me.

Slide 17 Detection of Aging Effects (2/2)

- Sample size
  - – Minimum of one canister at each site
  - – Canisters with the greatest susceptibility
- Data Collection
  - – Documentation of the examination of the canister
  - – Location and appearance of deposits
- Frequency
  - – Every 5 years
- Timing of Inspections
  - – Within 25 years of initial loading

This EPRI slide defines primary barrier as the welded canister and the secondary barrier as the fuel cladding. With the issues of high burnup fuel storage and transport, we cannot count on the cladding as a barrier. I provided numerous references on this in my paper. I'm not sure what you're referring to when you speak of "defense in depth" in your document. What "defense in depth"? I discuss this in the Damaged Fuel and High Burnup paragraphs in my paper.

EPRI Extended Storage: Research Perspective presentation, John Kessler, EPRI Used Fuel and High-Level Waste Management Program, NWTRB Meeting, September 14, 2011
http://www.nwtrb.gov/meetings/2011/sept/kessler.pdf

Slide 8
Confinement – The Number 1 Priority

- Three confinement barriers are considered
  - – Primary barriers:
- Bolted systems: seals and bolts
  - – Significant R&D completed or underway (Germany and Japan)
- Welded stainless steel systems: welded SS canister
  - – External inspection a common desire
  - – EPRI work on NDE tools ongoing
  - – Secondary barrier: fuel cladding
- Most cladding intact, but some is already degraded
- Cladding integrity contributes to sub-criticality and retrievability

The following NRC slides summarize key issues. Slide 76 summarizes why developing an adequate inspection method will be challenging. *Stress Corrosion Cracking of Spent Nuclear Fuel Dry Storage Canisters presentati*on, Greg Oberson, Materials Engineer, NRC, Office of Nuclear Regulatory Research, Meeting with Fuel Cycle and Materials Administration, September 16-19, 2013
http://pbadupws.nrc.gov/docs/ML1324/ML13241A391.pdf

> **Slide 74 Summary**
> • Austenitic stainless steel is susceptible to SCC when exposed to chloride-rich salts in certain conditions.
> • Operating plants have experienced chloride-induced SCC for outdoor stainless steel components.
> • Susceptibility to SCC appears to be greater at lower temperatures (<80^{o}C) because RH may be high enough to cause deliquescence of salts.
> • In laboratory studies, crack initiation was observed with salt quantity as little as 0.1 g/m2 and stress near the material yield stress.
>
> **Slide 76 Summary (con't)**
> • Canister inspections present a number of challenges including lack of physical accessibility, dose considerations, lack of qualified and benchmarked techniques, and interpreting the significance of finding.

This report regarding the Calvin Cliffs inspection provides some details on inspection challenges. *Data Report on Corrosion Testing of Stainless Steel SNF Storage Canisters*, D.G. Enos, et.al, Sandia National Laboratories, September 30, 2013, SAND2013-8314P [Calvin Cliffs]
http://www.energy.gov/sites/prod/files/2013/12/f5/CorrosionTestStainlessSteelSNFStorContainer.pdf

> Page v
> Salt deliquescence can occur on interim storage containers only over a small part of the temperature and RH range that the storage containers will experience. A reasonable maximum possible absolute humidity is 40-45 g/m3; for sea salts, this corresponds to a **maximum temperature of deliquescence of ~85ºC**. Existing experimental work investigating stress corrosion cracking (SCC) of stainless steel in marine environments indicates that SCC **is likely** to occur under storage conditions.
>
> Page 15
> For most dry cask storage systems, passive ventilation is utilized to cool the casks within the overpacks, and **large volumes of outside air are drawn through the system. As a result, atmospherically borne particulates (i.e., dust and aerosols) carried by the ventilation system will be deposited on the cask surface**. This was demonstrated recently at an inspection of the independent spent fuel storage installation at the **Calvert Cliffs** Nuclear Power Station in Calvert Cliffs, MD (Gellrich 2012).
>
> Page 18
> **Table 1. Maximum waste package surface temperature estimates for several storage systems**. [see chart in document]
>
> For several reasons, **determining the surface temperature on a storage container at any given time is difficult**. The initial temperature of each container will vary with the initial activity of the SNF it contains, and the surface temperatures evolve over time, as the radioactivity of the SNF decays and the thermal load decreases. Moreover, the temperature varies over the surface of the container, depending on the distribution of the heat-generating waste inside the container and on the air flow over and around the

container in the ventilated overpack. A recent thermal model of a specific NUHOMS storage cask at the Calvert Cliffs Independent Spent Fuel Storage Installation (ISFSI) illustrates the temperature variability (Suffield et al. 2012). The model implements both radiative and conductive heat transfer, as well as heat loss due to convective air flow through the overpack. **Predicted surface temperatures on the 24PWR storage container (which contains fuel removed from the reactor 25-30 years ago) varied over a range of 90ºC, from 27ºC to 122ºC (the assumed ambient temperature was ~14ºC).** For this horizontally emplaced cask, the ends were coolest, and the lower surface, where the incoming air first contacted the package, was much cooler than the upper surface. Although the actual temperatures and the range of temperatures will vary with the storage system design and the spent fuel load, it is apparent **some regions of the storage container surface will cool sufficiently for deliquescence, and potentially SCC, decades earlier than other regions.**

Page 18-19
...**a model would be very difficult to parameterize for storage containers across the nuclear waste complex,** as it would not only require complex thermal modeling of each individual container and heat load (the number, history, and burnup characteristics of each assembly), but also would have to be specific to individual locations on the waste package surface corresponding to welds. For instance, for the NUHOMS horizontally-emplaced container, the timing of deliquescence and total time of wetness for a longitudinal weld would vary not only with the radial location of the weld, but also along the length of the weld, with deliquescence occurring sooner at the cooler regions (lower surface and container ends). The surface temperature would potentially drop below the nominal 85ºC upper limit for deliquescence many decades earlier at cooler regions than at hotter regions.

Page 19
… some nitrate-chloride salt mixtures have been shown to deliquesce at very low relative humidities, and may never dry out, instead transitioning to molten salt mixtures as temperatures increase (SNL 2008).

Page 21
…marine environments are of greatest concern, and experimental work on SNF storage canister corrosion has largely focused on sea salt and its components. Magnesium chloride is especially important, as it deliquesces at very low relative humidities, and produces brine with high chloride contents. Since a mixture of salts will deliquesce at a lower RH [relative humidity] than any single component within it, sea salt deliquesces at an even lower RH than $MgCl_2$

The following document is particularly valuable in understanding the challenges in detecting SCC. The document analyses inspection methods for pipework and vessels. The method they recommended as most accurate cannot be used with spent fuel canisters. And it appears no method is fool proof. I've included key paragraphs below.

Chloride stress corrosion cracking in austenitic stainless steel – recommendations for assessing risk, structural integrity and NDE based on practical cases and a review of literature, UK, July 2010, ES/MM/09/48 HSL Project JN0004220, R. Parrott BSc PhD MIMMM CEng, H. Pitts MEng PhD *http://www.hse.gov.uk/offshore/ageing/stainless-steels.pdf*

Page vii

Recommendations for Structural Integrity and NDE

Wrought austenitic stainless steels have high fracture toughness and for pipework and vessels Leak-Before-Break is the most likely consequence of Cl-SCC. Leak detection is not a reliable indicator of Cl-SCC because cracks are highly branched and may be filled with corrosion products. Nevertheless, it is recommended that where pipework or vessels develop leaks in service, they should always be investigated for possible Cl-SCC by NDE or by in-situ metallography.

Cl-SCC can generate very large cracks in structures where, as in the case of reactors, the residual stress from welding dominates and operational stresses are low by comparison. If undetected by NDE, the large cracks might introduce failure modes with consequences that were not anticipated by the original design, e.g. complete separation of attachments, toppling of tall columns under wind loading or collapse of long pipe runs due to self-weight.

The simplest and most effective NDE technique for detecting Cl-SCC is dye penetrant testing. Eddy Current Testing (ECT) is effective with purpose-designed probes that have been calibrated on known defects. ECT was found to be ineffective on the samples from the reactor due to limited penetration and sensitivity to surface imperfections that could not be distinguished from cracking.

Crack sizing by eddy current testing may be limited and is not possible by penetrant testing.

Ultrasonic flaw detection can be applied as a manual or an automated NDE technique for detecting Cl-SCC. For structures with complex design features and welds as on the reactors, the trials indicated that ultrasonic testing would require a range of probes, several complimentary scans and be very time consuming. Ultrasonic flaw detection did not cover all design details and possible crack position orientations found on the reactor, and crack sizing was difficult.

Page 10

Table 4. Suggested Cl-SCC growth rates for determining inspection intervals

Risk category	***Crack growth rate,***	
	mm.yr^{-1}	***m.s^{-1}***
Low	0.6	2×10^{-11}
Medium	>0.6 and <30	$>2 \times 10^{-11}$ and $<10^{-9}$
High	>30	$>10^{-9}$

Notes for Table 4:

(i) Crack growth rates can vary by more than the factor of 50 given here. It is also important to recognise that while cracks can propagate rapidly under conditions classified as high risk, it is possible for cracks to grow slowly to a structurally damaging size over long periods of service under conditions classified as low risk.

(ii) With present knowledge of Cl-SCC, it is not possible to predict the time required for crack initiation from a smooth surface. In fact the time to initiate Cl-SCC probably depends on factors similar to those that affect crack growth rate. For low risk conditions, a crack growth rate of 0.6mm.yr^{-1} is likely to underestimate crack initiation time and give conservative inspection intervals. There is some evidence to suggest that initiation times can be relatively short with high chloride concentrations and temperatures >80°C.

Page 14

3.2.1 Rate of degradation

As discussed in Section 1.3, sites of crevice corrosion or pitting are necessary to initiate Cl- SCC. It seems reasonable to suppose, therefore, that cracking of the reactors involved an initial period of localised corrosion followed by a period of crack growth. Rates of crevice corrosion and pitting can be rapid at the start but they tend to decrease as the site of corrosion enlarges and the distance for outward diffusion of metal ions lengthens. According to the competition theory, the transition between localised corrosion and crack propagation occurs at a growth rate of ~10mm.yr^{-1}. In fracture mechanics terms, an area of localised corrosion would have to become large enough such that the stress intensity exceeded the critical threshold, K_{1SCC}, for Cl-SCC. Crack growth thresholds for Cl-SCC in austenitic stainless steels are quoted [6, 23, 29] as ranging from 1MPa.m$^{0\ 5}$ to 30MPa.m$^{0\ 5}$. If localised corrosion is considered as a surface breaking crack to estimate its stress intensity, the depth of corrosion would have to lie between 0.8mm to 3mm for K> K_{1SCC}, assuming that there was ~290MPa residual tensile stress from welding and/or fabrication. On this basis, therefore, it is possible that sufficient depth of localised corrosion could have existed in the reactor after the first year of service. This analysis is probably a considerable oversimplification because pitting and crevice corrosion are stochastic, and as discussed above, the rate at which pits or crevices deepen is likely to become slower with time. Nevertheless, it demonstrates that **localised corrosion and the conditions required for Cl-SCC propagation could have developed relatively early in the service life of the reactor**.

The **rate at which cracks propagate by Cl-SCC has been found to vary by a factor of approximately 500**. For example, laboratory tests with pre-cracked specimens have obtained Cl-SCC growth rates ranging from ~300mm [11.81in].yr^{-1} to ~0.6mm [0.0236in].yr^{-1}. The highest growth rate was measured by Speidel [6] in high chloride concentrations and at high temperatures (90°C [194F] to 110°C [230F]), whereas the lowest rate was found for a low chloride concentration and a temperature of 40°C [104F] by Turnbull [23]. However even if cracks propagated at the slowest rate of 0.6mm [0.0236in].yr^{-1} over the full 24 years service, it is quite feasible that Cl-SCC could have grown through the vessel wall thickness (~6mm) [0.236in] in that time. An alternative scenario is for a higher rate of Cl- SCC propagation to have caused crack extension through the full wall thickness during the high temperature cleaning cycles. For example the accumulative time of the cleaning cycles is approximately 6 months out of the 24 years reactor service. Crack growth at ~12mm.[0.4724]yr^{-1} would therefore have been required if propagation only occurred during the cleaning cycles. This rate is towards the upper end of the crack growth rate range found in laboratory tests for high chloride concentrations and temperatures >90°C [194F]. It is also possible that fatigue cracking, due to the ~150,000 pressure/vacuum cycles that the reactor would have experienced, could have contributed to the failure.

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The study found that type 316 had a higher resistance than type 304 and the higher number of sulphide inclusions in the surface of type 303 acted as nuclei for localised corrosion. Attention was also drawn to the formation of α' -martensite by cold working. The corrosion rate of α' -martensite was reported to be much higher than that of austenite in the active state. It concluded that selective corrosion of the α' -martensite resulted in lowered pH and increased chloride concentration within local pits, and this could lead to crack formation. A further conclusion was that up to 10 years could pass before Cl-SCC causes austenitic steels to fail in environments containing chlorides. The time to failure was considered to be very dependent on the pH value and chloride content of the surroundings.

Let me know if you need more references on stress corrosion cracking – I have many more. And I wouldn't rely on one EPRI report, especially when the NRC technical staff questioned some of their assumptions and calculations. I have a number of research articles from materials experts who evaluated SCC. All point to SCC problems with the steel used in the NUHOMS and Holtec canisters. And no one can predict when cracks will start. Wouldn't it be best to take a conservative position, since there are no near-term options in place to inspect, repair, replace or even monitor for helium?

Subject: for review pdf: "Mark Lombard to Donna Gilmore, 19 Sept 2014, 10:24am"
Date: Wednesday, October 8, 2014 at 7:19:47 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

From: <Lombard>, Mark <[redacted]
Date: Friday, September 19, 2014 at 7:24 AM
To: "Ted Quinn [redacted] <[redacted] Tom Palmisano <[redacted]
"David G. Victor" <[redacted]
Subject: FW: SCC

For you information.

Mark

From: Lombard, Mark
Sent: Friday, September 19, 2014 10:24 AM
To: 'Donna Gilmore'
Cc: Csontos, Aladar; Dunn, Darrell; Hsia, Anthony [redacted] Conley, Maureen
Subject: RE: SCC

Donna,

It is the responsibility of the user of the dry cask storage system to conduct an analysis to evaluate any observed degradation of materials. This analysis will determine whether the dry cask storage system can continue to perform its important to safety functions, including any seismic requirements that apply to that system. If the system can't continue to perform its important to safety functions or if the degradation indicates it may not, or will not, be able to perform its important to safety functions in the future, the user will have to determine the appropriate mitigative action. This action could include repair or taking the system out of service.

Mark

From: Donna Gilmore [mailto[redacted]
Sent: Thursday, September 18, 2014 2:12 PM
To: Lombard, Mark; Dunn, Darrell; Csontos, Aladar
Subject: SCC

Regarding stress corrosion cracking and the NRC's aging management proposal to take a canister out of service if it reaches a 75% through-wall crack,
how does this correlate with a canister's seismic rating? If a canister has a less than 75% through-wall crack, what is the seismic rating for this canister? Is a cracked canister evaluated for seismic issues? My understanding is a flawed container would be excluded from seismic evaluation.

Thanks,

Donna Gilmore
[redacted]

Radioactive Waste Management Associates

Memo

To: Gene Stone, Donna Gilmore

From: Marvin Resnikoff

Date: 10/8/14

Re: Critique of Victor piece

Prof. Victor would like you to agree with a set of facts, though not necessarily with his conclusions. Rereading his piece with that in mind, I find it is full of his opinions and recommendations and very lean on facts. It is clear he wants to get consensus on his recommendations and positions and not on the facts. Some of his facts are in error, but more importantly, his facts may not be your facts. His facts support his conclusion and confidence that Areva and the nuclear industry in general are doing things right. Our facts support the conclusion that there are major doubts and uncertainties in what Edison is doing. So, 2 set of facts and 2 sets of conclusions. Good luck on reaching a consensus. Much of his paper is devoted to criticizing Donna's well referenced paper. In general, I find his paper thin on facts and long on positions and opinions. From a distance, here goes.

Page 2: So we are clear, the fact is Areva is a French multinational corporation. The professor has a problem with German companies, but not French companies. This is a multinational industry; we should use the best technology. As his piece acknowledges, Areva has used all metal casks at the Fukushima reactor. If it wished, Areva could provide a clear comparison of the two systems, all metal cask, vs. NUHOMS canister system, but they have not done so.

I don't necessarily agree with Donna's push for the all metal cask, but the professor's concerns seem quite manufactured. He is concerned about long delays (is this a fact or opinion?), while delays are necessary to allow the fuel to cool. He is concerned about bankruptcy. Let's talk about the number of NRC regulated U.S. companies that have left the decommissioning bill to U.S. and State taxpayers: Nuclear Fuel Services (West Valley, NY), Maxey Flats, KY rad landfill (EPA decommissioning), Starmet U processing plant (Concord, MA – EPA decom), and so on – the list is long, and the NRC's financial oversight has been abysmal.

Despite my disagreement with his "facts," his recommendation, that Areva provide an objective assessment of the all metal vs NUHOMS system, has merit. But not just for regulatory delays, but for long-term safety in storage and transportation of high burnup fuel. That is our primary concern.

p. 3 His recommendation that we should meet with, not 2, but 3 cask manufacturers is well taken. "Defense in depth" or what I call, "the multi-sieve approach," should be discussed, particularly for the long-term. A set of questions should be prepared in advance. The professor lists problems that are "completely manageable;" clearly he has made up his mind after his careful study of the problem and it is only a public relations issue, the industry has just not explained it's resolution of these issues. No facts are presented here. I see it as an industry that lurches from one short term fix to the next, starting with a proposed waste repository in a salt formation in Lyons, Kansas in 1972, progressing to a failed reprocessing operation in West Valley, NY, progressing to a failed repository solution in Yucca Mountain, NV. It is like building a home without bathrooms, then setting up a continuum of porta-potties in the back yard. There are no facts presented.

p. 3 His next recommendation is to remove the fuel from the pool as early as possible. Most of us, maybe not Donna, would agree on this point. But "as early as possible" leaves time to arrive at the best solution, since fuel has to cool before being placed into a canister or cask.

p. 4 "Question1: Why are U.S. utilities using thinner walled stainless steel casks rather than thicker walled ductile iron or forged steel?" Rephrased Question 1: What is the best cask for SONGS in the long term? The professor discusses why a bolted cask is used in Europe compared to a welded canister in the U.S. His discussion of the bolted CASTOR cask is not correct. The casks in use at the Surry plant have **two** lids, with helium filler, to prevent oxidation and aid heat removal. Helium loss can be monitored at Surry. The DOE has not yet decided how the repository will be loaded, and whether storage casks will have to be unloaded and reloaded into disposal casks. Obviously a bolted system would facilitate an unloading process. The CEP should invite a DOE representative to discuss DOE's repository plans and how they intend to handle welded canisters. The professor states that thickness of the iron walls does not guarantee safety. This is his unsupported opinion, not a fact. It would be useful to have DOE's view on how nuclear fuel will be disposed in a repository. It might also be useful to have a frank discussion by cask vendors on why utilities prefer thin-walled canisters which require a transport overpack vs all metal casks that do not. The transportation cost is paid by DOE. His other arguments about GNS bankruptcy (p. 5) are mere speculation. This is his opinion and not fact.

p. 6 The professor raises the following: "Question 2: What is the track record with cracking of stainless steel similar to that used in casks?" To put the question in a proper context, we are concerned with stress and pitting corrosion in the 100-year time frame. Here, the EPRI study is cited, but not NRC inspection reports that show salt corrosion in an 18 month time frame. This is an example of 2 sets of facts. The professor uses facts that show the industry is on top of this problem, whereas Donna cites inspection reports that show a concern and uncertainty. (p. 7)

p. 8 The professor argues that periodic inspection and mitigation will solve this problem. But he does not discuss how this inspection and mitigation will take place. This is characteristic of his paper – it presents a rosy outlook, whereas Donna's analysis raises concerns that are not fully addressed.

p. 9 The professor says monitoring of radiation will be helpful in identifying a problem. If radiation levels rise, this would not be a good sign. This would indicate either a thinning of canister walls, weld issues or worse, release of radioactive materials. Then what? What are the mitigation steps?

p. 10 If a crack in a canister were detected, what then? Asks Question 4. He argues that the canister most likely to suffer aging effects would be pulled from the concrete overpack and inspected. Has this been done before? How will this inspection take place, with the intense radiation fields? All of this research that the professor extols are after the fact. This is an expert taking place in the field!

p. 11 The professor is extremely high on the NEI study. This is a study that takes place over the next ten years, in casks with bolted lids, not thin-walled canisters.

p. 12 This is my favorite. "In the case of canister defects the repairs are rapid—a matter of days to clean and resurface an affected area or perhaps weeks to arrange a new weld." How exactly will this be done? What are the comparable situations, where this has been done?

p. 13 His solution, not NRC-approved, is to pull the canister and put it into a transport overpack. From there, one could put the canister into a dry call or fuel pool – somewhere. It could then be inspected and repaired or replaced. No other mitigation plan exists, other than this emergency, adhoc and unsupported approach. Oy vey!

p. 15 His discussion and support for the industry becomes quite screwy louie in the last 3 pages. Here's an example, "in some respects HBF may prove easier and safer to store than non-HBF fuel." He asserts, without proof, that newer fuels have better cladding, and that is definitely not true.

p. 15 He even argues against monitoring. "Systems that are purely passive and welded shut are probably a lot safer than those that are bristling with through--wall sensors and can be opened and closed.

Subject: for review pdf: "Donna Gilmore to David Victor, 19 Sept, 3:53pm, minus attachment that was superseded by a more recent draft from Donna"

Date: Wednesday, October 8, 2014 at 7:20:01 AM Pacific Daylight Time

From: David G. Victor

To: Steven Carlson

On 9/19/14, 3:53 PM, "Donna Gilmore" <[redacted] wrote:

> David,
>
> After we discussed your paper, I promised to send you references for where I thought your facts differed from mine. Attached is a fully referenced document I prepared on the San Onofre dry storage issues. Thanks for sharing Lochbaum's and Frank's comments. I agree with most of their comments. I don't agree with Lochbaum's conclusion that the currently licensed casks are our best choice for San Onofre. I'm hoping once David read's my paper, he will agree.
>
> I listened to yesterday's NRC Commissioner's webcast on waste storage and transportation. Dr. Macfarlane asked great questions that are applicable to what we are facing at San Onofre. Mark Lombard, NRC Director of SFST Division, provided answers to her questions. I've included some of those in this paper.
>
> I agree with Lochbaum it's important to remove the fuel from the pools. However, living a few miles from this plant and learning about the potential short-term problems with these canisters, I believe there is time to select safer canisters. I was shocked to learn from the NRC that the steel/concrete canisters cannot even be adequately inspected on the outside and none have been. I've read some of Gordon's papers where he said the Castor type casks are better, but if the steel/concrete ones can be shown to last 100 years, that they would be good enough. He also recommended the Castor casks for Diablo Canyon before they had selected the Holtec.
>
> When Tom Palmisano said he though the process would take 3 to 5 years to receive approval from the NRC, I called Mark Lombard. He personally told me the 18 to 30 month time frame was more than adequate. With 30 month being the worse case. This assumes of course that the vendor can respond to all NRC concerns. And he said they've never denied a license application. Local citizens are willing to wait. The fuel needs to cool in the pools anyway, so we're not talking about a significant delay here.
>
> Thanks,
>
> Donna Gilmore
> [redacted]
>
> ---- "David G. Victor" <[redacted] wrote:

Dear Colleagues
Over the next 10 days or so I will revise my memo. If you have any further comments on the piece please do let me know.
Meanwhile, below please find comments from Frank von Hippel (Princeton) and Dave Lochbaum (UCS). Both have provided us with exceptionally helpful reviews (most of Dave's comments are embedded in the pdf file, which I attach). They also point to new citations and information about aging research.
I am enormously grateful to both and have thanked them on our behalf.
It is clear that it will be very helpful to have a vendor event with Holtec and Areva and I very much look forward to that.
all best
David
******COMMENTS FROM DAVE LOCHBAUM (SEE ALSO ATTACHED PDF)*****
From: Dave Lochbaum <[redacted]mailto[redacted]
Date: Thursday, September 18, 2014 at 10:54 AM
To: "David G. Victor"
<[redacted]mailto[redacted] Chris Thompson
<[redacted]mailto[redacted]
Subject: RE: email introduction
Dear Dr. Victor:
Thank you for the opportunity to review and comment on the draft memo about dry storage at San Onofre. My comments are embedded in the attached file. If I can clarify these comments or if a more formal response would help your work, please let me know.
None of my comments involves a recommendation/finding that is off-the-mark or suggests a key recommendation/finding is missing. Some of my comments suggest a minor expansion of the recommended effort, but these are more tweaks than wholesale revisions.
I think the tone and content of the memo are spot on. It is often tempting to explain why a product was selected or a pathway chosen by describing its many virtues. When decisions aren't as clearly black and white, as in this matter, a memo like the one you've drafted is invaluable. It broadens the decision-making rationale by also explaining why alternatives are less attractive.
The CEP is helping both the public and the company. I sincerely appreciate the time and effort you are applying to this outcome. If I can assist your efforts in any way, I will do so if I'm able.
Thanks,
Dave Lochbaum
Director, Nuclear Safety Project
Union of Concerned Scientists
[redacted]mailto[redacted]
************COMMENTS FROM FRANK VON HIPPEL
Dear David,
Good to hear from you!
A few reactions which are not definitive answers but may provide you with some additional questions at the least:
p. 2: Re Castor casks, The first casks in the U.S. (at Surrey in Virgina) were Castor casks. They are more robust with regard to attack.

I don't know whether they have been licensed for transport. (I am surprised at how much of your report is devoted to the Castor cask. I guess there are advocates on your committee.)
Re: Licensing period. The NRC has recently extended some existing casks to 60 years. I don't know whether that means that new casks can now be licensed for 60 years from the beginning.
p. 3:Re defense in depth. Some (Gordon Thompson is the lead technical person who works with US NGOs on this [redacted] argue that casks should be protected from direct attack. Germany has casks in thick-walled buildings and, at one plant, Neckarwestheim, in tunnels. I guess the new Holtec design has this feature.
p. 4. Re: recycling. Only two country of the 31 with nuclear power reactors systematically recycle spent fuel: France and the Netherlands (one 500-MWe reactor).
Japan is trying but failing. China, India and Russia have R&D on breeder reactors. The UK has been reprocessing but is quitting. France, Russia and the UK have had customers but all those customers have decided not to renew except for the Netherlands.
p. 5. Castor casks sit inside in Germany and outside in the US.
It is not clear that any current US cask would be accepted in a repository. The DoE put out design specifications for triple-purpose casks (storage, transport and disposal). The effort was cancelled but it might be interesting to compare those specifications with those of the casks that US utilities have been buying.
The primary reason that US utilities have gone with thin stainless canisters with reinforced concrete shielding is cost. They cost roughly half as much as Castors.
I don't think that the overpack can be given much credit for preventing corrosion. They may protect from direct rain and snow but not from humidity and leakage -- or salt at an oceanside site. Once again, Castor is licensed for use at Surry.
p. 8: I too am concerned what "periodic inspection" would involve. Do you pull the canister out? If so, you can't get close to it because of the thin walls. You would have to put it in a spent fuel pool, which would presumably be unavailable (or see below).
p. 9: I don't think that monitoring for temperature and radiation around the concrete overpack would be that useful. Measuring radiation would put you pretty late in the game if there were radioactive leakage. However, the canisters are filled with helium and are often equipped with valves through which you could measure the helium pressure.
p. 12: I would like to see a description of how canisters are inspected and repaired without incurring unacceptable radiation doses.
p. 13: The NRC, in its Generic Environmental Impact Statement for Continued Storage of Spent Nuclear Fuel shows a design for a way to repack a cask in a small shield building without a pool.
p. 14: A sample Surry cask was transported from Virginia to Idaho National Lab for external and internal inspection.
p. 15: "the temperature at which HBF faces cladding failures is dramatically higher than for non HBF." I think that you may be confused. The temperature that HBF reaches in a canister is higher.
I suspect that a Castor cask could be welded shut if desired.
p. 16: Degraded HBF will have the same temperature as non-degraded HBF.
Best regards,

Frank

From: "David G. Victor"
<[redacted]mailto[redacted]
Date: Monday, September 1, 2014 at 3:33 PM
To: Ted Quinn <[redacted]mailto[redacted] Bill Parker
<[redacted]mailto[redacted] Donna Gilmore
<[redacted]mailto[redacted] Gene Stone
<[redacted]mailto[redacted]
Cc: Tom Palmisano
<[redacted]mailto[redacted] Chris Thompson
<[redacted]mailto[redacted]
'[redacted]mailto[redacted]
<[redacted]mailto[redacted] Tim Brown
[redacted] Dan Stetson
Subject: draft report on spent fuel storage in dry casks
Dear Ted, Bill, Donna and Gene

Thanks again for agreeing to help review and shape my report on the literature and safety assessment concerning long-term storage in dry casks. As you know, some questions have been raised about the choice of cask‹pointing to possible thick-walled iron European casks as an alternative to standard American stainless steel. Those questions have been related to possible corrosion risks with stainless and a host of other concerns. Questions have also been raised about whether and how the industry has implemented ^{3}defense in depth.^{2}

As you will see from the attached, which includes a summary of my main observations and recommendations on the opening pages, I think it is time that we move on from the discussion of the thick-walled iron casks. It has been very useful to look at that option‹it has forced us to confront what we really know and what^{1}s still unknown. But that option is not viable in my view. Much more important is grappling with ^{3}defense in depth.^{2} I have found that there^{1}s a lot more ^{3}defense in depth^2 than originally meets the eye but that the industry can do better in articulating what ^{3}defense in depth^2 really means industry-wide as well as at SONGS. But we in the CEP may want to do more to make sure defense in depth is vibrant and the public understands how it will work. My recommendations include some follow-up with the thick-walled iron vendor and a possible vendor event with the two vendors that are most viable in the stainless steel market. I also outline what we in the CEP might do to help focus attention on the long haul.

Apologies for the length of time it took me to draft this. AS you will see, this became a much bigger job than I had anticipated. Once I have some reviews there may be places where I can shorten; however, the public may benefit from some repetition of key points when they affect the answers to multiple questions. Hopefully you will find the text both accurate and written in plain English so that the public can eventually read and understand the important detail. Some footnotes are incomplete, sentences are infelicitous and I am sure there are other fixable faults with the draft.

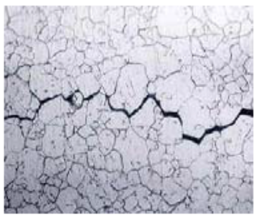
The idea, at this stage, is to get your review on matters great and small. Soon I will also ask‹probably informally rather than a formal review‹people at NRC, NEI and EPRI to take a look. NRC, in particular, has been implicated in much of the back and forth on this issue and I

> > know they are keen to get the record accurate. NEI is about to release
> > a big report on long-term aging management. EPRI has a huge program in
> > this area.
> > I am sure that nobody will agree with all I have written; some of you
> > might disagree vehemently with some of my conclusions. At this stage
> > what I write is nothing more than my independent assessment of the
> > facts, strategy and direction of the industry. But if you could send me
> > an assessment of any errors in fact, tone or synthesis‹including errors
> > of omission‹I would be grateful since we shouldn¹t let errors stand. I
> > am not trying to create a consensus document and I don¹t plan to ask you
> > to sign the assessment; if there are vehement disagreements then we can
> > talk about how those might be handled once we have a sense of where they
> > lie.
> > All best
> > David

Are San Onofre's aging nuclear waste canisters starting to crack?
Has salt erosion from the sea damaged them?
Are they about to leak radiation?
How would we know and what can be done about it?

According to the Nuclear Regulatory Commission (NRC)

- The thin (1/2" to 5/8") stainless steel canisters may crack within 30 years.
- No technology is currently available to inspect for or repair or replace cracked canisters.
- With limited monitoring capabilities, we will only know after they leak radiation.



Southern California Edison plans to select another dry cask storage system, possibly this month. Both the Areva NUHOMS 32PTH2 and Holtec UMAX/MPC-37 systems being considered have these and other problems.

The California Public Utilities Commission (CPUC) should not approve use of ratepayer funds until Edison resolves these and other nuclear waste storage issues. $400 million is currently estimated for the storage system.

The NRC has no current solutions to these problems, yet approved these steel/concrete dry storage systems. They have *unsubstantiated hope* that the nuclear industry will develop solutions before there is a radiation leak, even though they do not know what those solutions might be. We cannot rely on government or nuclear industry promises that they will have a solution in time. We do not want to be the next leaking nuclear waste dump like Hanford in Washington,[1] the "flagship" Waste Isolation Pilot Project (WIPP)[2] in New Mexico, the West Valley Demonstration Project in New York,[3] or Maxy Flats in Kentucky,[4] to name a few.

Edison should compare these welded steel/concrete storage systems with the thick, bolted-lid cask storage systems used internationally. The steel/concrete storage systems have many short and long term unresolved issues,[5,6] so Edison's statement that "this is what everyone else in the U.S. is doing" is not a good reason to procure inferior systems, now that we know the waste may be stored on our coastline for 60 to 100 years or more -- longer than the intended life of these canisters.

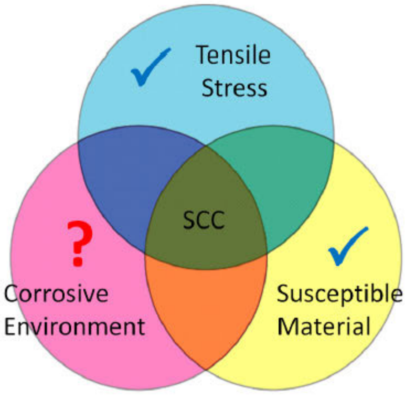
The steel/concrete systems were designed for temporary storage, yet the NRC decided they can stay near our coast for 60 or 100 years – or indefinitely, even though they have not finished their research and analysis on how to do that and do not even know if it is possible. The NRC, the Electric Power Research Institute (EPRI), the Department of Energy (DOE) and numerous other government and scientific sources have identified 94 technical data gaps for spent fuel storage and transportation. See the following pages for recommendations, licensing issues, background information and references.

No dry storage system is as good as it should be for extended storage. However, Edison can do better for Southern California. And as CPUC Commissioner Michel Florio recently commented, *ratepayers shouldn't have to buy this dry storage system more than once*. The CPUC should not release decommission funds to Edison until these nuclear waste storage issues are resolved.

Donna Gilmore
[redacted]

Stress Corrosion Cracking Background Information

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



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

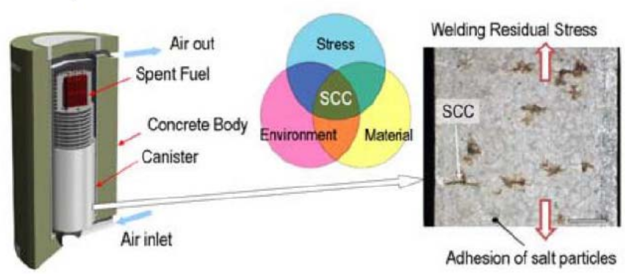
- 304 and 316 Stainless steels are susceptible to chloride stress corrosion cracking (SCC)
  - Sensitization from welding increases susceptibility
  - Crevice and pitting corrosion can be precursors to SCC
  - SCC possible with low surface chloride concentrations
- Welded stainless steel canisters have sufficient through wall tensile residual stresses for SCC
- Atmospheric SCC of welded stainless steels has been observed
  - Component failures in 11-33 years
  - Estimated crack growth rates of 0.11 to 0.91 mm/yr

2

Stress-Corrosion Cracking (SCC) of SS Welded Canisters

For SCC you need:

- Austenitic stainless steels (e.g. 304, 316)
- Tensile stress (residual weld stress)
- Corrosive environment
  - Salts in the air
  - Deliquescence
    - Surface temperature
    - Humidity



SCC can occur *under conservative lab conditions*

What we don't know …
What are the conditions on actual canisters?

 5

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Recommendations

The CPUC should not approve the $400 million for a dry cask storage system and should not release other decommissioning funds until the following issues are addressed.

1. **Cost/Benefit:** Edison should provide a long-term storage and transport Cost/Benefit Analysis to both the CPUC and Edison's Community Engagement Panel (CEP).
2. **Other casks:** Edison should be required by the CPUC to fully evaluate other dry cask storage and transport solutions used internationally. *The German CASTOR ductile cast iron casks, with about 20" thick walls (e.g., CASTOR V/19), are currently the most widely used transportation and storage containers for spent fuel rods in the world. Another common system used internationally is the French Areva thick forged steel cask (e.g., TN-24).*
3. **Buildings:** The casks should be stored in reinforced concrete buildings for additional protection against environmental and other external hazards. *This what Germany, Japan (at Fukushima) and other countries do.*[7,8] *Premature cask degradation caused by moisture at Peach Bottom and Three Mile Island would have been prevented if they were in buildings* .[9]
4. **Mitigation:** Edison should provide documentation to the public about how the dry storage system will be monitored, inspected, repaired and how fuel assemblies can be retrieved,[10] transferred to another canister or cask, and prepared for transport.[11,12] A system should be in place for all this.
5. **Seismic:** A seismic evaluation is needed for cracked canisters. *The NRC plan to allow canisters to have up to a 75% crack before they must be removed from service. However, there is no seismic rating for a cracked canister.*
6. **Fewer assemblies:** Edison should store no more than 24 fuel assemblies per cask, preferably less. *Edison plans to increase their current 24 assemblies per canister to 32 (Areva) or 37 (Holtec). Germany stores about 19 to 24 fuel assemblies per* cask. *Canisters designed for permanent storage have even fewer assemblies per canister. Fewer assemblies per cask are safer. Fewer assemblies reduce heat load and required cooling time for storage and transport, especially for high burnup fuel (HBF).*[13] *HBF burns longer in the reactor, resulting in waste over twice as radioactive, thermally hotter, and far more unpredictable in storage. Higher temperatures increase risk for fuel cladding failure.*
7. **Fuel pools:** Edison should keep the spent fuel pools until they have another system in place to replace canisters or casks.[14] Once the fuel assemblies are emptied from the pools, they may be able to use the pools to repackage the fuel under water. *The NRC allowed California's Humboldt Bay and Rancho Seco to destroy their pools and they plan to do the same at San Onofre, even though they have no adequate system in place to transfer fuel to other canisters.*
8. **Damaged fuel:** Damaged fuel should be stored in containers (cans) prior to loading in canisters/casks in order to meet fuel retrievability requirements.[15] *The Holtec system stores damaged fuel in unsealed containers (cans). The Areva NUHOMS 32PTH2 system doesn't even use damaged fuel containers. The German cast iron casks use sealed containers.*[16]
9. **High burnup fuel:** Questions about how high burnup and damaged fuel are handled should be clearly addressed by Edison. Storage, retrievability and transport of high burnup fuel assemblies that may develop cladding embrittlement and failure after storage should also be addressed. *Defense-in-depth protection is lost once cladding fails. Maine Yankee and Zion nuclear plants both can their high burnup fuel, due to the unknowns about high burnup fuel in storage and transport. However, the cans are not sealed.*

10. **Monitoring:** Monitoring for helium leak should be required. *The DOE considers this a high priority issue. However, neither the Areva nor Holtec welded canisters have this capability. Only bolted lid casks, such as the Castor and Areva TN-24 have this capability.*

11. **Technology gaps:** Dry storage and transport technology gaps should be evaluated against the current dry storage and transport technologies used in the U.S. and internationally to determine if the major issues can be eliminated or at least adequately managed and mitigated prior to any radiation leak. *The DOE, the NRC and the nuclear industry identified 94 technology gaps[17] in storage and transport of nuclear waste.*

Licensing

The cast iron and forged steel casks are not currently licenses by the NRC even though they are licensed for both storage and transportation internationally. A license certificate for a new or amended dry cask system takes 18 to 30 months, including for a ductile cast iron cask like the CASTOR, stated Mark Lombard, NRC Director of Spent Fuel Storage and Transportation Division. The time variance is based on how complete the vendor package is when it's submitted to the NRC. The NRC will not evaluate a dry storage technology unless a vendor requests a license and no vendor will request a license unless they have a customer, such as Edison.

Given the amount of cooling time needed for the spent fuel, particularly the high burnup fuel, there is plenty of time to consider another dry storage vendor. This decision has long term impacts and should not be based on Edison's artificial June 2016 dry storage loading deadline. California Energy Commission (CEC) policy is to expedite the fuel into dry storage after adequate cooling. However, CEC Chairman Robert B. Weisenmiller said he was never informed there may be aging issues with the canisters, such as stress corrosion cracking.

Siempelkamp manufactures the CASTOR casks and other ductile cast iron casks, such as the TUK-141 and TUK-153.[18] These casks meet international certifications, ASME standards and have "N3" stamp certification, which ensures independent quality inspections.[19] The canisters Edison is considering do NOT meet ASME standards and do NOT have "N3" stamp certification. The NRC allows exceptions to the ASME standards. The NUHOMS 24PT1 and 24PTH2 canisters currently loaded at San Onofre have the N3 stamp. The new canisters they plan to purchase do not.

Areva sells both steel/concrete and forged steel dry cask systems. It is unclear if they are interested in competing with themselves by bidding both the steel/concrete NUHOMS system and the forged steel dry cask system.

Background

On August 26, 2014, the NRC decided thousands of tons of nuclear waste can be stored at nuclear plants for 60 years (short-term), 100 years (long-term) and indefinitely, [20] even though they only have *unsubstantiated hope* of solving current technology issues.

The NRC currently only certifies dry cask storage systems for 20 years (for high burnup spent fuel)[21] and has not completed their evaluation for long term storage, so we cannot depend on the NRC for assurances these cask systems will last long term. NRC Director Mark Lombard said the NRC is not evaluating other systems and technology used internationally. They are limiting their research and analysis to currently approved systems.

The NRC, the Electric Power Research Institute (EPRI), the DOE[22] and numerous other government and scientific sources identified numerous problems with the current steel/concrete dry storage systems. Some of these are detailed below.

Cracks within 30 years

The thin 1/2" to 5/8" welded stainless steel canisters may have premature stress corrosion cracking within 30 years, due to our marine environment. This could result in major radiation releases to Southern California and beyond. Cracks in similar materials at nuclear power plants caused component failures in 11 to 33 years, including at San Onofre (25 years).[23,24] *Other cask systems, such as the German CASTOR V/19 (~20" thick) ductile cast iron casks, do not have this problem.*

A January 2014 limited inspection for salt and temperature on two Diablo Canyon canisters found sea salt crystals on a canister that was loaded for less than 3.5 years. Salts (chlorides) are a precursor to stress corrosion cracking.[25,26]

The NRC said once a crack occurs, it may go through-wall within 16 years and must be taken out of service after 12 years (e.g., when 75% through-wall). And the hotter the canister, the quicker the crack will go through-wall after the crack initiates.[27] Also, cracks in canisters are excluded from seismic evaluations.[28]

> **Recommendation:** The NRC standard for acceptable through-wall crack percentage needs to be reevaluated for seismic impact.

No inspections – internal or external

There is no technology to inspect even the exterior of stainless steel canisters for cracks once they are loaded with fuel.[29] In fact, no U.S. steel canisters have been opened or removed from their concrete overpacks or even inspected on the exterior of the canisters. The conditions on and in actual canisters are unknown (EPRI).[30]

Due to concerns of gamma radiation and neutrons (which the steel containers don't block) and the possibility of damaging the canister, the NRC does not require the utilities to remove the stainless steel canisters from the concrete overpacks.

The NRC is allowing the nuclear industry five years to develop technology to adequately inspect the exterior of the steel canisters.[31]

The NRC's proposed Aging Management Plan requires only one canister at each plant be inspected and only on the exterior surface. The first inspection would be at 25 years (allowing 5 years for inspection technology to be developed), then once every 5 years after that for the same canister.[32] After the inspection technology is implemented, future new licenses would require an initial inspection within 20 years.

The nuclear industry proposed an alternative "Toll-Gate Aging Management Plant (AMP)" requiring inspection of only one canister in the U.S. instead of one at each plant. And they propose licenses be renewed *before* inspecting any canisters.[33]

Cask systems, such as the German CASTOR, can be inspected, since, unlike steel canister systems, they do not need concrete overpacks for gamma ray and neutron protection.

No repairs

There is no technology to repair cracks in these canisters. Technology used for other stainless steel components cannot be used to repair canisters containing nuclear fuel waste.[34] The NRC is *optimistic* there will be a solution before it is needed, but they do not know what that might be.[35] The original assumption was these canisters would not be here long enough to need repairs.

No replacement – no pool or dry handling (hot cell) transfer facility

There is currently no method to replace failing canisters . Empty spent fuel pools might be useful for this. However, Edison plans to destroy the pools. Pools have already been eliminated at California's Humboldt Bay and Rancho Seco nuclear waste storage facilities. *The only fuel-handling method currently available to the commercial nuclear generating industry is to bring a cask [or canister] back into a spent fuel pool for reopening. However, dry handling of the cask and fuel is important to avoid disturbing the properties of the cask, cladding, fuel, and related hardware that would occur if the materials were rewetted and rapidly cooled. However, there is no dry handling facility available in the nation that is large enough to handle these canisters...and removal of a welded storage cask lid is problematic.*[36]

A dry handling (hot cell) facility would be very expensive to build. A recent DOE report estimated $500 million to build a hot cell facility and $300 million for a spent fuel pool.[37] These estimates exclude costs to manage those facilities. And, according to NRC's Mark Lombard, hot cells are difficult to build, operate and maintain. He also stated "*When you think about the realities of utilizing that, one thing that we try to avoid is cutting of canister systems and because there is dose and difficulty associated with that, too. That would require some sort of a cutting of one end of the canister to push or pull the fuel assembly through. But it is certainly feasible...*"[38]

Also, there are no dry handling (hot cell) mobile facilities.[39] Areva has a few smaller mobile hot cells in France, but they do not exist here and are not designed for transferring larger canisters. There are numerous issues to evaluate to determine if that option is even feasible.[40]

Note: Rancho Seco has six damaged fuel assemblies loaded in a canister not approved for damaged fuel. However, the NRC gave them a license exemption so they could keep them in the canister.[41]

> **Recommendation**: Edison should keep the spent fuel pools until they have another system in place.[42] Costs for this should be included in the decommissioning plan submitted to the CPUC. *The CASTOR type casks have bolted lids, designed for easier removal of fuel compared to welded canisters.*[43] *However, there still needs to be a pool at the site to replace the casks.*

Transport casks are not an acceptable solution for a failed canister

An option suggested by the nuclear industry is to store a defective canister inside a transport cask, such as the NUHOMS-MP197[44,45] and deal with the problem later. However, transport casks are approved by the NRC for transport and not for interim storage. And they are not approved for use with cracked canisters. In addition, once a crack starts, it will continue. Putting a cracked canister in a cask is kicking the "can" down a dangerous road. The MP197 is designed to be reusable. The cost to use this in lieu of a better cask means we will be paying over twice as much for storage and then be left without a transport solution. Putting a failed canister in a transport cask should not be considered an acceptable solution.

Concrete buildings

Germany, Japan (Fukushima) and other countries house their casks in reinforced concrete buildings for additional environmental and other external hazards.[46,47]

> **Recommendation:** Edison should store casks in reinforced concrete buildings, similar to those used internationally.

Monitoring

Edison monitors casks for radiation. However, radiation monitoring only notifies us AFTER the canister leaks radiation. Edison also has temperature monitoring, but without a remediation plan in place, that is not sufficient.

There is no monitoring for helium leaks in welded canisters. This would provide a warning prior to a radiation leak. The DOE said it is a high priority to have helium monitoring in welded canisters and considers this a deficiency of the welded technology.[48] Bolted, pressurized lid casks, such as the CASTOR, indirectly monitor for helium leaks.[49]

> **Recommendation:** Require helium leak monitoring.

Concrete overpack and cask aging

The unsealed concrete overpacks and concrete casks may develop structural degradation that could affect seismic rating.[50] The ductile cast iron and forged steel casks do not require concrete overpacks.

Damaged fuel

Damaged fuel assemblies in steel canisters are not stored in sealed containers. There is no replacement for the "defense in depth" protective fuel cladding lost from damaged fuel assemblies.[51] San Onofre has a record 95 damaged (failed) fuel assemblies in dry storage and an additional 31 in the spent fuel pools**.** The Holtec canister[52] uses retrievable damaged fuel assembly containers (cans), but they are not sealed. The Areva NUHOMS 32PTH2[53] does not even have retrievable damaged fuel assembly containers (cans). The German cask technology encloses damaged fuel in retrievable sealed containers (quivers)[54] prior to loading into the casks.

In addition, high burnup fuel may damage the fuel cladding while in dry storage. This issue has not been addressed.[55]

> **Recommendation:** Questions about how damaged fuel is handled should be addressed by Edison. And the issue of storage, retrievability and transport of high burnup fuel assemblies that may develop cladding embrittlement and failure after storage need to be addressed. Requirements for defense in depth, redundancy and fuel assembly retrievability need to be addressed.

Technology Gaps

The Department of Energy (DOE), the NRC and the nuclear industry identified 94 technology gaps[56] in storage and transport of nuclear waste.

Recommendations: Technology gaps should be evaluated against the current dry storage and transport technologies used in the U.S. and internationally to determine if the major issues can be eliminated or at least adequately managed and mitigated prior to any radiation leak. Edison should compare existing technologies used in the U.S. and internationally to ensure Southern California communities are provided the best solution available. The steel/concrete canister technology has many short and long term unresolved issues,[57,58] so Edison's statement that "this is what everyone else in the U.S. is doing" is doing it" is not a good reason to procure inferior technology, now that we know the waste may be stored on our coastline for 60 to 100 or more years -- longer than the intended life of these canisters.

Any decisions about dry cask storage and transport for San Onofre must include requirements for short term storage (60+ years) and long term storage (100+ years). Storage and transport requirements, including aging management, mitigation, and related costs should be included in a Cost/Benefit analysis submitted to the CPUC and Edison's CEP.

There should be documentation available to the public about how the dry storage system will be monitored, inspected, repaired and how fuel can be transferred to another canister, overpack or cask (if and when needed), and prepared for transport. A system should be in place for all this and the costs included in the decommissioning plan.

Canister or cask assembly capacity

Fewer fuel assemblies in a canister or cask is a safer and more flexible solution for short and long term storage, transportation and final disposal. Current San Onofre canisters hold 24 fuel assemblies. Edison plan to increase this to 32 (Areva) or 37 (Holtec) fuel assemblies. The CASTOR V/19 cask holds 19 PWR fuel assemblies. The Areva TN-24 forged steel casks hold 24 fuel assemblies. Fewer assemblies reduce heat load and required cooling time for storage and transport, especially for high burnup fuel (HBF). HBF burns longer in the reactor, resulting in waste over twice as radioactive, thermally hotter, and unpredictable in storage. Higher temperatures increase risk for fuel cladding failure. Maximum exterior of canister is 400° C for storage, but must be a maximum of 185° C for transport. This means the ability to transport fuel must be delayed for decades.[59]

Transport

All canisters and casks are designed for both storage and transport. However, the NRC has rarely approved transportation for high burnup fuel. The German and French casks are approved for storage and transport internationally. Independent testing has been done on the CASTOR and other cask systems by BAM. [60] This information may be useful to compare with other vendors' product testing and analysis. The NRC approved the NUHOMS MP-197 overpack transport cask for high burnup fuel and for mitigation of a failed cask. However, the **entire** justification for that approve is labeled proprietary, so the public does not have access to the information. It is unclear how this canister can possibly meet the NRC's own regulatory guidance (ISG-11) for transport of high burnup fuel.[61] The public was not allowed an opportunity to comment on this approval. The MP-197 approval was released May 1st, 2014,[62] just in time for Areva to make a presentation at the May 5th CEP meeting and claim they have NRC approval for storage *and* transport of high burnup fuel. However, neither the NRC nor Areva mention it was a new approval and didn't mention why they were given this approval, in spite of the NRC's ISG-11 regulatory guidance to the contrary.

Ductile cast iron and forged steel casks

The German ductile cast iron casks are the most widely used for both storage and transportation internationally. Many of the limitations of the steel/concrete technology are eliminated with the ductile cast iron technology, although there is no proven safe long term storage solution. That is why the ability to monitor, inspect, and mitigate problems is critical.

> **Recommendation:** Edison should meet with the ductile cast iron (DCI) vendor technical staff to learn the facts about this technology and the company. Edison should allow vendors of the German ductile cast iron technology and other cask technology to bid and provide the technical information needed to compare their cask technology with the current U.S. steel/concrete technology**.** Any potential issues with these technologies, such as bolt and seal aging, should also be identified and documented in the Cost/Benefit analysis.

The information Edison has shared about the Castor technology is missing critical information needed to make an informed decision. And Edison appears to have misinformation about the ductile cast iron technology.[63] For example, Edison's concerns about embrittlement are unfounded, per this Sandia Labs report:[64]

> *Sandia Abstract*
>
> *The use of a fracture mechanics based design for the radioactive material transport (RAM) packagings has been the subject of extensive research for more than a decade. Sandia National Laboratories (SNL) has played an important role in the research and development of the application of this technology. Ductile iron has been internationally accepted as an exemplary material for the demonstration of a fracture mechanics based method of RAM packaging design and therefore is the subject of a large portion of the research discussed in this report. SNL's extensive research and development program, funded primarily by the U. S. Department of Energy's Office of Transportation, Energy Management & Analytical Services (EM-76) and in an auxiliary capacity, the office of Civilian Radioactive Waste Management, is summarized in this document along with a summary of the research conducted at other institutions throughout the world. In addition to the research and development work, code and standards development and regulatory positions are also discussed.*
>
> *Sandia Page viii*
>
> *The proposed use of ferritic materials for packaging containment has not been without controversy and critics. Ferritic materials, unlike austenitics, such as stainless steel, may exhibit a failure mode transition with decreasing temperatures and/or increasing loading rates from a ductile, high-energy failure mode to a brittle, low-energy fracture mode at below-yield stress levels. Regulators have thus been justifiably cautious regarding the use of ferritics for RAM package applications and have indicated that certification of such packages would require extensive confirmatory research and supporting data (although ferritic RAM packages for storage applications have been certified by the NRC). However, the general conclusion of the research reported herein is that appropriate engineering design methodologies exist which, when rigorously applied to RAM transport packaging conditions and environments, warrant the use of suitable ferritic materials for packaging containment. This report summarizes the Sandia work in support of that conclusion. The report also cites and references parallel research and conclusions of other institutions.*

Sandia Page 53

The numerous studies cited show that DI [ductile iron] is a well characterized material that does have sufficient fracture toughness to produce a containment boundary for RAM packagings that will be safe from brittle fracture. All the drop tests discussed in this report were conducted using DI packagings and the studies indicate that even with drop tests exceeding the severity of those specified in 1 OCFR7 1 the DI packagings perform in an exemplary manner.

Dry Storage Technology Options

The two major types of interim dry storage are the Steel/Concrete dry storage system and the ductile cast iron or forged steel cask system.

Steel/Concrete: Thin (1/2" to 5/8") welded stainless steel canisters with thick unsealed reinforced concrete casks or overpacks is the main type of dry storage system used in the U.S. Transport approval of this technology has been extremely limited due to insufficient data on potential fuel cladding failures from high burnup fuel (>45 GWd/MTU), even after dry storage.[65] High burnup fuel is fuel that is allowed to burn longer in the reactor, resulting in spent fuel that is over twice as radioactive, unstable in storage and transport and thermally hotter. This fuel normally requires longer cooling times before it can be placed in dry storage. [66]

Ironically, the research done to "prove" it is safe to use the steel/concrete cask technology was based on an examination of a CASTOR V/21 bolted cask, storing lower burnup fuel.[67,68] No such exam has been done for high burnup fuel on any cask; and none has been done for high or low burnup fuel with the steel/concrete welded casks.[69] *Note: the TAN dry fuel handling facility used to open this cask has since been destroyed and no new one is available.[70] The EPRI Demonstration Project[71] to do a confirmatory evaluation of high burnup fuel in a cask does not have a plan as to how they will open the cask. Also, the cask they are choosing to do their evaluation for high burnup fuel is a bolted cask – not any of the current canister designs currently approved to store or transport high burnup fuel.*

The U.S. chose the steel/concrete system because it was less expensive than the cask systems, such as the CASTOR V/21. The canisters were supposed to be moved to the proposed Yucca Mountain geological repository within a short time, so these canisters were not designed for long term storage and do not have adequate aging management systems. The cost difference between the steel/concrete systems and the ductile cast iron and forged steel systems needs to be reevaluated. Material costs have changed and there may be other cost variables. However, unless Edison allows vendors of the other technology to bid, they will not be able to do a cost/benefit analysis.

The steel/concrete cask technology has many short and long term unresolved issues,[72,73] so Edison's statement that "this is what everyone else in the U.S. is doing" is not a good reason to procure inferior technology, now that we know the waste will be here longer than the original intended life of these canisters.

The U.S. steel/concrete system has been used since 1993, starting with Calvert Cliffs.[74] The Calvert Cliffs dry storage license (similar to what Edison plans to procure) has not been renewed by the NRC due to aging concerns. Prairie Island's dry storage license has also not been renewed. Both licenses are expired. The NRC currently only certifies dry cask systems that store high burnup fuel for an initial 20 years. Before renewing these and other licenses, the NRC plans to require an aging management plan, due to numerous unresolved aging issues. They intend to issue a proposed revision to NUREG-1927 *Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance*, in 2015.[75]

Thick casks: Thick (14" to 20") monolithic ductile cast iron (DCI) casks with sealed and double bolted lids are the main long term interim storage and transport technology used internationally. The DCI casks do not require concrete overpacks. They are frequently housed in buildings for better environmental and external hazards.[76] Other thick casks used international are the Areva thick forged steel casks, such as those used at Fukushima, Japan. The Fukushima casks currently store only low burnup fuel (14 casks <24 GWd/MTU and 5 casks <29 GWd/MTU). The Fukushima casks are also housed in a building.[77]

Germany no longer reprocesses their waste and has numerous interim dry storage sites. The German DCI casks have been in use since 1983 – over 30 years.[78] *…A key advantage for the CASTOR as a system as a whole is the monolithic structure of the cask body, which under the principle of "all from a single cast" meets the requirements for completely safe and reliable enclosure and the shielding function without any additional seams. The suitability of the material must be proved in a series of highly involved tests and the specifications for the design include the transportation accident conditions set out by the IAEA (e.g. a drop from 9 m onto an inflexible ground surface, a 1 m drop onto a spike and a subsequent heating test).* The CASTOR technology is currently the most widely used transportation and storage container for spent fuel rods in the world.[79] Over 1100 CASTOR casks are now in interim storage worldwide.[80] This is not a recommendation for a particular cask product, but the DCI technology appears to be more suited to longer term storage.

Financial Analysis

Multi-year annual reports and financial analysis of all vendors considered should be evaluated to determine any potential financial concerns about vendor viability. Even if vendors have sold a large number of products in the U.S. does not mean they will continue to be viable vendors in the future, especially since dry cask storage requirements have changed.

Conclusion

It is of critical importance Southern California communities have assurance that the best dry storage technology is being procured for Southern California, given these cask systems may be here for 60 to 100 years or longer and given the NRC and many others identified possible short-term failure of the thin stainless steel canisters, such as stress corrosion cracking from marine environments and with no adequate remediation.[81,82,83] The CPUC should not approve decommissioning funds until these issues are adequately addressed. We cannot rely on the federal government to decide this for us. The future of California may depend on this decision.

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for technical support in considering license extensions for dry-cask storage. The draft Gap Analysis report states that the CASTOR V/21 cask and fuel conditions differ in significant ways from those typical for fuel in dry storage. In particular: the fuel was loaded into the demonstration cask dry (and not in a SNF pool as is typical). Consequently, the cask did not require drying and did not have the large temperature swings that occur during vacuum drying; the retention of residual water after drying; and the loaded SNF had assembly average burnups of approximately 36 GWd/MTU, which is lower than is typical. The Board thus supports the caution stated in the draft Gap Analysis report that the CASTOR V/21 demonstration results may not represent the cask and fuel conditions of all the commercial fuel currently in dry-cask storage in the United States.

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Subject: for review pdf: "Gene Stone to David Victor, 10 Sept 9:53AM"
Date: Wednesday, October 8, 2014 at 7:19:40 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

From: Gene Stone <[redacted]
Reply-To: Gene Stone <[redacted]
Date: Wednesday, September 10, 2014 at 9:53 AM
To: "David G. Victor" <[redacted]
Subject: Page 8, bullet point 2,

David,

Page 8, bullet point 2, "There are two trends that move in"
This would be a great place for a chart if you have one.

Gene Stone
[redacted]

"The secret of change is to focus all of your energy not on fighting the old, but on building the new." Socrates

Subject: for review pdf. "Gene Stone to David Victor, 21 Sept 10:13Am; David Victor to Donna Gilmore, 21 Sept 6:11AM; Donna Gilmore to David Victor, 20 Sept 3:21PM; Marvin Resnikoff to Donna Gilmore and Gene Stone, radiation memo of unknown date"
Date: Wednesday, October 8, 2014 at 7:17:56 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

From: Gene Stone <[redacted]
Reply-To: Gene Stone <[redacted]
Date: Sunday, September 21, 2014 at 10:13 AM
To: "David G. Victor" <[redacted] Donna Gilmore <[redacted] Ted Quinn <[redacted] Bill Parker <[redacted]
Cc: Marvin Resnikoff <[redacted] Tom Palmisano <[redacted] Chris Thompson <[redacted] Dan Stetson [redacted] Tim Brown [redacted] ' [redacted] < [redacted]
Subject: Re: MEMO ON DRY FUEL STORAGE

David,

I guess clarity is important from the beginning. Because my understanding the night at the CEP meeting you asked Donna,Ted, William and I to **write a report with you** it meant just that, **write a report together.** That is not what has happened. You have written a report while we were waiting for some guidance from you how we should all begin. Now in my mind that meant that we would get together and have meetings to share information for all to read and then each of us talk about our conclusions and come up with our report. **That is not what happened**. Part of what you have done in the Victor report is to find someone in the industry to counter most of what Donna and I have said. That is a easy tactic to use on either side of any issue. Commenting on the **Victor report** is far different than writing a report together in collaboration with three other people in my mind therefore you will find attached my rebuttal. Please remember when read my remarks that I mean no disrespect at all, it's just that I have seen information used in this way to promote the pro nuclear industry propaganda to the masses from the beginning and it sadden me deeply to see it your report. This is why I can't sign on to the Victor report but can only give you a rebuttal.

Sincerely,

Gene Stone
[redacted]

"The secret of change is to focus all of your energy not on fighting the old, but on building the new." Socrates

On Sunday, September 21, 2014 6:11 AM, David G. Victor <[redacted] wrote:

Dear Donna

thanks for your notes and the updates on your version of the issues paper. I am a bit puzzled as to what I do next, however. The plan, as I understood it, was that we would agree on the core questions, I would draft, and then folks would then comment on that draft‹identifying errors in fact and analysis, disagreements over analysis and tone, etc. In the end, probably we wouldn¹t agree on everything‹and from your paper clearly we don¹t‹but at least we would have a solid, core agreed base of facts as possible. That¹s what I thought we were doing, and I thought we were doing that with the respect of working inside this small agreement and getting to the point where we understood agreements and differences. And then, once we had done that, we would publish our results along with any disagreements. Maybe I am too much of a wonk, but all I am trying to do is get us focused on what¹s known and not known; and the only way that can be done practically is to write it down and subject it to intensively peer review. That¹s what we were doing, I thought. I am not trying to keep anything away from the public‹quite the opposite. But what I am trying to do is help people understand, in plain English, a bunch of complex things and help them understand where people agree and where they disagree and why.

So that is what I thought we were doing, but given your posting maybe we are doing something different here?

So how do you want me to handle your 15 page single spaced document that you have just circulated? Are there specific places where you think the facts are incorrect, or are you satisfied with the reviews that others‹Dave L and Frank vH‹have given?

Just as an illustration, your memo points to ³cracks within 30 years² and cites to a paper by Westinghouse (which concerns cracks in operational piping‹my memo explains why that is almost certainly not relevant) and a presentation by Darrel Dunn that summarizes some idealized crack research. (Your reference numbers 26 and 27). Does your 30 year number come from slides 9 and 10 of that presentation? If so, I have spent a lot of time reading the original literature in this area and found that the cracking dates on those slides are not relevant for spent fuel storage. These dates are a combination of so-called U-bend studies on SCC under ideal conditions (low temperature, high humidity, high salt) that can¹t be applied directly to the analysis for spent fuel casks‹especially because temperatures on the casks are much higher. The NRC, itself, has explicitly NOT used the 30 year number as a hazard point for stainless casks. Instead, what they are doing with these presentations is triangulating around the issue by showing a variety of worst case studies while explicitly NOT connecting the circumstances that lead to such outcomes to real world conditions on the surface of casks in the presence of chloride. Moreover, chloride deposition itself (e.g., as you cite has been observed at Diablo Canyon) is not the triggering factor‹it is a combination of factors, of which low temperature is particularly critical. I am not a chemist, but I have now read that literature and talked with many in the field and that conclusion comes squarely out of those discussions. In my memo I offered an assessment of that literature and also, therefore, pointed us all to the EPRI hazard analysis which takes into account the multiplicity of factors that lead to SCC along with real world conditions when assessing the hazard. (And per the comments from Frank and Dave L, I will put more emphasis on the areas where the EPRI study did not yet do analysis‹such as materials defects at manufacturing.) That study points to radically different conclusions about much lower risks of SCC than suggested in your paper and also tells us that ³defense in depth² requires regulators and operators look at the whole range of conditions actually present around the casks and also do regular inspections. I have learned that NRC is evolving that direction (and I will add more detail on that in the revision of my memo). I have also come to the conclusion, exactly as you have that it is essential that there be a long-term game plan for aging management. And my evaluation of that plan, similar to yours, is that part it must include proving up the technologies that will be needed for surface repairs, onsite removal and replacement of casks, etc. That hasn¹t been done but it could be; we should recommend, as I do and as you do, that the industry develop those technologies and best practices.

The above is just an illustration‹a place where your 15 page paper seems to come to different conclusions than the memo I drafted on behalf of our group. My sense is that there are many others. For example, I sense that your comment on page 6 concerning transport canisters. Is that an area where you believe that my memo is in error‹in suggesting transport casks along with a variety of interim strategies in case a cask were found to be cracking?

So is it your view that my read of that literature is incorrect? Or is your view that with the adjustments noted above (per Dave and Frank) that my assessment of the literature IS correct? And if there are errors, specifically where are they?

Sorry to press you on this, but that is what we agreed we would do. And we agreed we would do it with drafts that are NOT part of the public domain so that we can get the facts right as much as possible and then identify areas where we disagree. Instead, I have learned that yesterday you posted your document on your website as a new report. Everyone should do what they want to do, but if our goal here is to really zero in with the benefit of many different perspectives and expertise on the facts then making documents public domain along the way before we have all had a chance to assess, debate and discuss is exactly the opposite of what I thought we were trying to do.

So if there are specific areas where you think the memo is wrong in fact, analysis, omission and such please do let me know. It is clear to me that you and I will disagree on the overall recommendation (concerning cask choice strategy) and that¹s fine. Disagreement is important for debate. But what I need to do right now is something different‹which is to find exactly where in the analysis the disagreements arise so that we can all help the public that wants to be informed become as informed as possible. And so we can help them understand what¹s known and what¹s not known and

where we might do better, collectively, in managing these fuels as they
age.

all best

David

On 9/20/14, 3:21 PM, "Donna Gilmore" <[redacted] wrote:

>Here is a link to an updated version of the San Onofre Dry Cask Storage
>Issues paper. I've revised the first page for clarity and reformatted
>
>[redacted]
>
>Thanks,
>Donna
>
>---- Donna Gilmore <[redacted] wrote:
>> David,
>>
>> After we discussed your paper, I promised to send you references for
>>where I thought your facts differed from mine. Attached is a fully
>>referenced document I prepared on the San Onofre dry storage issues.
>>Thanks for sharing Lochbaum's and Frank's comments. I agree with most
>>of their comments. I don't agree with Lochbaum's conclusion that the
>>currently licensed casks are our best choice for San Onofre. I'm hoping
>>once David read's my paper, he will agree.
>>
>> I listened to yesterday's NRC Commissioner's webcast on waste storage
>>and transportation. Dr. Macfarlane asked great questions that are
>>applicable to what we are facing at San Onofre. Mark Lombard, NRC
>>Director of SFST Division, provided answers to her questions. I've
>>included some of those in this paper.
>>
>> I agree with Lochbaum it's important to remove the fuel from the pools.
>>However, living a few miles from this plant and learning about the
>>potential short-term problems with these canisters, I believe there is
>>time to select safer canisters. I was shocked to learn from the NRC that
>>the steel/concrete canisters cannot even be adequately inspected on the
>>outside and none have been. I've read some of Gordon's papers where he
>>said the Castor type casks are better, but if the steel/concrete ones
>>can be shown to last 100 years, that they would be good enough. He also
>>recommended the Castor casks for Diablo Canyon before they had selected
>>the Holtec.
>>
>> When Tom Palmisano said he though the process would take 3 to 5 years
>>to receive approval from the NRC, I called Mark Lombard. He personally
>>told me the 18 to 30 month time frame was more than adequate. With 30

>>month being the worse case. This assumes of course that the vendor can
>>respond to all NRC concerns. And he said they've never denied a license
>>application. Local citizens are willing to wait. The fuel needs to
>>cool in the pools anyway, so we're not talking about a significant delay
>>here.
>>
>> Thanks,
>>
>> Donna Gilmore
>> [redacted]ety.org
>> [redacted]
>>
>> ---- "David G. Victor" <[redacted] wrote:
>> > Dear Colleagues
>> >
>> > Over the next 10 days or so I will revise my memo. If you have any
>>further comments on the piece please do let me know.
>> >
>> > Meanwhile, below please find comments from Frank von Hippel
>>(Princeton) and Dave Lochbaum (UCS). Both have provided us with
>>exceptionally helpful reviews (most of Dave¹s comments are embedded in
>>the pdf file, which I attach). They also point to new citations and
>>information about aging research.
>> >
>> > I am enormously grateful to both and have thanked them on our behalf.
>> >
>> > It is clear that it will be very helpful to have a vendor event with
>>Holtec and Areva and I very much look forward to that.
>> >
>> > all best
>> >
>> > David
>> >

Final Draft 1; **Rebuttal for David Victor's report to SCE/CEP on Dry Cask technology**

In my opinion, it must be stated clearly that building any type of Nuclear Waste facility cannot be built on "just faith and hope." It must be built with the best technology and several layers of "defense in depth" to prevent any accident that would put in jeopardy California's children and our future, NO MATTER THE COST. We must have in our plan to Decommission San Onofre a method to:

1. Find a way to inspect canisters in a meaningful way, including radiation, heat and helium monitoring systems.
2. Repair cracks in canisters.
3. Hotbox or pool to deal with any troubled casks on site.
4. SCE should provide to the CPUC and SCE/CEP a cost estimate analysis on dry casks.
5. SCE must have a real plan in place using "Defense in Depth" tactics to store nuclear waste in our community.
6. How will SCE deal with damaged fuel in the dry cask system they choose?
7. SCE needs to show how the NRC regulations will be satisfied.

These 7 items must be in our plan from the beginning, not something to be worked for in 10 or 20 yrs in the future now that the DOE and the NRC are just beginning to understand how far the nuclear industry is lagging behind and is not prepared for the care and management of aging spent fuel in dry cask. It must start here and now with the Decommissioning of San Onofre.

What was not addressed is what are the NRC regulations on dry cask storage and will the SCE's plan meet that criteria? If so, with minimum standards or best practice going above minimum code requirements? What are these regulations? Here is the link from the NRC **http://www.nrc.gov/reading-rm/doc-collections/isg/isg-22.pdf** **(from NRC doc line 18 to 57).** Link to full document**: http://www.nrc.gov/reading-rm/doc-collections/cfr/part072/**

Regulatory Basis:

1. The regulations for storage in 10 CFR Part 72, and those for transportation in 10 CFR Part 71, have the following common safety objectives: (1) ensure that the radiation doses do not exceed the limits prescribed in the regulations, (2) maintain subcriticality, and (3) ensure there is adequate confinement or containment of the spent fuel. Additionally,

2. 10 CFR Part regulations require that the spent fuel be readily retrievable from the storage systems. In particular, the following regulations are applicable to this ISG:

3. 10 CFR 72.120(d) states in part – "no significant chemical, galvanic or other reactions between or among the storage system components, spent fuel...The behavior of materials under irradiation and thermal conditions must be taken into account."

4. 10 CFR 72.122(h)(1) states in part – "The spent fuel cladding must be protected during storage against degradation that leads to gross ruptures in the fuel or the fuel must be otherwise confined such that the degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage."

5. 10 CFR 72.122(l) states in part – "Retrievability…allow ready retrieval of spent nuclear fuel... for further processing or disposal."

6. 10 CFR 72.236(m) states in part – "To the extent practicable...consideration should be given to compatibility with removal of the stored spent fuel from reactor sites, transportation, and ultimate disposal by the DOE."

7. The requirements of 10 CFR 72.122 (h)(1) ensure safe fuel storage and handling and minimize post-operational safety problems with respect to the removal of the fuel from storage. As required by this regulation, the spent fuel cladding must be protected during storage against degradation that leads to gross rupture of the fuel and must be otherwise confined such that degradation of the fuel during storage will not pose operational problems with respect to its removal from storage. Additionally, 10 CFR 72.122(l) and 72.236(m) require that the storage system be designed to allow ready retrieval of the spent fuel from the storage system for further transportation, processing or disposal. Draft ISG-2 2

8. 10 CFR 71.33(b) states that applications for NRC approval must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package; including, with respect to the contents of the package -the chemical and physical form of the contents. Thus, any significant oxidation of the UO2 55 fuel pellets to U3O8 would change the chemical form from that which was approved in the certificate of compliance.

The question that has to be asked is: How will the SCE plan and any cask manufacturer that is chosen meet and answer to the 8 NRC Regulations listed above? The Victor report is ambiguous on these points at best.

David Victor's report on dry cask technology paints a rosy if not "glowing" review for our future. The trouble is it takes the same position that the Atomic Energy Commission and DOE, the NRC and the Nuclear Industry have taken from the beginning. And that is to approve anything to keep the nuclear industry going, hope for the best and then say they will have it figured out sometime before there's a problem. This report chimes right along with that same tune, Zippity do Dah, it is a wonderful day for Nuclear Waste storage at San Onofre! Without any supporting documents or proof, the public is once again asked to take it on "faith and hope." Hope there will be no accident, have faith they will solve the massive problems facing SoCal while we store Nuclear Waste on our coastline in the middle of 8.4 million people before we have an accident.

I would remind us all that the DOE's top two flagship state of the art nuclear waste storage facilities, Hanford in WA state (leaking for 30 yrs now), and WIPP in NW (has leaked twice in the last few months) both are still leaking at this time.
To be clear, these sites store many types of nuclear waste and may include military grade waste. However the fact remains that this is our history of how the government through the DOE has appallingly handled Nuclear Waste, past and present. It has been said over and over again by DOE, NRC, SCE and at each of the sites listed "DON'T WORRY SAFETY IS OUR FIRST CONCERN", and of course we believe it. Because we have no other choice, but the reality with each step in the nuclear process has proven to us over and over again to be far different!

Here are links to just a few articles on Hanford:http://www.huffingtonpost.com/news/hanford-nuclear-reservation/ *With titles like "The Mess Gets Worse at Hanford's Nuclear Site" or "Whistle-Blower Who Raised Safety Concerns At Nuclear Reservation Fired"*

Link to WIPP Nuclear accident Carlsbad NW:

http://enenews.com/concern-for-full-plutonium-flash-at-wipp-nuclear-site-that-affects-other-drums-and-triggers-spreading-disaster-plutonium-239-is-a-main-radioactive-material-in-drum-that-exploded-

Concern over "full plutonium flash" at WIPP nuclear site triggering disaster that spreads to multiple waste drums — Plutonium-239 is main radioactive isotope in container that exploded — Anonymous Employee: The warnings were ignored… "They put us in danger"

There are numerous other examples of rad waste disposal gone wrong. All 3 former and now closed rad landfills have leaked: West Valley (NY), Maxey Flats (Ky) and Sheffield (IL). Landfills in Barnwell (SC) and Hanford (WA) are still operating for specific States. Will San Onofre be added to this list sooner later?

The NRC's record speaks for itself. **It has more guidelines and recommendations than regulations and strict enforcement procedures.** NRC's has an extremely poor enforcement record. We only have to look at many examples in the nuclear industry where companies have taken years to comply if at all to NRC requests. The DOE's record is much worse from anyone's point of view, to the point that many of us call it criminally negligent. California's economy, it's people and children, it's very future calls for nothing less than the very best **"State of the Art Decommissioning"** that we were promised by Southern California Edison at the first Community Engagement Panel meeting.

At this juncture on the roadmap to decommissioning San Onofre, the road signs are not pointing to "state of the art", but seem to be headed to **"designation business as usual."**

Gene Stone
Residents Organized For a Safe Environment (ROSE), SCE/CEP Member

<u>Attached below is a Memo from Marvin Resinkoff</u> with calculations to show us the levels of radiation we are dealing with. It also emphasizes the need for the proper mitigation tools to be on hand if we ever have a problem with any of the dry cask storage systems we may choose for the safety of everyone.

Memo

Radioactive Waste Management Associates

To: D Gilmore, G Stone

From: M Resnikoff

Date: October 8, 2014

Re: Rad Dose 20 yrs

I used Microshield to calculate the gamma dose due to Cs-137 from a canister and without a canister after 20 years cooling of high burnup fuel, 55 MWD/MTU. Twenty years of cooling could be 10 years in the fuel pool, and 10 years in a dry storage cask. Since some high burnup fuel (HBF) has higher burnup, and since other gamma emitters are also present, **this calculation is an underestimate.** The purpose of this calculation without a canister is to simulate a canister that has cracked; bare fuel assemblies are obviously an upper bound.

I made the following assumptions, all of which are estimates, just to get an order of magnitude result. I assumed the canister has a 2.5 foot diameter, is 12 feet long, and contains 10 metric tons of HBF, i.e. 24 PWR assemblies. Uranium is assumed to have specific gravity of 11 g/cc, and steel 8 g/cc. The canister has a thickness 5/8 inch. The dose point is at the center of the canister, 6 feet from the ends and 3 inches from the surface of the canister.

The results are the following. The total effective gamma dose from an intact canister is 480,000 rems/hr, and 2 million rems/hr from bare fuel assemblies, i.e., about 4 times greater. To translate, the dose from an intact canister is 133 rems/sec; an LD50 dose (which would be lethal to 50% of exposed persons) would be received in 3 seconds from an intact canister, and less than 1 second from bare HBF assemblies.

The standard gamma detector from Ludlum pegs out at 1000 rems/hr, far below the rad field from an intact canister. I haven't looked into all gamma detector instruments on the market. But clearly, a standard gamma detector could not distinguish between a cracked or intact canister.

Marvin

Subject: for review PDF "Manuel Camargo to David Victor, 5 Sept 5:18pm, plus attachment 'SCE Position Papers on ISFSI location, Tsunami Hazards and other factors'"
Date: Wednesday, October 8, 2014 at 7:19:39 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

From: '[redacted] <[redacted]
Date: Friday, September 5, 2014 at 5:18 PM
To: "David G. Victor" <[redacted]
Subject: Re: Two minor comments on your draft

Dav d,

Go ng through the transcr pts for our var ous meet ngs, I cannot find a d rect d scuss on of tsunam r sk at San Onofre. What I do have n my records s a note I d str buted on your beha f on 7/10 (pasted be ow) as a fo ow-up to the 5/22 Regu ar Meet ng of the CEP. One of the attachments to that notes was an SCE pos t on paper on the tsunam hazard ana ys s for San Onofre.

ope th s he ps.

Manue

From Manuel Camargo/SCE/E X
To [redacted] "Ea on Marisol" < [redacted] "Strachan Ruth" < [redacted]
Cc [redacted] < [redacted] Steven Carlson < [redacted] Vie ran/SCE/E X Chris opher Abel/SCE/E X Larry Labrado/SCE/E X [redacted] < [redacted] JAMES MAD GAN/SONGS/SCE/E X Julie C Hol /SONGS/SCE/E X@SCE [redacted] Veronica Gu ierrez/SCE/E X Alexander Pugh/SCE/E X@SCE "David G Victor" < [redacted]
Date 07/10/2014 02 30 PM
Subject 22 May Follow up (From Chairman Victor)

FOR INTERNAL USE ONLY

Sent on beha f of Cha rman Dav d V ctor

Dear Co eagues,

At the ast meet ng of the CEP on 22nd may we rev ewed Ed son's Irrad ated Fue Management P an (IFMP). We have comp ed the major po nts ra sed at that meet ng as we as po nts that CEP members made n comments on the IFMP n the weeks after our 22nd May meet ng. Attached p ease find four documents that respond to those comments and quest ons:

1. SCE's fina IFMP subm tta
2. Q&A address ng IFMP comments and ssues ra sed 22 May
3. Wh te papers w th deta ed content on arger ssues put forth by the CEP
4. Areva paper on BF

P ease note that the IFMP tse f has not changed much from the draft we rev ewed—that s because the IFMP, by des gn, s a genera document. What matters more are tems 2, 3 and 4. I note that tem 4 was rece ved n response to a ser es of quest ons that CEP members put to Areva about cann ng, fue assemb es and re ated ssues.

I note that there was an exchange of ema s on 30 June and 2 Ju y regard ng the process that NRC w   fo ow to approve Areva's new cask; that process, n turn, cou d have some effect on the process for mov ng fue   nto casks. We w   get a br ef update on those ssues at our workshop next week.

Over the ast few weeks I have rece ved three etters re ated to the work of the CEP, a   of wh ch I attach:

5. Ray Lutz correspondence
6. Kent Co e/NAC etter
7. Dan Dom nguez/ abor etter

F na y, I w   test fy at the Nuc ear Regu atory Comm ss on next week and w   so c t c ar ficat on from NRC on some ssues mportant for the SONGS decomm ss on ng process. Attached s my test mony:

8. V ctor test mony at NRC on 15 Ju y.

As has become our pract ce, mater a s w   be posted to the songscommun ty webs te for pub c consumpt on.

A   best w shes,

Dav d V ctor
Cha rman, CEP

IFMP ==>
Responses to comments/quest ons ==>
SCE pos t on papers ==>
Areva paper ==>
Lutz/CDSO documents ==>
Co e/NAC etter ==>
Dom nguez/ abor etter ==>
NRC remarks ==>

Manuel C. Camargo Jr.
Pr nc pa Manager, Decomm ss on ng
San Onofre Nuc ear Generat ng Stat on
O[redacted] M[redacted]
[redacted]

SOUTHERN CALIFORNIA EDISON
www.SONGScommun ty.com

From "David G Victor" <[redacted]
To William Parker <[redacted]
Cc [redacted] <[redacted]
Date 09/03/2014 06 28 AM
Subject Re Two minor comments on your draft

Bill

Thanks for your note. I will make both of those changes (and thanks for pointing Gene to the relevant EPRI footnote).

By copy I ask Manuel to find, in the next week if possible, the location in the cep meeting transcript (may meeting I think) where we discuss tsunami issues. I will cite that for Tsunami and you for seismic

All best

D

**Sent from limited typing device

> On Sep 2, 2014, at 6:34 PM, "William Parker" <[redacted] wrote:
>
> David,
>
> I continue to review your comprehensive review of issues generated by the choice of casks for the storage of the spend fuel at SONGS. There is much to digest in your review.
>
> But first a couple of minor comments.
>
> 1) The partial footnote #2 on page 4 should be deleted since the full footnote appears on page 6.
>
> 2) I suggest footnote #18 be limited to seismic risks, I did not address the risks of tsunami.
>
> Bill

SCE Position Paper

Independent Spent Fuel Storage Installation (ISFSI) Location

I. Summary

A variety of locations were considered and evaluated for the permanent dry fuel storage location of the spent fuel assemblies at San Onofre. The fuel assemblies will remain at this location until collected by the Department of Energy (DOE). SCE's current plan is to expand the current location of the ISFSI because it offers the highest level of certainty for safely moving the spent fuel from wet to dry storage as expeditiously as possible as well as the lowest cost for customers.

II. Scope

The purpose of this paper is to provide the background and basis for SCE's decision for the location of the ISFSI at San Onofre.

A detailed evaluation of options for the final ISFSI pad site included analysis of three categories of locations. The sites were identified without regard for the current licensing status (i.e., these locations may or may not have the NRC license to store nuclear fuel). The three categories of locations were as follows: (1) within the San Onofre Easement, (2) the surrounding area of Camp Pendleton including the San Onofre Mesa location, and (3) offsite areas. Currently only the San Onofre Easement is permitted under the 10 CFR Part 50 license to store spent fuel, while neither the surrounding area of Camp Pendleton nor the offsite areas are licensed for spent fuel storage.

Factors considered in the evaluation were:

1. Siting requirements
2. State permits, geological analysis
3. Ability to transport spent fuel to these locations
4. NRC regulatory license requirements
5. Length of time the spent fuel would be in wet storage before it could be transferred to dry storage at the ISFSI pad

III. Analysis

A summary table of the evaluation compares the main factors for determining the ISFSI pad location.

Table 1. SCE ISFSI Pad Location Evaluation

A. Location	B. Currently maintains a license to store nuclear fuel (10 CFR Part 50 or Part 72)	C. Requires Siting, Permitting, Licensing and Geological studies	D. Duration of wet storage*	E. Confidence of stakeholder approvals (i.e., Regulatory, City, State, Public)	F. Direct Cost
Within San Onofre Easement	Yes	Minimal for existing, Yes for other sites	5-12 years	High	\$400M + \$50-\$300M
Camp Pendleton Area including SCE Mesa area	No	Yes	24-33 years	Low	>\$400M + \$1 -\$2.9B for extended wet storage
Offsite areas	No	Yes	40+ years	Very Low	>\$400M + \$1.8-\$3.6B for extended wet storage

*Years from 2014

In considering the various locations for spent fuel storage, SCE assumed that selecting a location would entail four phases – agreement of site selection, site permitting and licensing, site construction and offloading the spent fuel pools and transporting the spent fuel to that site. For site selection, each potential location was evaluated for its technical feasibility to design and construct a licensed dry fuel storage system. The locations were then evaluated based on the ability to get consent to site an ISFSI, such as with state and local permitting, NRC licensing process, including Environmental Impact and the ability to transport spent fuel to the location. Activities highlighted in column C add uncertainty to options that are beyond the 10 CFR Part 50 licensed area.

Three specific San Onofre locations within the currently licensed area were considered: (1) the current location, (2) the South Bluff area and (3) the Reservoir. The benefits of these easement locations are that they are in the 10 CFR Part 50 licensed area, and can support a timely transportation of the spent fuel from the wet storage in pools to dry storage on the pad within 5-12 years. Among the options within the San Onofre Easement, the timing and success for the geological soil preparations, state and local permitting of the South Bluff and Reservoir areas bring uncertainty into the decommissioning project.

For the Camp Pendleton, including the Mesa dry storage site area option, SCE roughly estimates that it would take approximately 24-33 years. For example, for planning purposes, SCE estimates the consent-based process for site selection would be likely take 3-5 years, 10 years for site permitting and licensing, 5-10 years for site construction and 6-8 years to transfer fuel spent fuel to that site. For offsite areas, the rough order of magnitude estimate is 40 years or more – with 10 years for consent-based process for site selection, 10 years for site permitting and licensing, 5-10 years for site construction and 10 years to transfer fuel spent fuel to that site.

Column E of the table reflects these uncertainties and the level of confidence for approval of options. Another consideration was the ability to quickly move the spent fuel from wet to dry storage - a high priority for SCE, the San Onofre Community Engagement Panel, and the general public. As seen from Table 1 above, the locations within the San Onofre Easement provide the most practical options.

SCE concludes that the existing location best meets criteria of the most predictable licensing and permitting outcome, providing the quickest offload from wet to dry storage and most prudent cost to customers.

IV. Conclusion

SCE's analysis of the range of options concludes the existing ISFSI site as the best location for the expansion of the pad. The current location provides the highest level of certainty for safely moving the spent fuel from wet to dry storage as expeditiously as possible combined with the lowest cost.

SCE Position Paper
High Burnup Fuel Storage and Transportation

I. Summary

San Onofre Nuclear Generating Station has 1,115 high burnup fuel (HBF) assemblies, all of which are undamaged, currently stored in spent fuel pools. There has been some discussion on the purpose and requirements for “canning” undamaged, high burnup, spent fuel assemblies. SCE’s position is when these HBF assemblies are moved to dry storage, they do not need to be placed in “damaged fuel “cans. The NRC has determined “there is no safety basis to require canning of all high burnup fuel.”

SCE has concluded that canning undamaged HBF does not provide additional safety benefits, has no technical advantages, no regulatory requirements, and is unnecessary.

II. Scope

The purpose of this paper is to provide the background and basis for SCE’s decision related to canning undamaged HBF assemblies at the San Onofre Nuclear Generation Station (SONGS).

III. Analysis

Background

During the Community Engagement Panel (CEP) workshop on spent fuel, there was discussion on the storage of HBF assemblies and the CEP requested SCE to clarify its position on canning HBF.

SCE’s rationale for not canning its undamaged HBF assemblies is threefold:

- Canning does not provide an additional safety benefit
- There are technical drawbacks in canning undamaged fuel, such as diminished heat transfer capability, increased structural loading, complexity in fuel handling, and increased radiation exposure to workers
- It is not a regulatory requirement to can undamaged fuel

In the past, regulatory uncertainty led two sites to "can" their undamaged HBF for dry storage and transportation. Since that time, the NRC has clarified there is no safety basis for canning undamaged HBF, and they should be stored in accordance with the same regulatory requirements as other fuel types.

Regulatory Requirements

The governing NRC requirements for spent nuclear fuel are contained in 10 CFR Part 72 for storage and 10 CFR Part 71 for transportation. To meet these requirements the NRC provided additional definitions and guidance in Nuclear Regulations (NUREG) with definitions of when spent fuel assemblies are required to be canned.

NUREG-1536 defines:

> “C. Canning Damaged Fuel
> Spent fuel that has been classified as damaged for storage must be placed in a can designed for damaged fuel, or in an acceptable alternative. The purpose of a can designed for damaged fuel is to (1) confine gross fuel particles, debris, or damaged assemblies to a known volume within the cask; (2) to demonstrate that compliance with the criticality, shielding, thermal, and

structural requirements are met; and (3) permit normal handling and retrieval from the cask….."

The purpose of canning is to confine damaged fuel to a known volume during storage and to facilitate future handling and ready retrieval of content, not just because it is a HBF assembly.

Contrary to some public opinions that canning would add additional protection, the dry cask storage industry experts have stated unnecessary canning of HBF has technical drawbacks, such as diminished heat transfer capability, and increased structural loading. Furthermore, the cans are actually not fully sealed; there are small holes at the top and bottom to allow water in the containers to be removed during drying operations. Canning also adds additional complexity and time to the cask loading evolution, resulting in workers receiving unnecessary radiation exposure.

To confirm safe storage of HBF for an extended period, the US Department of Energy sponsored a full-scale study by Electric Power Research Institute (EPRI) in 2013. The study will monitor conditions, long-term characteristics and behaviors of HBF assemblies in dry storage for the next 10 years. This study is similar to the mid-1980s demonstration at Idaho National Laboratory, where dry storage of low burnup fuel was studied and no degradation was found.

Undamaged HBF is currently being loaded into dry storage at multiple U.S. nuclear sites without being canned. Maine Yankee and Zion remain the only two plants to can their undamaged HBF. In the past, Maine Yankee and Zion placed their undamaged HBF in failed fuel cans due to regulatory uncertainty about requirements to transport HBF. With an approved license to transport HBF, there is no such uncertainty for SCE's HBF.

IV. Conclusion

There are no technical advantages and no regulatory requirements for canning HBF, however there are consequences in more fuel handling operations needed for canning and radiation exposure to workers. SCE's conclusion is that canning undamaged HBF is not necessary, and does not provide additional safety benefits.

SCE Position Paper
Tsunami Hazard Analysis & Protection

I. Summary
The effects of potential tsunamis at San Onofre are bounded by the design capability of the dry storage cask system and seawall protection for the Units 2&3 site (including the Spent Fuel Pools). The site is protected by two seawalls. The dry storage cask system seawall is constructed of continuous steel "sheetpile" members and the seawall for Units 2&3 spent fuel pools are constructed of reinforced concrete. Both seawalls are higher than the maximum water level postulated for a potential tsunami at San Onfore. In addition, the dry cask storage system (canisters and modules), are designed for total submersion during an extreme design basis flood event, postulated to result from natural phenomena such as tsunami. Engineering analyses demonstrate acceptable performance of the storage system for tsunami flood effects.

II. Scope
The purpose of this position paper is to explain how spent nuclear fuel stored at the San Onofre site (at the Independent Spent Fuel Storage Installation and Units 2&3 Spent Fuel Pools) is protected against a potential tsunami hazard. The paper summarizes the results of the site-specific tsunami analyses that have been performed, and how protection is assured for the ISFSI and the Spent Fuel Pools.

III. Analysis
Federal regulations require that spent fuel storage installations as well as nuclear structures, and systems are designed to withstand the effects of natural phenomena such as . . . tsunami [Code of Federal Regulations, Title 10, Part 72 (Sections 92 and 122), and Part 50, Appendix A (Criterion 2)].

<u>Tsunami Characteristics</u>

- A tsunami is generated by rapid large-scale dislocations of the surface or bottom of the sea, or of some equivalent impulse. This large wave action is generally caused by an earthquake.
- Because of its broad shelf topography offshore, the Southern California coast is not sensitive to tsunami waves generated by distant sources on the Pacific Rim, unlike other locations in the world. Because of the moderating effect of Southern California's offshore borderland, the maximum analyzed tsunami wave will be generated by a local offshore fault zone.
- An analysis of the local offshore fault zone, referenced in the Updated Final Analysis Report , results in a maximum tsunami water height for San Onofre site of not greater than 27 feet (for reference, sea level is elevation = 0 feet).

<u>Protection of the Units 2&3 Spent Fuel Pools</u>

- Tsunami protection for the Unit 2&3 site is provided by a reinforced concrete seawall and intake screen well perimeter wall constructed to elevation 30 feet above sea level. The San Onofre Units 2&3 plant grade is also 30 feet above sea level.

- The SONGS 2&3 seawall, intake perimeter wall, and plant grade elevation are above the maximum analyzed tsunami water level and there is no impact to the Units 2&3 Spent Fuel Pools.
- Even if a tsunami would disrupt spent fuel cooling, there is over 99 hours for the station to respond and return cooling to the pool with portable equipment.

<u>Protection of the Independent Spent Fuel Storage Installation (ISFSI)</u>

- Although the Unit 1 site was cleared of most structures for construction of the ISFSI, the 28 foot high seawall remains. It is constructed of continuous steel "sheetpile" members driven into the sandstone bedrock and covered in gunnite (a concrete protective coating).
- Both the dry shielded canister (DSC), which provides confinement of the spent nuclear fuel, and the Advanced Horizontal Storage Modules (AHSMs) are designed for an enveloping design basis flood, postulated to result from natural phenomena such as tsunami. To evaluate design capability from an extreme flood event, a water depth of 50 feet (measured from the bottom of the concrete modules) having a water velocity of 15 feet per second was used.
- The storage modules are located on a reinforced concrete foundation, at elevation 19.75 feet above sea level. As a result, San Onofre's dry cask storage system flooding design capability is 69.75 feet. As determined by computer structural analysis, the strength of the storage cask system exceeds the forces generated during a tsunami flood event. The forces generated for overturning and sliding during a flood (tsunami) event are bounded by seismic design criteria, so the modules will be stable.
- Submersion of the modules does not adversely affect the thermal analysis for the self-cooling dry storage cask system. The dry cask system needs no electric power for cooling since it is a totally passive system. Any blockage would be identified during post-tsunami inspections. The reinforced concrete storage modules are designed to safely withstand tornado-generated missiles traveling at high velocity, including wooden telephone poles, steel pipes, and large deformable objects (e.g., automobiles) traveling at least 185 feet per second (over 100 miles per hour). Any debris moving with the tsunami wave would have a velocity much less than the tornado missiles for which the modules have been analyzed.

IV. Conclusion

The Units 2&3 site is protected from tsunami by a reinforced concrete seawall which is higher than the maximum water level determined for a tsunami at San Onfore. In addition, the SFP structure itself provides significant protection against external flooding, and the San Onofre has over 99 hours to respond to a sustained loss of SFP cooling with portable equipment.

The continuous steel seawall located between the Pacific Ocean and the ISFSI provides protection against inundation of the ISFSI site from ocean hazards. The design capability of the ISFSI is much greater than the potential effects of tsunami at the San Onofre site. The design of the DSC and AHSM exceeds the maximum analyzed tsunami water level, with significant design margin. Engineering analyses demonstrate acceptable performance of the storage system for tsunami flood effects, including structural capacity, stability, thermal effects during submersion, and missile protection.

Subject: for review pdf: "Al Csontos to David Victor, 19 Sept, 8:35pm, with two attachments"
Date: Wednesday, October 8, 2014 at 7:19:24 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

On 9/19/14, 8:35 PM, "Csontos, Aladar" <[redacted] wrote:

> David,
>
> My apologies for the delay in providing the info from the August 5th public meeting on the CISCC RIRP program.
>
> The summary of the meeting with the various public Q&A's as well as Darrell's presentation are attached.
>
> Al
>
> ____
> From: David G. Victor [redacted]
> Sent: Friday, September 19, 2014 8:38 PM
> To: Lombard, Mark; Csontos, Aladar
> Cc: Dunn, Darrell; Ted Quinn [redacted]
> Subject: Re: follow up on new NRC procedures for cask management
>
> Mark
>
> that is terrific‹thanks so much.
>
> Unrelated to all this, below is an email that I got today from Donna with her comments on the paper‹more, actually, a huge attachment with her own take on the issues. That is fine. But her letter includes a quote to you for the time needed for Castor to get a license. You may or may not want to comment on this, but if you do could you let me know fully what you said.
>
> all best
>
> David
>
> ----------
>
> David,
>
> After we discussed your paper, I promised to send you references for where I thought your facts differed from mine. Attached is a fully referenced document I prepared on the San Onofre dry storage issues. Thanks for sharing Lochbaum's and Frank's comments. I agree with most of their comments. I don't agree with Lochbaum's conclusion that the currently licensed casks are our best choice for San Onofre. I'm hoping once David read's my paper, he will agree.

I listened to yesterday's NRC Commissioner's webcast on waste storage and transportation. Dr. Macfarlane asked great questions that are applicable to what we are facing at San Onofre. Mark Lombard, NRC Director of SFST Division, provided answers to her questions. I've included some of those in this paper.

I agree with Lochbaum it's important to remove the fuel from the pools. However, living a few miles from this plant and learning about the potential short-term problems with these canisters, I believe there is time to select safer canisters. I was shocked to learn from the NRC that the steel/concrete canisters cannot even be adequately inspected on the outside and none have been. I've read some of Gordon's papers where he said the Castor type casks are better, but if the steel/concrete ones can be shown to last 100 years, that they would be good enough. He also recommended the Castor casks for Diablo Canyon before they had selected the Holtec.

When Tom Palmisano said he though the process would take 3 to 5 years to receive approval from the NRC, I called Mark Lombard. He personally told me the 18 to 30 month time frame was more than adequate. With 30 month being the worse case. This assumes of course that the vendor can respond to all NRC concerns. And he said they've never denied a license application. Local citizens are willing to wait. The fuel needs to cool in the pools anyway, so we're not talking about a significant delay here.

Thanks,

Donna Gilmore
[redacted]

From: <Lombard>, Mark <[redacted]mailto[redacted]
Date: Friday, September 19, 2014 at 1:08 PM
To: "David G. Victor"
<[redacted]mailto[redacted] "Csontos, Aladar"
<[redacted]mailto[redacted]
Cc: "Dunn, Darrell" <[redacted]mailto[redacted]
"Ted Quinn [redacted]mailto[redacted]
<[redacted]mailto[redacted] Tom Palmisano
<[redacted]mailto[redacted]
Subject: RE: follow up on new NRC procedures for cask management

Sorry for the delay David. It has been a busy week here, yet again. I think this is the presentation you are looking for: http://pbadupws.nrc.gov/docs/ML1419/ML14192A702.pdf. It is the one that Donna Gilmore has on her website (slide 2). Please let us know if you need anything else.

Mark

From: David G. Victor [mailto[redacted]
Sent: Wednesday, September 17, 2014 8:03 PM
To: Lombard, Mark; Csontos, Aladar

Cc: Dunn, Darrell
Subject: follow up on new NRC procedures for cask management

Dear Mark and Al

thanks so much for the call last week. I am enormously grateful for your help as I try to navigate the issues related to long-term management of casks on site.

On the call you mentioned a new process, still taking shape, for periodic inspection of canisters‹a process that would go beyond the critical canister approach. You said that there was a mid July presentation by Darrel that had more details and I wonder if you could send me a copy? I would like to draw attention to this and to cite it in my memo.

thanks so much

all best

DAvid

--
David G Victor
Professor & Director, Laboratory on International Law & Regulation
School of International Relations & Pacific Studies, UC San Diego
[redacted]

September 9, 2014

MEMORANDUM TO: Anthony Hsia, Deputy Director
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

FROM: Kristina L. Banovac, Project Manager /RA/
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

SUBJECT: SUMMARY OF AUGUST 5, 2014, PUBLIC MEETING WITH THE NUCLEAR ENERGY INSTITUTE ON CHLORIDE INDUCED STRESS CORROSION CRACKING REGULATORY ISSUE RESOLUTION PROTOCOL

Background

The U.S. Nuclear Regulatory Commission (NRC) staff held a public meeting with the Nuclear Energy Institute (NEI), their members, and consultants on August 5, 2014, to discuss topics associated with the chloride induced stress corrosion cracking (CISCC) Regulatory Issue Resolution Protocol (RIRP), including aging management, flaw growth, and flaw tolerance.

The meeting was noticed on July 24, 2014 (ML14206A735). The meeting attendance list is provided in Enclosure 1.

Discussion

The meeting discussion generally followed the meeting agenda, which is included in Enclosure 2. Enclosure 3 contains the presentations given by the NRC and NEI as meeting handouts.

NEI provided an update of the schedule and remaining tasks of the RIRP resolution plan, as reflected in their February 7, 2014 letter (ML14052A015). The RIRP will be closed after agreed-upon susceptibility criteria are developed. The Electric Power Research Institute's (EPRI's) current work on flaw growth and flaw tolerance is another step towards developing the susceptibility criteria.

Industry representatives provided an overview of EPRI's Flaw Growth and Flaw Tolerance Assessment for Dry Cask Storage Canisters. EPRI mentioned that the future report on susceptibility criteria will describe different actions that may be taken and how that will impact risk, but it will not specify at what point mitigation measures are needed. The licensees' corrective action programs will need to evaluate and determine what mitigation measures are needed and when. NRC staff mentioned that it would like to see some discussion and explanation in the report on any actions that can be taken to prevent CISCC. Industry representatives presented a summary of the literature and data used to develop the crack growth rate model, details on the crack growth rate methodology, and the flaw tolerance assessment.

NRC staff mentioned that current data indicates that a crevice environment (e.g., where a canister meets the support rails in a horizontal storage system, or deposits such as a wasp nest on a side of a canister in a vertical system) may promote stress corrosion cracking, and the staff inquired how industry will consider this in its work. Industry representatives mentioned that this was not an area it was specifically planning to explore in the CISCC RIRP. However, NEI took an action to consider the addition of this work to consider crevice effects and whether it needed to be added to the scope of work or as a specific deliverable for the CISCC RIRP. NEI will also consider whether this work could be done within the current schedule for the RIRP resolution plan or whether any adjustments to the schedule are needed.

NRC staff questioned the conclusions that crack growth rate is generally not dependent on the stress intensity (K) value, given the limited data set. Industry noted that they compensated for the limited data by taking a conservative statistical approach to derive conservative values for the crack growth rate coefficients and modeling the crack growth rate.

NRC staff noted that we would like to see some discussion in the susceptibility report on prioritization of inspection/examination, based on the various stainless steel alloys that may be more susceptible to CISCC. Industry representatives mentioned that they are planning to look at this in the work on initiation of cracking, and this will be an important part of the susceptibility assessment and criteria. EPRI representatives also noted that the EPRI report: Literature Review of Environmental Conditions and Chloride-Induced Degradation Relevant to Stainless Steel Canisters in Dry Cask Storage Systems (EPRI-3002002528, May 2014) does discuss this, but they will make sure it also gets discussed in the susceptibility criteria report.

NRC staff noted that the susceptibility criteria report should also discuss the weld heat affected zone and how this impacts CISCC susceptibility. An industry representative also mentioned that the report should discuss how multiple or combined susceptibility factors (e.g., intersection of the weld heat affected zone at a crevice location, like a canister and support rail intersection) would affect overall susceptibility. EPRI noted they will address this in the susceptibility report.

There were some questions on the flaw tolerance assessment regarding the calculation of the critical flaw size for structural tolerance of the system (for consideration of what would structurally challenge the system to the point where it should not be moved), as the critical flaw sizes were very large. Industry representatives clarified that the critical flaw size was calculated only for the purposes of obtaining information on the size of the flaw that could lead to structural concerns if there was a need to move the system. There is no intent for allowing a flaw to get to this size, or any expectation that this flaw size would be used as an acceptance criterion for the point where mitigation measures would be needed. NRC staff noted that it appreciated the clarification, but acceptance criteria will need to be developed for determination of when mitigation actions are needed.

NRC staff questioned whether the assessment of helium depressurization and air ingress in the flaw tolerance assessment considered oxidation of components in the canister. Industry representatives noted that the flaw tolerance assessment did not look at this, but the Failure Modes and Effects Analysis (FMEA) of Welded Stainless Steel Canisters for Dry Cask Storage Systems (EPRI-3002000815, December 2013) does discuss oxidation of fuel cladding and the effects.

NRC staff and industry representatives agreed that a through-wall crack would not be acceptable, and industry representatives noted that they are not planning to make a risk argument for the acceptability of a through-wall crack.

NRC staff questioned whether EPRI considered the number of flaws on a canister. Industry representatives noted that they may consider this in their future probabilistic assessment to look at the surface area to crack ratio to see how many flaws could occur in a certain area on a canister. However, they found that depressurization occurs somewhat quickly (on the time scale of extended storage), so multiple cracks may not really be an issue for maintaining a helium environment inside the canister.

NRC staff questioned whether EPRI's work will include guidance on how to select a canister at a site for inspection based on various considerations, like the way fabrication was done (e.g., if there were any repairs, if there were any temporary structures welded to the canister during the fabrication, etc.). Industry representatives noted that they will consider fabrication practices and repairs.

NRC staff had some questions on the calculation of the crack growth rate parameters. Industry representatives noted there were errors on slide 22 of the EPRI presentation. Following the meeting, industry representatives provided the corrected slide, which is included in the attached EPRI presentation.

The NRC presented a summary of NRC-sponsored CISCC testing. In response to an industry question, the NRC clarified that there was cracking observed in the as-received (not sensitized) material at 0.1 g/m^2 salt concentrations in the U-bend tests (included in NUREG/CR-7170, "Assessment of Stress Corrosion Cracking Susceptibility for Austenitic Stainless Steels Exposed to Atmospheric Chloride and Non-Chloride Salts," ML14051A147). NRC staff also clarified that pits were observed on the specimen surface and the pits were surrounded by the presence of corrosion products on the U-Bend and C-ring specimen surfaces. Stress corrosion cracks were observed to originate from the pits on the specimen surface; however, the time from the observance of pitting to the initiation of the crack was not recorded.

There was a question on whether there was any planned industry work to measure atmospheric chloride concentrations at the sites listed on slide 9, which included power plant operating experience with SCC of stainless steels. Industry representatives noted that there is no planned work to do so, although the EPRI susceptibility report will discuss how to measure atmospheric chloride concentrations for sites to be able to use the susceptibility criteria. The NRC noted that if the atmospheric chloride concentration is to be used by industry to determine susceptibility, then adequate data will be needed to account for seasonal changes.

NRC staff also presented an example aging management program (AMP) for CISCC. In its presentation, NRC staff clarified that the proposed timing of inspections in the CISCC example AMP (i.e., within 25 years of initial loading) provides for a 5-year period from the end of the initial storage period for industry to develop a qualified inspection method. However, once a qualified method exists, the expectation is that the first inspection for CISCC would occur around 20 years (i.e., at the beginning of the period or extended operation). The NRC clarified that based on information obtained in lead system inspections where the composition of atmospheric deposits were characterized, NRC staff independently estimated the time necessary to accumulate a sufficient concentration of chloride containing salts on the canisters surfaces necessary to initiate stress corrosion cracking was at least 30 years. It was noted that a similar conservative estimate on the time necessary to accumulate a sufficient surface chloride concentration was provided by a licensee. NRC staff also clarified that the proposed inspection frequency of every 5 years is based on the estimated crack growth rates from reactor operating experience with CISCC of stainless steels. Based on estimated crack growth rates as a function of temperature and assuming the conditions necessary for stress corrosion cracking continue to be present, the shortest time that a crack could propagate and go through-wall was determined to be 16 years after crack initiation. A 5-year inspection frequency would result in at least 2 inspections that would provide an opportunity to find indications of degradation and allow corrective actions to be implemented to prevent localized corrosion or stress corrosion cracking penetration of the canister.

An industry representative noted that NRC's example AMP on CISCC needs to be clear in its discussion of preventative actions (AMP element 2) that this includes information on whether anything has been done in the past that may be considered a preventative action, and not future preventative actions expected from renewal applicants.

In response to industry questions on development of a qualified inspection method, NRC staff clarified that at this time, the inspection needs to be able to detect SCC. However, if cracking is found, industry needs to be prepared to size and characterize the cracking. NEI mentioned that if cracking was found, licensees would assess and determine what actions were needed through their corrective action programs. NEI's planned aging management guidance in NEI 14-03 (Operations-Based Aging Management for Dry Cask Storage) will discuss how the licensee's assessment should consider the susceptibility criteria. NRC encouraged industry to begin work on development of volumetric methods now rather than waiting until a crack is found, and noted that industry could develop topical reports in this area to obtain NRC's review.

After NRC's presentation, members of the public were given the opportunity to make comments or ask questions of the NRC staff.

One public member noted that the NRC should initiate a rulemaking to prohibit construction of new reactors in locations considered susceptible for CISCC. Also, as the quality of vendors varies, NRC should evaluate individual vendor's fabrication practices. He also noted that modeling work should not be postponed for storage periods beyond 60 years. NRC staff noted that it is focused on preventing through-wall cracks, and that industry can respond to SCC operating experience with the proposal and use of better materials. NRC staff also noted that the NRC does inspect vendors, their fabrication practices, and their quality assurance programs. NRC staff noted that one of the reasons it's shifting to an operations-focused approach to aging management is so that AMPs can be used to manage aging effects into the future (including periods beyond 60 years).

Another public member asked whether the NRC is also looking at carbides in grain boundaries, in addition to looking at atmospheric chlorides. NRC staff responded that it is looking at this and the sensitization of materials. The public member made a detrimental comment about the behavior/conduct of welders. The NRC noted that welders need to be qualified, and the NRC looks at welder and personnel training and qualifications during vendor inspections. The public member questioned whether there were other chemicals in water that could impact the dry cask storage systems, and NRC staff noted that it did look at other atmospheric deposits besides chlorides in NUREG/CR-7170.

Another public member noted that the NRC should look at radiological degradation of canisters. NRC staff mentioned that we do assess neutron exposure and the effects of the exposure on the mechanical properties of the canister materials. There have not been any potential issues identified regarding materials degradation due to radiation in the period of extended operation, but the staff does look at and continues research in this area. The commenter noted that a 2 meter crack (critical flaw size) did not take into account accidents that could happen during transportation. The NRC noted that industry's calculation of critical flaw size was not intended to be used or considered for storage or transportation licensing and certification. The commenter noted that timing of inspections and inspection frequency in the example SCC AMP was confusing, and questioned why the NRC would allow the first inspection to be conducted at 25 years, if it may only take 16 years for a crack to go through-wall. The NRC responded that the calculated time for the crack to go through-wall does not include the time for cooling to the point where deliquescence of the deposited salts could occur on the canister surface or the time for initiation of cracking. The commenter questioned the NRC's reasoning for the recommended sample size of at least one canister at each site. The NRC noted that this is consistent with the NRC's current expectations for the lead system inspection. The expectation is that the licensee would inspect the canister that is most likely to have corrosion or cracking. If any corrosion or cracking was identified, supplemental inspections would be conducted to determine the extent of condition.

Another public member noted agreement with the example SCC AMP that canisters that do not meet the prescribed evaluation criteria must be repaired or removed from service. The NRC noted that licensees have contingency plans in case of fabrication or loading issues, which include unloading procedures and a reflood analysis in case the licensee needs to remove the fuel after loading and drying a canister.

Another public member noted terrorism is a real threat. He noted that inspection of one canister at a site is not sufficient, as there may be hundreds of canisters eventually stored at an ISFSI site. The NRC repeated the earlier discussion that the licensee would be expected to select and inspect the canister that is most likely to have corrosion or cracking for this first inspection. If any corrosion or cracking was identified, supplemental inspections would be conducted to determine the extent of condition. The commenter questioned how a licensee would be able to unload a canister if it needed to be removed from service, if it decommissions its spent fuel pool. The NRC staff noted that there is a requirement in 10 CFR 72.218 for a licensee's 10 CFR 50.54(bb) spent fuel management plan to include a plan for removal of the spent fuel stored under the Part 72 general license from the reactor site. The plan must show how the spent fuel will be managed before starting to decommission systems and components needed for moving, unloading, and shipping this spent fuel.

Another public member noted that it wasn't clear when CISCC could initiate. The NRC noted that it is difficult to calculate a generic minimum time to crack initiation, as there are several site-specific factors that need to be considered in such a calculation (e.g., atmospheric chloride concentrations, atmospheric and environmental conditions, the time for the canister to cool to the point where salts can deliquesce, which depends on the specific loading of the canister and the decay heat, the amount of chlorides deposited on the canister, etc.). The commenter asked for a rough time range, and the NRC responded that a rough estimate (assuming favorable conditions for cracking per the factors above) would be 30 years to initiate a crack. The commenter repeated the earlier concern regarding decommissioning of the spent fuel pool if it is needed in the future to unload a canister that needs to be removed from service. NRC staff mentioned that there is a separate effort at the NRC to consider cask unloading capability, as this issue was raised in the Petition for Rulemaking submitted by C-10 Research and Education Foundation, Inc. (PRM-72-6). The staff is still considering the petitioner request to require a safe and secure hot cell transfer station coupled with an auxiliary pool to be built as part of an upgraded ISFSI design certification and licensing process.

TAC No.: LA0233

Enclosures:
1. Meeting Attendees
2. Agenda
3. Handouts
   - EPRI Flaw Growth and Flaw Tolerance Assessment for Dry Cask Storage Canisters (EPRI)
   - Chloride-Induced Stress Corrosion Cracking Tests and Example Aging Management Program (NRC)

safe and secure hot cell transfer station coupled with an auxiliary pool to be built as part of an upgraded ISFSI design certification and licensing process.

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Chloride-Induced Stress Corrosion Cracking Tests and Example Aging Management Program (NRC)

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DATE	9/9/14	9/9/14	9/9/14

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Agenda

Public Meeting with Nuclear Energy Institute on Chloride Induced Stress Corrosion Cracking Regulatory Issue Resolution Protocol

August 5, 2014
8:30 AM – 12:00 PM

8:30 – 8:40 AM	Welcome, Introductions, and Meeting Objectives (All)
8:40 – 8:55 AM	Update of RIRP Schedule/Tasks (NEI)
8:55 – 9:10 AM	Overview of Flaw Growth and Tolerance Report (Electric Power Research Institute)
9:10 – 10:25 AM	Literature Review – Flaw Growth and Tolerance Methodology (Dominion Engineering, Inc.)
10:25 – 10:40 AM	**Break**
10:40 – 11:20 AM	Overview of Aging Management Program for Stress Corrosion Cracking (NRC)
11:20 – 11:35 AM	Discuss Next Milestones and Anticipated Dates (All)
11:35 AM – 12:00 PM	Public Comments and Wrap Up

Enclosure 2

PRESENTATION HANDOUTS

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

Chloride-Induced Stress Corrosion Cracking Tests and Example Aging Management Program

Darrell S. Dunn

NRC/NMSS/SFST

Public Meeting with Nuclear Energy Institute on Chloride Induced Stress Corrosion Cracking Regulatory Issue Resolution Protocol

August 5, 2014

Outline

- NRC sponsored testing
- Power plant operating experience
- Potential for chloride-induced stress corrosion cracking (CISCC) of stainless steel dry storage canisters (DSCs)
- Example aging management program (AMP) for CISCC
  - Regulatory basis
  - Description of AMP elements

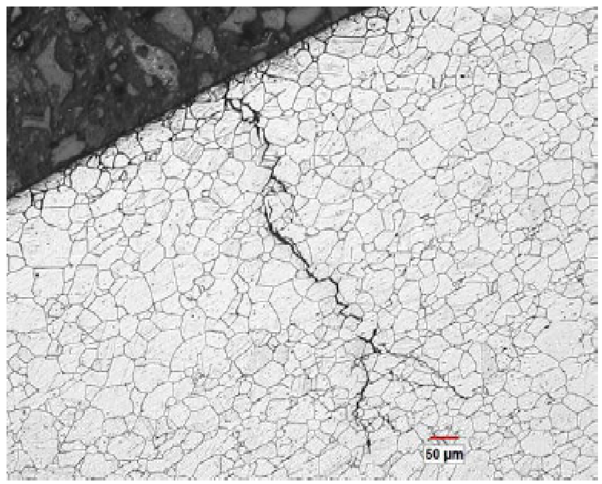
NRC Sponsored Testing NUREG/CR-7170

- Test objectives:
  - Limit absolute humidity (AH) to about 30 g/m^3
  - Vary test temperature, surface salt concentration and material condition
- Test methods:
  - ASTM G30 U-bend specimens with 0.1, 1, or 10 g/m^2 of sea salt
    - Expose to salt fog for various times
    - Quantity determined by control specimen weight gain
    - As-received or sensitized (2 hours at 650 ^{o}C) Type 304
    - Exposed in test chamber to cyclic AH (15 and 30 g/m^3)
  - ASTM G38-01 C-ring specimens at ~0.4% or 1.5% strain
    - Tested with 1 or 10 g/m^2 of simulated sea salt 35, 45, and 52^{o}C
  - ASTM G30 U-bend specimens with non chloride salts (No SCC)
  - ASTM G30 U-bend specimens at elevated temperatures (SCC observed)

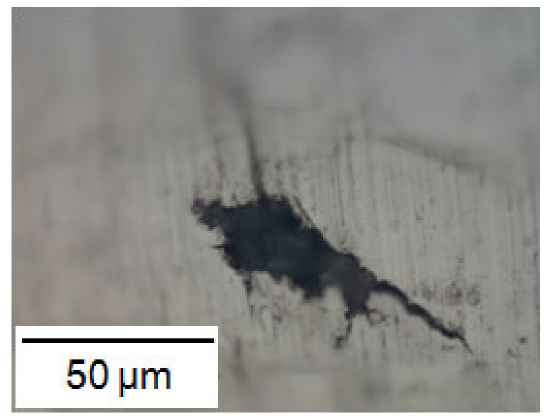
Surface Chloride Concentration

Specimen Temp. (°C)	Relative Humidity (RH) (%)	Exposure Time	SCC Observed?	Lowest salt concentration at which SCC was observed
27	56-100	8 months	No	N/A – salt deliquesced and drained off
35	38-76	4 – 12 months	Yes	0.1
45	23-46	4 – 12 months	Yes	0.1
52	16-33	2.5 – 8 months	Yes	1
60	12-23	6.5 months	Yes	10

Pitting on specimens at 1[illegible] m^2 (top), 1 g/m^2 (middle), and 0.1 g/m^2 (bottom)

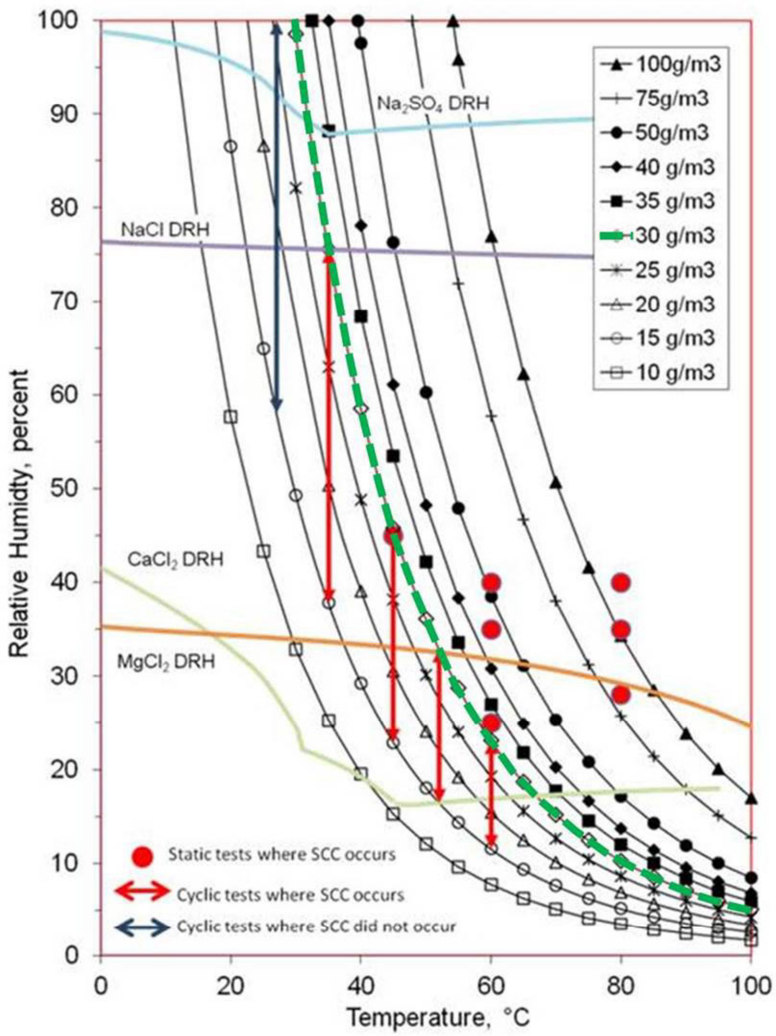


Cross section of sensitized, 0.1 g/m^2 specimen at 45°C after 4 months



Top view of sensitized specimen with 10 g/m^2 tested at 60°C for 6.5 months

U-bend Testing Summary



- CISCC observed at temperatures up to 60 °C with absolute humidity values less than or equal to 30 g/m^3
- No observed CISCC at 25 °C is believed to be a result of salt solution draining from the specimens
- CISCC observed with salt concentration of 0.1 g/m^2, lower than previous reports
- CISCC at 80 °C required absolute humidity values above 30 g/m^3

C-ring Specimen Tests

- ASTM G38-01 C-ring specimens used to evaluate lower strain condition relative to U-bend specimens
- Specimens strained to slightly above yield stress (~0.4% strain) or 1.5% strain, as measured by strain gage
- Specimens tested with 1 or 10 g/m^2 of simulated sea salt
- Specimens exposed at conditions of 35^{o}C and 72% RH, 45^{o}C and 44% RH, and 52^{o}C and 32% RH (AH ~ 30 g/m^3)

C-ring Specimen Tests

Specimen Temp. (°C)	RH (%)	AH (g/m^3)	Salt Conc. (g/m^2)	Strain (%)	Exposure Time (months)	Crack Initiation
35	72	29	1	0.4	2	No
			10	0.4	3	Sensitized
45	44	29	1	0.4	3	No
			10	0.4	3	No
				1.5	2	As-received and sensitized
52	32	29	1	0.4	2	As-received and sensitized
			10	0.4	3	Sensitized
				1.5	2	As-received and sensitized

Conclusions from NRC Sponsored SCC testing

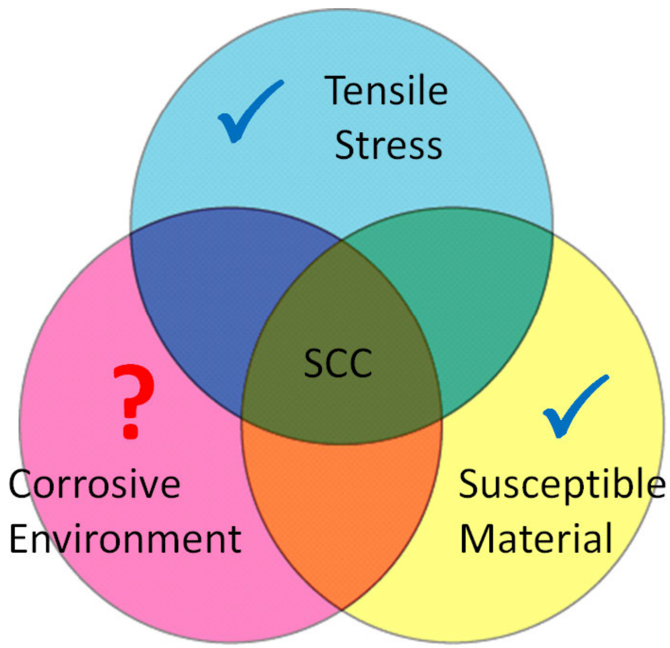
- CISCC observed on specimens with deposited sea salt at temperatures from 35 to 60°C with absolute humidity values less than or equal to 30 g/m^3
- CISCC initiation is observed at salt quantity as low as 0.1 g/m^2 (U-bend specimens) or strain as low as 0.4 % (C-ring specimens) but the extent of cracking increased with increasing salt quantity or strain
- Sensitized material was more susceptible to CISCC than material in as-received (mill-annealed) condition
- No SCC was observed for specimens exposed to simulated atmospheric deposits that did not contain chloride salts
- CISCC observed at temperatures of 80°C when RH was sufficiently high for deliquescence of deposited sea salts (AH > 30 g/m^3)

Power Plant Operating Experience with SCC of Stainless Steels

Plant	Distance to water, m	Body of water	Material/ Component	Thickness, or crack depth, mm	Time in Service, years	Est. Crack growth rate, m/s	Est. Crack growth rate, mm/yr
Koeberg	100	South Atlantic	304L/RWST	5.0 to 15.5	17	9.3×10^{-12} to 2.9×10^{-11}	0.29 to 0.91
Ohi	200	Wakasa Bay, Sea of Japan	304L/RWST	[illegible]	30	[illegible] $\times 10^{-12}$ to 7.9×10^{-12}	[illegible] to 0.25
St Lucie	800	Atlantic	304/RWST pipe	6.2	16	1.2×10^{-11}	0.39
Turkey Point	400	Biscayne Bay, Atlantic	304/pipe	3.7	33	3.6×10^{-12}	0.11
San Onofre	150	Pacific Ocean	304/pipe	3.4 to 6.2	25	4.3×10^{-12} to 7.8×10^{-12}	0.14 to 0.25

- CISCC growth rates of 0.11 to 0.91 mm/yr for components in service
  - Median rate of 9.6 x 10^{-12} m/s (0.30 mm/yr) reported by Kosaki (2008)
- Activation energy for CISCC propagation needs to be considered
  - 5.6 to 9.4 kcal/mol (23 to 39 kJ/mol) reported by Hayashibara et al. (2008)

Potential for SCC of Welded Stainless Steel DSCs



2/3 of the requirements for CISCC are present in welded stainless steel dry storage canisters (DSCs)

- 304 and 316 Stainless steels are susceptible to CISCC
  - Sensitization from welding increases susceptibility to CISCC
  - CISCC has been observed with low surface chloride concentrations
  - Crevice and pitting corrosion can be precursors to CISCC
  - Residual stresses from welding likely sufficient for CISCC
- Atmospheric CISCC of welded stainless steels has been observed
  - Component failures in 16-33 years
  - Estimated crack growth rates of 0.11 to 0.91 mm/yr
- Limited data on the atmospheric deposits on welded stainless steel canisters

Potential for SCC of Welded Stainless Steel DSCs

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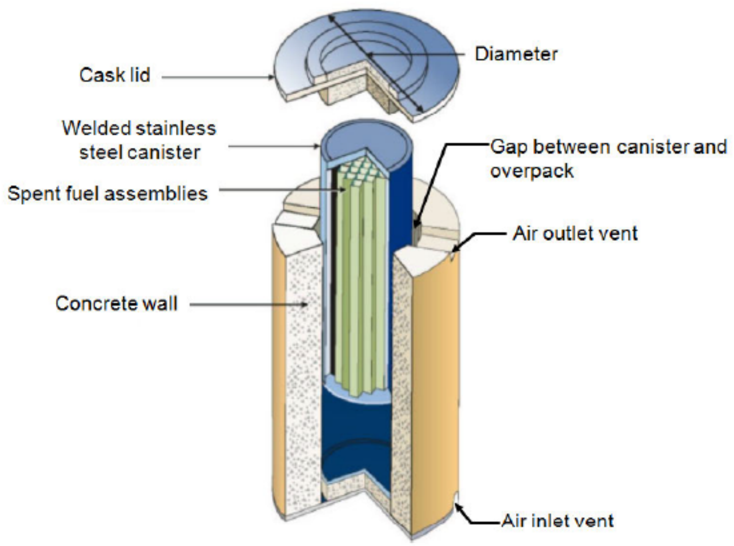

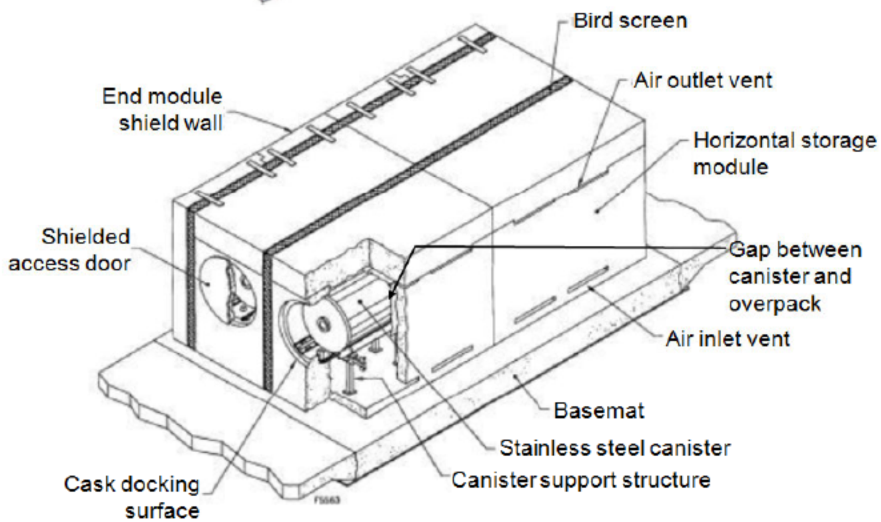

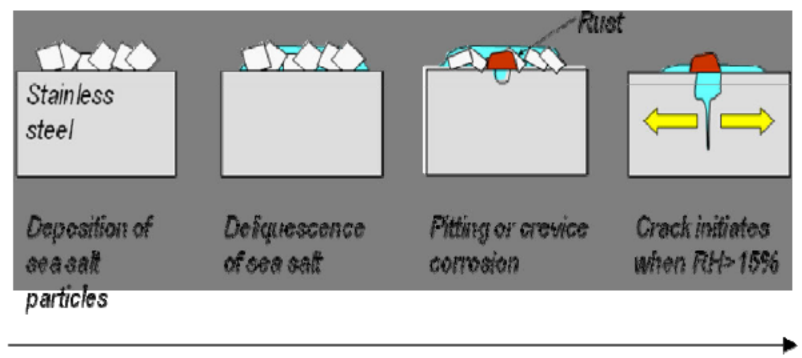

- Cl salts could be deposited by air flow from _ assive coolin_
- Relative humidity increase as canister cools may lead to deliquescence of deposited Cl salts and ClSCC
- Reactor operating experience indicates ClSCC is a potential a_in_ effect that re_uires management

Regulatory Basis for Aging Management Programs

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- **<u>10 CFR 72.42(a), 72.240(c):</u>**
  - Time limited aging analysis (TLAA) that demonstrate that important to safety (ITS) structures systems and components (SSCs) will continue to perform their intended function for the period of extended operation.
  - A description of the aging management program (AMP) for management of issues associated with aging that could adversely affect ITS SSCs.
- **<u>Guidance: NUREG-1927 AMP Elements:</u>**

1. Scope of the Program
2. Preventive Actions
3. Parameters Monitored/Inspected
4. Detection of Aging Effects
5. Monitoring and Trending
6. Acceptance Criteria
7. Corrective Actions
8. Confirmation Process
9. Administrative Controls
10. Operating Experience

AMP Element 1
Scope of the Program

NUREG-1927: The scope of the program should include the specific structures and components subject to an aging management review (AMR)

- Welded stainless steel dry storage canisters
  - Fabrication and closure welds
  - Weld heat affected zones
  - Locations where temporary supports or fixtures were attached by welding
  - Crevice locations
  - Surface areas where atmospheric deposits preferentially occurs
  - Surface areas with a lower than average temperature

AMP Element 2
Preventative Actions

NUREG-1927: Preventive actions should mitigate or prevent the applicable aging effects

- Aging Management Program is for condition monitoring.
  – Preventative actions are not presently incorporated into existing dry storage canister designs
- Future designs or amendments could include
  – Surface modification to impart compressive residual stresses on welds and weld heat affected zones
  – Materials with improved localized corrosion and SCC resistance

AMP Element 3
Parameters Monitored/Inspected

NUREG-1927: Parameters monitored or inspected should be linked to the effects of aging on the intended functions of the particular structu.e and component

- Canister surfaces, welds, and weld heat affected zones for discontinuities and imperfections
- Size and location of localized corrosion (e.g., pitting and crevice corrosion) and stress corrosion cracks
- Appearance and location of atmospheric deposits on the canister surfaces

AMP Element 4
Detection of Aging Effects (1/2)

NUREG-1927: Define method or technique, frequency, sample size, data collection, and timing to ensure timely detection of aging effects

- Qualified and demonstrated technique to detect evidence of localized corrosion and SCC:
  - Remote visual inspection, e.g. EVT-1, VT-1, VT-3, or Eddy Current Testing (ET) may be appropriate
- Pending detection findings, sizing SCC would require volumetric methods

AMP Element 4
Detection of Aging Effects (2/2)

- Sample size
  - Minimum of one canister at each site
  - Canisters with the greatest susceptibility
- Data Collection
  - Documentation of the examination of the canister
  - Location and appearance of deposits
- Frequency
  - Every 5 years
- Timing of Inspections
  - Within 25 years of initial loading

AMP Element 5
Monitoring and Trending

NUREG-1927: Should provide for prediction of the extent of the effects of aging and timely corrective or mitigative actions

- Document canister condition, particularly at welds and crevice locations using images and video that will allow comparison in subsequent examinations
- Changes to the size and number of any corrosion product accumulations
- Location and sizing of localized corrosion and stress corrosion cracking

AMP Element 6
Acceptance Criteria (1/2)

NUREG-1927: Acceptance criteria, against which the need for corrective action will be evaluated; should ensure that SSC functions are maintained

- No indications of:
  - Pitting or crevice corrosion
  - Stress corrosion cracking
  - Corrosion products near crevices
  - Corrosion products on or adjacent to fabrication welds, closure welds, and welds for temporary supports or attachments

AMP Element 6
Acceptance Criteria (2/2)

- Locations with corrosion products require additional examination for localized corrosion and/or SCC
- Size of the area affected and the depth of penetration if localized corrosion and/or SCC is identified
- Canisters with localized corrosion and/or SCC must be evaluated for continued service in accordance with ASME B&PV Code Section XI IWB-3514.1 and IWB-3640

AMP Element 7
Corrective Actions

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NUREG-1927: Corrective actions, including root cause determination and prevention of recurrence, should be timely

- Supplemental inspections to determine the extent of condition at the site
- Subsequent inspections of canisters with indications
- Canisters that do not meet the prescribed evaluation criteria must be repaired or removed from service

AMP Element 8
Confirmation Process

NUREG-1927: Confirmation process should ensure that preventive actions are ade uate & a ro riate corrective actions have been completed & are effective

- Licensee Quality Assurance Program consistent with 10 CFR 72 Subpart G, or 10 CFR 50 Appendix B
- Ensure that ins ections evaluations and corrective actions are completed in accordance with the Site Specific or General Licensees Corrective Action Program (CAP)
  - Extent of condition
  - Evaluation for continued service
  - Repair, replace, mitigation actions

AMP Element 9
Administrative Controls

NUREG-1927: Administrative controls should provide a formal review and approval process

- Licensee Quality Assurance Program consistent with 10 CFR 72 Subpart G, or 10 CFR 50 Appendix B
- Training requirements for inspectors
- Records retention requirements

AMP Element 10
Operational Experience

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NUREG-1927: Include past corrective actions; provide objective evidence to support a determination that the effects of aging wil. be adequately managed so that the SSC intended functions will be maintained during the period of extended operation

- Current operating experience limited to a few inspections
  - Deposits and corrosion products on surfaces
  - Evidence of water contacting DSC
- Reactor operating experience
- Similar DSC designs and canister materials at other ISFSI locations

Summary

- Conditions necessary for chloride induced SCC have been evaluated in well controlled laboratory tests
- CISCC growth rates for welded stainless steels available from both laboratory and field testing are comparable to rates derived from reactor operating experience
- CISCC is a potential aging mechanism for welded stainless steel DSCs that requires an Aging Management Program
  - Several reported cases of CISCC from atmospheric deposits observed in operating reactors (NRC Information Notice 2012-20)
  - Limited data available from DSC inspections
- Analysis of the potential for CISCC needs to consider both the range of available test data and operating experience with welded stainless steel components

Acronyms

AH: Absolute Humidity

AMP: Aging management program

AMR: Aging management review

ASME B&PV code: American Society of Mechanical Engineers Boiler and Pressure Vessel code

CAP: Corrective action program

CISCC: Chloride induced stress corrosion cracking

CFR: Code of Federal Regulations

DSC: Dry storage canister

EVT-1: Enhanced visual testing-1 (Boiling water reactor vessels and internals project, BWRVIP-03)

ISFSI: Independent spent fuel storage installation

ITS: Important to safety

RH: Relative humidity

SCC: Stress corrosion cracking

SSC: Structures systems and components

TLAA: time limiting aging analysis

VT-1: Visual Testing-1 (ASME B&PV code Section XI, Article IWA-2200)

VT-3: Visual Testing-3 (ASME B&PV code Section XI, Article IWA-2200)

Subject: for the review pdf. "William Parker to David Victor, 21 Sept, 1:33pm"
Date: Wednesday, October 8, 2014 at 7:20:02 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

From: Bill Parker <[redacted]
Date: Sunday, September 21, 2014 at 1:33 PM
To: "David G. Victor" <[redacted]
Cc: Ted Quinn <[redacted] Donna Gilmore <[redacted] Gene Stone <[redacted] Tom Palmisano <[redacted] Chris Thompson <[redacted] '[redacted] <[redacted] Tim Brown [redacted], Dan Stetson [redacted]
Subject: Re: UPDATE: MEMO ON DRY FUEL STORAGE

David,

I have no substantive comments on your excellent summary of issues related to dry fuel storage. However I do believe both Dave Lochbaum and Frank von Hippke have made a number of comments that you should incorporate into your document. Their reviews of your draft are thoughtful and constructive.

Bill

On Sep 19, 2014, at 8:23 AM, David G. Victor <[redacted] wrote:

> Dear Colleagues
>
> Over the next 10 days or so I will revise my memo. If you have any further comments on the piece please do let me know.
>
> Meanwhile, below please find comments from Frank von Hippel (Princeton) and Dave Lochbaum (UCS). Both have provided us with exceptionally helpful reviews (most of Dave's comments are embedded in the pdf file, which I attach). They also point to new citations and information about aging research.
>
> I am enormously grateful to both and have thanked them on our behalf.
>
> It is clear that it will be very helpful to have a vendor event with Holtec and Areva and I very much look forward to that.
>
> all best
>
> David

Subject: for the review pdf. "Mark Lombard to David Victor, 22 Sept, 12:35pm"
Date: Wednesday, October 8, 2014 at 7:17:42 AM Pacific Daylight Time
From: David G. Victor
To: Steven Carlson

From: <Lombard>, Mark <[redacted]
Date: Monday, September 22, 2014 at 12:35 PM
To: "David G. Victor" <[redacted] "Csontos, Aladar" <[redacted]
Cc: "Dunn, Darrell" <[redacted] "Ted Quinn [redacted] <[redacted] Tom Palmisano <[redacted]
Subject: RE: follow up on new NRC procedures for cask management

Actually that quote is pretty accurate. It will take the applicant some time to ensure their design complies with our requirements in 10 CFR 71, hence the number Tom provided included that time, I believe. My time frame was just speaking to the time required for NRC review.

Mark

From: David G. Victor [mailto:[redacted]
Sent: Friday, September 19, 2014 8:39 PM
To: Lombard, Mark; Csontos, Aladar
Cc: Dunn, Darrell; Ted Quinn ([redacted]
Subject: Re: follow up on new NRC procedures for cask management

Mark

that is terrific—thanks so much.

Unrelated to all this, below is an email that I got today from Donna with her comments on the paper —more, actually, a huge attachment with her own take on the issues. That is fine. But her letter includes a quote to you for the time needed for Castor to get a license. You may or may not want to comment on this, but if you do could you let me know fully what you said.

all best

David

David,

After we discussed your paper, I promised to send you references for where I thought your facts differed from mine. Attached is a fully referenced document I prepared on the San Onofre dry storage issues. Thanks for sharing Lochbaum's and Frank's comments. I agree with most of their comments. I don't agree with Lochbaum's conclusion that the currently licensed casks are our best choice for San Onofre. I'm hoping once David read's my paper, he will agree.

I listened to yesterday's NRC Commissioner's webcast on waste storage and transportation. Dr. Macfarlane asked great questions that are applicable to what we are facing at San Onofre. Mark Lombard, NRC Director of SFST Division, provided answers to her questions. I've included some of those in this paper.

I agree with Lochbaum it's important to remove the fuel from the pools. However, living a few miles from this plant and learning about the potential short-term problems with these canisters, I believe there is time to select safer canisters. I was shocked to learn from the NRC that the steel/concrete canisters cannot even be adequately inspected on the outside and none have been. I've read some of Gordon's papers where he said the Castor type casks are better, but if the steel/concrete ones can be shown to last 100 years, that they would be good enough. He also recommended the Castor casks for Diablo Canyon before they had selected the Holtec.

When Tom Palmisano said he though the process would take 3 to 5 years to receive approval from the NRC, I called Mark Lombard. He personally told me the 18 to 30 month time frame was more than adequate. With 30 month being the worse case. This assumes of course that the vendor can respond to all NRC concerns. And he said they've never denied a license application. Local citizens are willing to wait. The fuel needs to cool in the pools anyway, so we're not talking about a significant delay here.

Thanks,

Donna Gilmore
[redacted]

From: <Lombard>, Mark <[redacted]
Date: Friday, September 19, 2014 at 1:08 PM
To: "David G. Victor" <[redacted] "Csontos, Aladar" <[redacted]
Cc: "Dunn, Darrell" <[redacted] "Ted Quinn [redacted] <[redacted] Tom Palmisano <[redacted]
Subject: RE: follow up on new NRC procedures for cask management

Sorry for the delay David. It has been a busy week here, yet again. I think this is the presentation you are looking for: http://pbadupws.nrc.gov/docs/ML1419/ML14192A702.pdf. It is the one that Donna Gilmore has on her website (slide 2). Please let us know if you need anything else.

Mark

From: David G. Victor [mailto:[redacted]
Sent: Wednesday, September 17, 2014 8:03 PM
To: Lombard, Mark; Csontos, Aladar
Cc: Dunn, Darrell
Subject: follow up on new NRC procedures for cask management

Dear Mark and Al

thanks so much for the call last week. I am enormously grateful for your help as I try to navigate the issues related to long-term management of casks on site.

On the call you mentioned a new process, still taking shape, for periodic inspection of canisters—a process that would go beyond the critical canister approach. You said that there was a mid July presentation by Darrel that had more details and I wonder if you could send me a copy? I would like to draw attention to this and to cite it in my memo.

thanks so much

all best

DAvid

--
David G Victor
Professor & Director, Laboratory on International Law & Regulation
School of International Relations & Pacific Studies, UC San Diego
[redacted]

To: Community Engagement Panel (CEP) for SONGS

From: David G. Victor, CEP Chairman

Re: Safety of long-term storage in casks

Date: 1 September 2014

DRAFT FOR REVIEW BY THE CEP DRY CASK REVIEW GROUP AND SELECTED EXTERNAL REVIEWERS

This is a DRAFT of a memo that I will eventually circulate to the CEP and the broader public about important questions that arise with long-term storage of spent fuel in casks. One outcome of the CEP's work on spent fuel management is the realization that spent fuel is likely to be stored on site at San Onofre for very long periods of time—most likely well beyond the 20-year period for initial licensing of dry casks. Thus many CEP members, along with the public, have urged us to pay attention to the long-term plan for management of those casks. Some CEP members have also raised specific questions about the procedures for inspecting and repairing casks if needed. The need for a long term strategy emerged as one of the central themes of a survey of CEP members that vice-chairman Tim Brown and I conducted over the last month. Mindful of that, he and I expect that the CEP will revisit these issues in early 2015 with a special focus on long-term management of spent fuel as well as what, if anything, the CEP can do to help Washington focus on its obligation to remove the spent fuel from sites such as San Onofre.

Until we revisit this topic, this memo offers answers to 7 questions that several CEP members have agreed should be answered because of their pivotal importance to a long-term management strategy. We have also benefitted from the input of Donna Gilmore, a particularly well informed member of the community who has been tracking these issues and helped us review these questions. I have also sought detailed input from Edison, which I attach to this memo. We have also benefitted from indirect input from the Nuclear Regulatory Commission (NRC) and other experts. I expect that this draft will be reviewed at NRC and other organizations and the facts I recount here may be adjusted as a result of that review.

This memo is designed to present factual information in plain English. In a few places, where readers may want more detail, I have added footnotes. Along the way, I also offer my assessment of the best strategic options for us in the San Onofre communities. This is my assessment as an independent person having now looked at a massive array of data and analysis with an eye to the best options for our situation.

I don't expect everyone to agree with everything I write below, and that's partly why I am releasing this memo in draft form. But I see three conclusions emerging from this work:

1. It has been very useful for us to pause and look more widely at the range of options—including European vendors of canisters not currently licensed in the United States. We have learned a lot. It is now time to move on. My assessment is that the SONGS co-owners are wise to be focusing on just the three vendors of stainless steel casks who have a significant presence in the US. I appreciate that some folks want SONGS to look at vendors from Europe who use a different technology with very thick iron walls rather than thinner stainless steel. Having looked at the totality of the evidence—in particular, a thick walled cask from a German company Castor—I don't see that option as viable for the long haul here in the US. Opting for that cask would put us alone in the U.S. industry and thus unable to benefit from lessons learned at other U.S. facilities. It would expose us to possibly long delays in initial regulatory approval and it would leave us vulnerable if Castor's manufacturer went bankrupt or otherwise decided not to continue investment in the U.S. market. My assessment is that safety with long-term storage comes from good design, "defense in depth," and working with technologies that many other peer companies use at the same time. As of June 2013—which was the last full inventory of US casks that I have seen—Castor had less than 1% of the U.S. market. In totality, the Castor option is possibly the most dangerous of the major options that have been discussed. Of the three cask vendors the best options are with Areva TN or Holtec—the two companies that dominate the U.S. market. These are exactly the two vendors that the SONGS co-owners are evaluating for final decision on cask vendor. (The third vendor, NAC, is not seriously being considered. They have only 16% of the US market.) **Recommendation**: before we move on, we should ask Edison for its final assessment of the Castor option, including an assessment of the possible regulatory delays and design problems that might arise from thick-walled ductile iron casks. We have a preliminary assessment from Edison attached as Appendix A, but we would benefit from Edison talking directly with Castor to resolve any remaining issues. A serious analysis of this option will require access to proprietary information and thus it would be inappropriate for the CEP to do that analysis—a task for which we are not qualified. But we should review what Edison has done at arm's length and quickly.
2. We in the communities around SONGS must look way beyond 20 years, which is the initial license period for casks by the Nuclear Regulatory Commission (NRC). When I began this research project I was concerned that, on the surface, it appears that NRC wasn't focused on this period beyond 20 years and that the whole process of setting 20-year time horizons was artificially short. What I have learned is that NRC's regulations in this area are only a small part of how the industry is facing this challenge and that NRC's approach is highly procedural. If we want to learn how long-term monitoring, repair (if necessary) and adjustment to new information will

actually occur we must look not just to NRC but also new procedures taking shape through the Nuclear Energy Institute (NEI), the Electric Power Research Institute (EPRI) and others. This memo outlines some of the key insights from that broader industry-wide program to manage aging materials, including casks. I call that program "defense in depth"—that is, layers of defense and monitoring so that the system, overall, is robust for the long term. Any long-term scheme like this involves uncertainties. Those uncertainties require management and new information along the way. My impression is that the industry is focusing on this task but has, so far, not conveyed to the public in a clear way exactly what "defense in depth" will mean in practice. Part of this lack of information simply reflects that the public has never asked for that information. Part of it reflects that the regulatory process is highly focused on cask licensing and license renewals—along with all the head-spinning technical details associated with those processes—rather than explaining in plain English the long-term strategy for management of spent fuel on site. **Recommendation**: We should meet with the two viable cask vendors and ask them what "defense in depth" means and how they, as vendors, will service these casks for the long haul. We need to ask these questions of the vendors themselves because it is clear that the vendors play a pivotal role in the regulatory and management process. At the same time, we should ask Edison to articulate over the coming year how "defense in depth" will work and how the industry is preparing for long-term management. When the CEP revisits this issue in early 2015 we should consider holding a workshop with NEI, EPRI, NRC, and national watchdog groups that are focused on this issue industry-wide. One of our roles in the CEP could be to help articulate in plain English how "defense in depth" will work at SONGS. That would help all of us focus on the elements of that strategy—including the uncertainties—that are really important. My assessment is that the uncertainties involved—such as long-term aging of the fuel inside the casks, integrity of cask walls, repairs of the walls and overpack if needed—are all completely manageable, do not require fundamentally new types of material and other sciences, and are within the realm of what good organizations know how to do already.

3. I remain convinced that the safest option for us is to get the fuel out of pools and into casks as soon as that's practical. In the pools all the fuel is sitting in two locations and is kept cool with active systems—pumps, circulating water, etc. In casks it is divided into more than 100 new independent containers—each designed to withstand massive shocks—and relies only on passive cooling. All else equal, decentralized passively managed systems are safer than centralized active schemes. **Recommendation**: while we should study the many options and continue to articulate views about the best strategies, we must also remain mindful that there are tradeoffs with delay. Demand for casks in the U.S. is surging and the SONGS plant needs to "get in line" to buy its casks; we need to participate centrally in the industry-wide aging management program. And delays come with the cost of leaving the fuel in pools for unnecessarily long periods of time.

Question 1: Why are U.S. utilities using thinner walled stainless steel casks rather than thicker walled ductile iron or forged steel?

For better or worse, the United States long ago decided to have a "once through" nuclear fuel cycle. We put fuel in reactors and burn it partly and then refuel the reactor with fresh fuel. The spent fuel is then cooled on site, put into casks, and as a final step sent to a permanent long-term repository. Of course, that last step hasn't happened yet. By contrast, Europe (and most of the rest of the world) recycles its fuel. In those countries, fuel is put into reactors and burned partly; then it is cooled in pools, put into casks and sent to reprocessing facilities where fresh fuel is fabricated in part from the old fuel. I won't get into the question of whether "once through" or "reprocessing" are better economically or in terms of safety, but the reality for us is that it leads to radically different strategies for casks.

In the American system, the cask is designed to be a permanent home for the fuel. We put fuel into the cask, seal it, and then keep it there forever. That strategy means that we in America want to select materials for the cask that have extremely long lifetime (usually stainless steel—more on that below) and we want to weld the whole thing shut so that it is hard for anyone to open the cask.[1] Europe, by contrast, puts a premium on casks that can be opened and re-used and that have monitors and other systems inside the cask that can be routinely inspected and repaired. European casks, as well, rely on bolted lids that can safely be opened and closed because the trip into the cask for spent fuel is a brief affair. Because the bolted lid relies on an O-ring and sealing between the lid and the cask, such designs also require more active monitoring to ensure that the O-ring keeps working as designed. Such risks of lid failure should be dramatically lower when the lid is sealed with a weld, although I have not yet seen a true "apples to apples" comparison of lid failure risks over the long term.

These fundamental differences make it very hard to compare European and American casks. One of the three vendors under consideration for SONGS casks (TN Areva) has a large European operation but uses slightly different casks in Europe than in the United States. So even within a single vendor there are important differences.

Because of the emphasis in Europe on fuel removal from casks, at least one vendor (Castor) uses very thick (about 14 inches) ductile iron walls. Iron may have some advantages over stainless steel in terms of integrity of the cask alone, but that is a hypothesis rather than anything proven. Thickness doesn't automatically mean safety, especially when it concerns long-term aging that might involve

[1] A small minority (11% by my calculation) of US casks have bolted lids. Most are welded shut and essentially all new cask designs envision welding.

[2] EPRI 2013, "Failure Modes and Effects Analysis (FMEA) of Welded Stainless Steel

embrittlement. The Department of Energy has raised serious concerns (so far unanswered to my knowledge, but a conversation between Edison and Castor's manufacturer can resolve this) about whether thick-walled casks have sufficient integrity. There are concerns about nodules in the iron, rusting and other aspects of aging. Some of these concerns appear to be much greater for thick walled casks because they are design to sit alone and exposed to the elements; by contrast, all the stainless steel options under consideration for SONGS would sit inside a concrete "overpack." What is clear, however, is that the thick walled casks have not taken off in the US—partly, perhaps, because it unclear whether such a cask would ever be accepted in a permanent fuel repository. The Castor cask has never been licensed in the US for transport or for permanent storage. The main U.S. facility that has about two dozen Castor casks has a site-specific license and thus little can be gleaned from that experience that might tell us about licensing of newer Castor designs at other sites such as SONGS. Absent a license for transport or permanent storage, if utilities bought these casks they would potentially need to move the fuel from the cask into a new, final storage cask—which is exactly the opposite of the "once through" fuel strategy and would expose workers to additional radiation hazards as the fuel is transferred. U.S. utilities know that so they don't purchase these casks—except for a small number used on an experimental basis. Even the utility that owns the two dozen Castor casks mentioned above hasn't bought any more of them.

All this creates a "chicken or egg" problem for Castor. It is imaginable that the U.S. industry might follow a radically different path and use thick-walled casks. But nobody wants to go first—in part because there are good technical reasons to use stainless steel with concrete overpacks. And the vendors know what the industry thinks so nobody makes a big investment in marketing and servicing these casks in the U.S. (Worse, the European vendors are about to face a severe crisis over their own since electricity demand in Europe is flat; few new reactors are being built; and some countries, notably Germany, are shutting all their reactors. That reality should make us worried about depending heavily on vendors whose financial lifeblood is in Europe unless they have other serious options elsewhere in the world.) This reality will not be altered by what we do at SONGS, and if we purchased Castor casks we might find ourselves stuck in the middle—neither chicken nor egg. That could mean that we would need to "repurchase" all of our casks when the time came to transporting the fuel off site or if some aging management problem arose that the vendor wasn't around to help us fix.

<u>For our purposes, what is crucial to know is that these thick walled casks have essentially zero market presence in the US.</u> In fact, the Castor design isn't currently licensed for use in the U.S. and thus even if SONGS were to purchase them there would be a period of uncertainty (and delay) in getting those casks into service. Edison's assessment is that would introduce 5-10 years in delay just for licensing. In email traffic with members of the CEP the NRC has said that its licensing process could run only 18-30 months, but I suspect that assessment is for licenses that use materials and procedures that are already familiar to the NRC. It is quite plausible that SONGS would suffer the much longer term estimate of a decade of delays in

light of all the uncertainties at NRC and the complete lack of operational experience with these casks in the U.S. along with the many questions that have been raised about whether thick walled ductile iron is viable. My assessment is that the safest options for the long haul require buying casks that lots of other utilities use provided that Edison and the communities have confidence that these casks are matched with "defense in depth." That assures us that we can learn from the real experience across the US industry and it assures us that we have lots of partners in case issues arise with casks over time. Even if the vendor of our casks were to go bankrupt, the large number of similar casks across the US industry would guarantee that other vendors would appear to help us manage these casks safely as they age.

I have asked Edison for their assessment of the potential for the Castor cask, which I attach as Annex A to this memo. It summarizes many of the issues raised above. There are still a few unturned stones—for example, the manufacturer's response to the concerns raised about ductile iron and the need for a fresh assessment of the likely delays in obtaining regulatory approval. But as soon as those concerns are resolved—which can be done through a direct meeting between Edison and the vendor—I would consider this matter resolved. I am mindful that there have been calls, as well, for a public meeting with the vendor but if the vendor is not a viable option I don't see the purpose in such a public event.

Question 2: What is the track record with cracking of stainless steel similar to that used in casks?

Stainless steel has been used extensively and for decades and thus the experts know a lot about how it ages under stress.

The Nuclear Regulatory Commission (NRC) has focused heavily on how aging materials might fail and has an active program in this area. However, when we look at information from this program we must remember that most of NRC's focus is on stainless steel in pipes, vessels and other uses in ACTIVE nuclear reactors. These pipes operate under extreme pressure (hundreds or thousands of pounds per square inch, psi) in direct contact with water; they are cycled between hot and cold, high pressure and low, and thus will experience a LOT more wear in those extreme flexing environments than the stainless steel that is relevant for casks. Within a cask the wall is dry; the pressure is low and constant and the temperature nearly constant.

What really matters, therefore, is an assessment of risks for stainless steel used in cask systems. In that regard, I have found it particularly helpful to review a massive recent (2013) EPRI study that looks at ways welded stainless casks could fail.[2] They look at a 120-year time horizon, and this study is part of a pair of studies along with

[2] EPRI 2013, "Failure Modes and Effects Analysis (FMEA) of Welded Stainless Steel Canisters for Dry Cask Storage Systems." Online at epri.com

an ongoing EPRI program on materials aging in nuclear plants. This risk management approach is the right way to analysis risks across the whole system, but first let me comment on what I have learned about stainless steel itself.

In parallel with the EPRI study, NRC itself funded some research focused on one particular kind of failure—so-called stress corrosion cracking (SCC) due to chlorides and other materials deposited on the surface of the casks.[3] The NRC study includes a literature review—the most current one published, to my knowledge. Among the findings from the NRC study is that risks depend on the type of stainless steel, the filler material used in stainless welds, the ambient temperature and humidity, and a host of other factors. This is clearly an area of ongoing research, and at this stage it is very difficult to interpret what the NRC results mean for any operational spent fuel storage site.[4] The study reports fundamental results—for example, the rate of corrosion and cracking for a given temperature and exposure to corrosive salts—<u>but was not designed to connect those results to real environmental exposures at real sites</u>.[5] This helps to explain some confusion as some of these results have been used to argue that casks at SONGS will suffer corrosion cracking. When pressed on this point, the NRC itself has underscored that such results can't be used in isolation from knowledge about the actual environmental conditions at the plant as well as any mitigating measure that NRC would require if corrosion-prone conditions actually existed.[6] Such research tells us that we should be attentive to risks of stress corrosion cracking, as with an array of other risks, but doesn't tell us much about the specific level of risk.

Because it is unwise to pluck results out of studies that look at cracking under hypothetical conditions, here I will focus on the EPRI study because it is based on a full failure analysis through which the EPRI team looked at every mode that could lead to canister failure and then identify the relevant risks in each mode. They do that with an eye to every different configuration of welded lid stainless steel casks

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[3] NRC, "Assessment of Stress Corrosion Cracking Susceptibility for Austenitic Stainless Steels Exposed to Atmospheric Chloride and Non-Chloride Salts" NUREG/CR-7170 (2014)

[4] The same can be said for many other studies on corrosion in stainless steel, which tend to focus on other applications (notably piping) rather than the settings most germane to casks. For example, I am grateful to Donna Gilmore for pointing me to: R. Parrott et al 2010 "Chloride stress corrosion cracking in austenic stainless steel – recommendations for assessing risk, structural integrity and NDE based on practical cases and a review of literature," ES/MM/09/48 U.K. Health and Safety Laboratory.

[5] Looking across this research it is clear is that the industry and scientists are still learning about these casks. The first stainless cask was put into service in 1989 and only a few (3-5) cask systems have been through their first round of relicensing after the initial 20 year period.

[6] [cite here the email traffic between Mark Lombard, Donna, and Tom Palmisano from last week]

currently in service in the US. When we look at how the industry updates its procedures in light of information we should expect to see studies like the 2013 EPRI analysis adjusted periodically as new data comes in. That's crucial to a long-term plan that is adaptive to new information. What I see at EPRI and elsewhere is a big effort, delivering results, to do exactly that.[7]

The EPRI report is a complicated study, but let me highlight a few key observations and findings:

- While the license period is 20 years the typical useful service time for casks is probably more like 40-50 and could extend to 120 years;
- There are two trends that move in opposite directions. On the one hand, the risks of corrosion and damage to casks rises over time as environmental exposures accumulate and as materials age. On the other hand, the consequences of cask failure—in particular, cracking—decline over time because the half life of the materials that could most readily escape through a crack (gases) is relatively short. And the heat load on the cask also gradually declines over time.
- The dominant risks come from hazards OUTSIDE the casks, such as salt and biological corrosion. That insight suggests that the first line of monitoring should come from inspection of the outside of the casks on a regular basis (more on that below);
- Many of the cracking modes that have been the subject of concerns with stainless steel elsewhere in reactors—such as fatigue and the production of corrosive materials through "radiolysis"—are "non-credible" (see section EPRI report, section 4.2.6).
- The process of license renewals is producing substantial amounts of useful information about aging—for example, the license renewal for casks at Calvert Cliffs has provided much information about the impacts of fatigue. We should be happy that we in the SONGS communities are making cask purchase decisions and will be developing aging management programs later in the game. We will learn a lot from the others who precede us.
- There are three basic failure modes for cask walls that need attention (see section 4.3). Two of them are particularly unlikely. For the casks in our marine environment at SONGS the failure mode that seems to be of greatest concern is through-wall cracking that begins with corrosion on the surface from salt. That this problem exists does not mean that it can't be readily mitigated. Mitigating this problem requires periodic inspection of the canisters as well as monitoring of the composition and concentration of the deposits that accumulate on the surface of the canister. At this stage, it isn't clear to me what "periodic inspection" might really means in practice—nor

[7] Full disclosure: I am one of the independent directors on EPRI's Board of Directors. As with the other independent directors, one of my tasks is to hold EPRI accountable to its public mission as a non-profit research entity; these long-term aging programs are one of the areas where I have focused.

how much we can learn by looking at aging results at other sites versus the amount of real inspection that needs doing at SONGS itself. As fundamental knowledge rises the need for inspection may decline; as casks age the need for inspection may rise. More on that below.

- The best solutions to these problems come from monitoring and prevention. Particularly important will be the regular monitoring of temperatures and radiation around the concrete overpack as they can signal the conditions that would be pre-cursors to canister failure and also canister failure itself.
- A variety of expert studies reviewed and assessed in two EPRI studies shows that there is "no credible … pathway" to criticality of the fuel inside canisters. In the worst case analysis of an implausible scenario—substantial cracks in a cask followed by the intrusion of water sloshing around inside the cask—it is still impossible for the fuel to become critical (page 4-26). Results from an actual cask that has been allowed to leak slowly for 2 years show, as well, that intrusion of water and the formation of hydrogen gas can't reach explosive levels (section 4.4.3, page 4-25). I learn two things from this work. First, there is simply zero basis for the highly emotive statements that I have seen in the press and various other locations for the view that long-term storage of the fuel on site at SONGS has put "another Fukushima" or "another Chernobyl" in our backyard. We do the public a disservice with such emotive language since it creates images that are not in any way rooted in the technical assessment of the real risks. I would prefer the fuel gone, but the explosive consequences of highly concentrated critical fuel and accumulation of explosive hydrogen gas that were the root causes of Chernobyl and Fukushima has absolutely nothing in common with our situation here at SONGS. Second, we in the SONGS communities stand to learn a lot from the broader industry experience with aging casks provided that we actually use casks that are similar to the industry standard. Particularly important for us is the data coming from the other sites in the US that are further along and from the collective research and operational studies at EPRI, NEI, NRC and some of the national labs. I have been struck that this is one of many reasons for the "safety in numbers" logic when choosing a cask vendor.

As these casks age there may need to be a more active non-destructive evaluation (NDE) program for inspection that would evaluate casks on-site beyond just visual inspections. In addition to NDE there may need to be a more active modeling program to assess and predict corrosion and aging over time; in turn, those efforts could guide physical monitoring and NDE with greater precision. My sense is that the building blocks for all these efforts are in place, but it isn't clear how far along the industry and NRC are in developing such a strategic plan that would be adaptive to new information. We should ask the vendors and we should ask the experts, perhaps in the context of a workshop held in tandem with a CEP meeting when the CEP next looks closely at spent fuel. What is clear from the research is that this field encompasses a well-understood realm of chemistry and metallurgy and the relevant responses are within the realm of what industries that work with stainless steel already do.

Question 3: How would cracks be detected and addressed—especially since casks are stored in overpack and not readily monitored directly?

See answer to question 4.

Question 4: If a crack were detected in a cask, what is the timeline for removing fuel from the cask, replacing or repairing the cask and putting the fuel back into cask? Without an onsite spent fuel pool, how would this be done safely and efficiently?

I think questions 2 and 3 are two of the most important questions that the CEP has asked me to investigate. While this question 3 focuses narrowly on how we detect problems with the casks and question 4 focuses on the timeline for action after detection, both of these questions are central to a larger question of how the SONGS site will adopt what might be called “defense in depth.” What are the layers of monitoring and defense that will help us detect and fix problems before they become serious, and how the site managers respond if such problems arise?

My read of the literature is that the industry has not articulated what “defense in depth” means in practice but that <u>there is a lot more going on in this realm than is immediately apparent.</u>

My impression is that defense in depth is unfolding on three fronts. First, the cask system is designed for layers of defense with the concrete overpack distinct from the cask that sits inside.[8] The collection of concrete overpacks are, in turn, surrounded by a berm at SONGS and layers of active defensive systems—a scheme described in more detail in a document from Edison attached as Appendix B.

Second, the NRC offers periodic oversight—in particular during the renewal of cask licenses after 20 years. I say “some” because it is not yet clear to me how aggressively NRC oversees this process, and with an array of license extensions in the near future—12 in the next six years alone—we will learn a lot more about how this process really works. I am comfortable with that approach because by the time that the existing casks at SONGS need relicensing (beginning about 2020) we will know a lot about what works and doesn't.[9] What is clear is that NRC has a set of

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[8] And within the cask, depending on the design, there are multiple layers of defense as well. We should ask the cask vendors how each ofthese systems perform under different circumstances—for example, in an extreme seismic event how will the fuel racks inside the cask perform and will they protect the fuel and cladding against failure.

[9] The existing casks at SONGS are relatively young and are still in their first 20 year license period. According to NRC rules, the casks on site today will need to file for a renewal in 2021 and obtain it no later than 2023.

process-oriented regulations that guide license renewal.[10] Although the specific obligations are general—for example, licensees must that include, among many other things, "evaluate potential aging effects"—the renewal process includes extensive flowcharts and procedures aimed at the weakest links in the canister system. Overall, it is performance-oriented, as it should be, so there is flexibility for each site to develop its own plan. One striking aspect of the process is the idea of a "critical canister." Prior to license renewal the canister most likely to suffer damage—for example, the canister that has experienced the most extreme heat loads or exposure to corrosive salt—is subjected to particularly intense scrutiny. My read of the process is that that the canister must be pulled from the concrete overpack and inspected. If that canister is found wanting that perhaps others would be pulled as well and inspected until the NRC is satisfied that another 20 years extension is warranted. That means that the whole industry will be gaining information from many canister pulls associated with license renewals.

As more of these extensions are granted and the industry gains real experience of real hazards to the canister I assume that the "critical canister" concept will be adjusted—perhaps it is multiple canisters that should be pulled in some environments. In addition, the regulatory system is based on what NRC calls "Time Limited Aging Analysis Evaluation (TLAA) and an Aging Management Program (AMP) that can be tailored to individual canisters. Perhaps, at some sites, none need be pulled. It strikes me that this is the right kind of regulatory system—one that is adaptive to new information and is performance-oriented so that it can be adjusted to local circumstances and real world experience. The system is designed to avoid the need to open canisters and look inside—something that is quite difficult and probably should be avoided whenever possible since that process can add extra risk to workers. When I look across the totality of the NRC program it is also clear that the NRC is focused, as it should be, on places where there are still substantial uncertainties—it is risk averse where we know less and concentrated getting research done to narrow those uncertainties. For example, there are uncertainties about how fuel pellets swell over time and how they respond to water; there are uncertainties about when and how radioactive gases might be released from the pellets stored inside canisters.[11] This information and adjustment strategy strikes me as important not just because it can lead to better regulation but also because it is focused on ways to gain information that can be used across the industry. For example, there are periodic studies that do actually open canisters and look inside—many of those are cited in the NRC regulations (see p.20). Wherever possible, SONGS should be doing exactly what everyone else in the industry does—that maximizes the opportunity to learn from other plants and minimizes risk.

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[10] e.g., NUREG 1927 "Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance" (2011)

[11] see especially pages 2-3 of: *Annual Status Report: Activities Related to Extended Storage and Transportation*, USNRC, SECY-13-0057, dated May 31, 2013.

Third is a plan emerging in parallel from the Nuclear Energy Institute (NEI). This plan, known as "NEI 14-03," is expected to be released in final form for NRC review next month and approved by NRC before the end of the year.[12] What I know about it I glean from a 14 March presentation by the key person at NEI;[13] when the final version is released I will send around copies to the whole CEP. Some of the key points from NEI's work that are most germane for us in the SONGS communities include:

- To date, there have been three detailed inspections of actual canisters at actual coastal sites analogous to SONGS—none of them indicate any significant problems with chloride corrosion.
- The NEI approach will be based heavily on "toll gates"—that is, periodic checks on the performance of the casks that is an "extra layer of assessment" beyond what is done through regular checking and assessment (slide 13);
- The overall approach would make license renewals more streamlined (something that matters to the industry) and safety-focused (something that matters to the communities around these plants). I think we benefit from a licensing process that can focus like a laser on the parts of the system that might become vulnerable with aging—and then apply lessons from one site across the rest of the industry, including SONGS—rather than a system that is ad hoc and plodding.

At this stage I don't know if we can provide definitive answers to question #4. My impression is that the only defects that are likely to arise with long-term aging of the casks are minor defects on the surface of canisters and possibly with concrete overpacks. In the case of canister defects the repairs are rapid—a matter of days to clean and resurface an affected area or perhaps weeks to arrange a new weld. The NRC has stated that the industry has already proven that it has methods for identifying and repairing stainless steel cracks in difficult environments and has proven the ability to develop new methods as needed.[14] What's not clear to me is the strategy that would be followed in a worst case situation—where a cask started leaking for some highly unlikely reason. We should put that question to the vendors; I have already done this once, in a query to the vendor for the existing casks, and it is clear that there are several remedies that could be feasible.[15] My guess is that the most prompt response would involve putting the leaking cask into

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[12] Since this plan is not an official NRC activity I am not sure, as a legal matter, that NRC actually approves the plan. What is clear is that NRC and NEI both have a strong interest in each other agreeing on a common strategy.

[13] Cite here 14 March NEI aging plan. Possibly adjust main text if NEI supplies newer draft.

[14] Email replies from Mark Lombard (26 August 2014) in response to questions raised by Tom Palmisano and Ted Quinn and points made in a 25 August petition by Gene Stone and Donna Gilmore.

[15] Fact sheet from Areva (via Jim Madigan at Edison) in response to the questions posed on 23 August by David Victor; email detailed 25 August 2014.

a transport cask so that it is sealed from the environment. Then, the fuel might be moved in a "hot cell" or a pool—the industry has developed both technologies, although hot cells of adequate size do not currently exist "off the shelf" and a pool would not exist on site once the rest of SONGS is decommissioned. I don't see a need to have firm, final answers to these questions immediately but clearly these will be part of long-term "defense in depth." Having an on-site pool for such a remote contingency is probably quite impractical and would lead to an ISFSI that has a much larger footprint than the public favors---various comments from the public suggest to me that the public wants the footprint as small and secure as feasible. The transport cask option—or a similar arrangement with a spare overpack sleeve—might be the best one, but that could require pre-positioning such casks in the US for such contingencies, just as the industry shares other types of pre-positioned material. All of these are questions that are amendable to analysis using existing methods and probably require an industry-wide strategy.

For the concrete overpacks the timing of repairs is not critical assuming that defects are caught in time—which is what the NRC and NEI schemes would assure. According to Tom Palmisano at Edison, there is one documented case of a concrete overpack suffering minor external damage—something that was readily detected and repaired.[16] This type of activity doesn't strike me as rocket science and the industry is already adequately focused on the problem of concrete aging. In the worst case, an overpack could be replaced easily with the cask simply moved to the new overpack on the same pad.

Very far down the road at the end of the lifetime of the casks—which might be 50 to 100 years if not longer—then a temporary pool would need to be constructed on site to allow offloading of fuel and reloading of the new canisters. I don't see that contingency as material to our decisions today since the need for such a pool would be easy to anticipate with many years of advance notice.

After reviewing all these materials I see a "defense in depth" program that has physical, informational and strategic elements. The physical layers of defense start with the cask and the over-pack. The informational elements include monitoring the casks—especially temperature and radiation—as signs of failure, along with ongoing monitoring of corrosion and decay. The strategic elements, which are perhaps the most crucial for the long-term, are just taking shape—they include research on aging and industry-wide sharing of experiences. When I started this research project, frankly, not much of this was evident and that has created the false impression that less is going on in this domain than needed.

When I look across all the elements of "defense in depth" I draw three conclusions. First, the next time the CEP looks at spent fuel management we should ask Edison to articulate for us in plain English what "defense in depth" means for the SONGS site. The document at appendix B of this memo is an excellent start to helping us

[16] Cite Tom Palmisano statement at CEP meeting about Crystal River overpack

understand the procedures, but what exactly will be done, when and how? Answering this question really is a matter for the whole industry—vendors, utilities, NEI, EPRI, and the NRC along with the research community—in addition to Edison itself. As we grapple with these issues in the CEP we should be paying more attention to the broader industry-wide efforts.

Second, I have seen in the press much discussion of the need to wait to buy the "right" casks because this is an expensive purchase and we should "purchase them once." (I am paraphrasing comments from many officials.) I don't think this is the right way to think about the challenge. We have casks that are widely used in the industry that deploy the latest technology and are licensed by the NRC. Those are our options. Waiting doesn't change the laws of physics and chemistry that dictate how materials like stainless steel age. What's needed is the smartest cask decision today and then a smart aging and defense and depth scheme for the future.

Third, we should ask Edison to explore nominating SONGS to be one site where the industry does long-term aging research. Clearly that would be beneficial to the industry but it would also help assure us in the SONGS communities with the largest amount of real data on the real status of casks at this site. As a practical matter that might involve pulling additional canisters for surface inspections and more detailed monitoring of concrete overpacks. I don't know if the SONGS site would be a viable one for actual internal canister inspections since the site itself may not be an effective place to open canisters and moving canisters from SONGS to some research location may be impractical. But we should explore what might be done with research on the site, whether the costs could be reasonably recovered in the trust fund, and how this site might fit into the industry-wide aging management program.

Question 5: What is the internal pressure of a cask during storage, and how would leaks from helium over-pressure be detected? Are we safer with casks that have pressure monitors built in or with welded casks that do not contain those monitors?

The EPRI 2013 study cited above includes detailed information on cask designs. It appears to me that the internal pressures vary by design and are as high as 100 pounds per square inch (psi). Compared with many other uses for stainless steel in piping, where pressures rise to thousands of psi, these pressures strike me as quite modest. At SONGS the casks with the unit 1 fuel are pressured with Helium to 1.5 psi; the casks for units 2 & 3 fuel are 6.5 psi.[17]

The helium injected at pressure into the casks before they are sealed is extremely important as it helps keep the fuel cool and prevents contaminants, including water, from entering the cask. A helium leak would be detectable both through variations in temperature and also, in the extreme, release of radioactive materials. The EPRI

[17] Email from Jim Madigan to David Victor, 25 August 2014

2013 study makes it clear that one of the central issues in assessing the impacts of a cask failure is the rate at which helium escapes and is replaced by air or other contaminants. As air replaces the helium the temperature of the fuel rises and that raises the risk that the wrapping around the fuel (known as "cladding") that holds the fuel together will fail and a variety of other risks. These risks decline as the fuel ages and cools. These risks also vary with fuel type. The CEP has devoted considerable time and attention to HBF, and thus it is worth noting that the temperature at which HBF fuel faces cladding failures is dramatically higher than for non-HBF. This is a reminder that in some respects HBF may prove easier and safer to store than non-HBF fuel. It is also a reminder that the technology keeps improving. Newer fuels are essentially all HBF but they also have better cladding. Newer casks hold more fuel assemblies but they also have much better mechanisms for dissipating heat. (Holtec, for example, has now built a rack to hold the fuel inside the cask out of carbon nanotubes that probably has lower risks than older racks that are made from aluminum.)

How much equipment is needed on the cask itself to monitor pressure and safety? At first blush the right answer might be "as much as possible," and that is one reason that the Castor system might be attractive. My sense is that is not the correct answer for three reasons. First, we must remember that the Castor system has a removable, bolted lid—an application that makes sense in Europe but is probably unwise for extremely long-term storage that is envisioned here in the US. A lid with moveable bolts and O-rings needs more monitoring.

Second, with helium under pressure inside the casks and good monitoring of other parameters outside the cask we can gain essentially the same information—including early warning of failures.

Third, safety systems such as through-wall monitors bring risks of their own. In my professional life I do a lot of research on how real organizations manage complex systems. In that work, once of the books that has influenced me the most is Charles Perrow's *Normal Accidents*. Written by a sociologist, that book looks at why some complex systems are easier to manage safely than others and one of the central conclusions from his study is that sometimes active safety systems actually makes things less safe. When you drill a hole through the wall of a reactor vessel or a cask and install a sensor you get information about what's going on inside, but you also get a new failure point. Thus systems that are purely passive and welded shut are probably a lot safer than those that are bristling with through-wall sensors and can be opened and closed. I think that insight applies especially for systems that need to be safe for the very long haul and in environments where we don't know exactly how the sensors and lids would age.

Question 6: What is the track record with corrosion in concrete overpacks? How can corrosion be detected and addressed?

The concrete overpacks play a crucial role for "defense in depth" in the US system for storing spent fuel on site. They are the first line of defense. They provide physical protection for the canisters as well as radiation shielding and they help manage the heat flow away from the canisters as the fuel cools slowly over time. The fact that the overpack is physically distinct from the canister is probably a big advantage in the U.S. system for long term storage when compared, say, with the thick-walled European casks that are "all in one" systems with no overpack. If there is a problem with the concrete overpack then the canister can be moved to a new one.

As noted above, to my knowledge there is just one incident of a concrete overpack suffering material damage from aging. Since the most vulnerable to corrosion elements of the concrete overpack are directly visible I don't expect that any significant issues will arise with this, and if they do it is trivial task to remove a canister and put it in a new overpack. There may be some licensing issues with that if, for example, a new overpack would need to be built and that expanded the footprint of the "ISFSI" pad on which the casks are stored, but addressing those issues would be straightforward.

The CEP has already looked into the questions related to seismic and tsunami risks and found that the design of the current (Areva TN) system to be vastly beyond any plausible risk in that domain.[18] The underground Holtec system, which is the other leading contender for the SONGS contract, has similar performance.

Question 7: With fuel assemblies stored inside casks and not observable directly, how will we know if fuel assemblies—including HBF—degrade or damage with age? How will missing knowledge on this question be filled in and practices adjusted?

I think this question has been answered in the answers to questions 3 & 4. It is clear that the single most important indicator of fuel assembly integrity is temperature.

[18] This issue arose at the first CEP meeting in March 2014. On the CEP's behalf, CEP member Bill Parker researched it and reported back to the Panel on 22 May by email and also with a statement at our CEP meeting that same day.

Safety of long-term storage in casks:
Issues For San Onofre

Report of the Chairman of the Community Engagement Panel of the San Onofre Nuclear Generating Station

David G. Victor

20 October 2014

It is likely that spent fuel will be stored in dry casks at the San Onofre nuclear site for very long periods of time—most likely well beyond the 20-year period for initial licensing of the casks. Thus many members of the Community Engagement Panel (CEP), along with the public, have urged us to pay attention to the long-term plan for management of those casks. Indeed, the need for a long-term strategy emerged as one of the central themes of a survey of CEP members that vice-chairman Tim Brown and I conducted in July 2014.[1] The CEP will revisit these issues in early 2015 with a special focus on what, if anything, the CEP and the communities around San Onofre can do to help push the Department of Energy and the rest of the federal government to honor the promise that they would remove the spent fuel from sites such as San Onofre. Meanwhile, important events are happening at San Onofre—including decisions about which vendor will supply the casks. Many CEP members have raised questions about how those decisions affect the long-term strategy for storing spent fuel on site; some have also questioned the integrity of the cask systems.

Over the last three months, I have led a task force, organized around answering 7 questions that cover the main concerns and issues raised about the choice of casks and the long-term strategy for spent fuel storage at San Onofre.[2] The central purpose of that task force has been to learn what the technical literature says about these issues and to map out the areas of disagreement that are relevant to us at San Onofre. This report, one result of that work, distills my assessment of what we have learned and presents the relevant technical information in plain English. It also offers my assessment of what the facts imply for long-term storage of spent fuel at the San Onofre plant. In a few places, where readers may want more detail, I have added footnotes. I have also signaled many of the areas of disagreement, as there is a range of opinions on many of these questions; Appendix C also has some additional views from task force members to help the reader understand the fuller range of views.

This report is my assessment as an independent person having now looked at a massive array of data and analysis with an eye to the best options for our situation here in San Onofre. I alone am responsible for the conclusions of the main report, but I have benefitted from an extensive peer review of earlier drafts, including many conversations in our task force, and extensive correspondence with industry experts, regulators and members of the community. I have made all of those review materials available as a matter of public record.[3]

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[1] Tim Brown and David Victor, "Interim Assessment of the CEP's Work," 19 August 2014 (circulated to CEP members in advance of the 28 August 2014 regular meeting)

[2] Task Force Members: William Parker, Ted Quinn, Gene Stone and David Victor (all members of the CEP) joined by Donna Gilmore (member of the public).

[3] "Reviews of 1 September Drafts: Memo and Related Materials" (online at songscommunity.com). A special thanks to David Lochbaum and Frank von Hippel

I see four conclusions emerging from this report:

First, we in the communities around SONGS must look way beyond 20 years, which is the initial license period for casks by the Nuclear Regulatory Commission (NRC). When our task force began its work I was concerned that, on the surface, it appeared that NRC wasn't focused on this period beyond 20 years and that the whole process of setting 20-year time horizons was artificially short. What I have learned is that NRC is in the midst of developing a new system for long-term monitoring and regulation of aging casks, and NRC has already been through re-licensing (for another 20 years) casks at two sites and will soon re-license many other aging casks. This relicensing process has included visual inspections of some canisters, and new rules are likely to require additional inspections based on the actual operation of aging casks. Moreover, NRC's regulations in this area are only a small part of how the industry is facing this challenge and its approach is highly procedural. New procedures are taking shape through the Nuclear Energy Institute (NEI), and there is an active research program on aging at the Electric Power Research Institute (EPRI), several national labs and other locales.

Kessler 10/28/2014 8:17 PM
Comment [1]: More than two sites have been granted license renewals now for a total storage period of 60 years. EPRI can get the exact number if desired.

This report outlines some of the key insights from the multi-layered effort to manage aging materials, including casks. I call that program "defense in depth." "Defense in depth" means routine inspections; redundant systems with safety margins so that if one fails others are still in place; physical security against natural and human hazards; and physical isolation of hazardous materials and activities from those hazards. If one element of defense in depth is weak then other elements need strengthening so that the overall system functions safely and effectively. "Defense in depth" is about layers of defense and monitoring so that the system, overall, is robust for the long term.

Kessler 10/28/2014 8:24 PM
Comment [2]: NRC includes this concept when it uses the term "reasonable assurance". From NRC's regulation for spent fuel storage, 10 CFR Part 72:
72.3 Definitions:
Structures, systems, and components important to safety means those features of the ISFSI, MRS, and spent fuel storage cask whose functions are--
(1) To maintain the conditions required to store spent fuel, high-level radioactive waste, or reactor-related GTCC waste safely;
(2) To prevent damage to the spent fuel, the high-level radioactive waste, or reactor-related GTCC waste container during handling and storage; or
(3) To provide **reasonable assurance** that spent fuel, high-level radioactive waste, or reactor-related GTCC waste can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public

Any long-term scheme like this involves uncertainties. My impression is that the NRC and the industry have not, so far, conveyed to the public in a clear way exactly what "defense in depth" will mean in practice. Part of this lack of information simply reflects that the public has never asked for that information. Part of it reflects that the regulatory process is highly focused on cask licensing and license renewals—along with all the head-spinning technical details associated with those processes—rather than explaining in plain English the long-term strategy for management of spent fuel on site.

I have learned to appreciate that not everyone trusts the industry to do "what's right" and the levels of mistrust around the regulatory process are high as well. Some elements of what will be needed for "defense in depth" are not yet fully in existence—for example, actual equipment that would allow removal of fuel from

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who provided full, independent reviews of an earlier draft as well as several officials from the Nuclear Regulatory Commission and Edison who provided extensive input—as detailed in the review materials. I am also grateful to Marvin Resnikoff, a cask without an onsite pool has been designed but not yet actually built. Similarly, full-blown procedures for repairing all forms of cask cracking are not yet fully certified because they have not yet been needed. The industry, however, is already using these same techniques in many situations that are much more challenging than repairs on a spent fuel canister—for example repairs of nozzles in operational nuclear reactors. For people who are prone not to trust the industry and regulators, the lack of a full-blown system being in place feels like another promise that might be unfulfilled. For people that are more comfortable with how these technologies evolve and are regulated, the overall direction of this system is more comforting. It is very easy for people with these "two views" of the industry and its regulators to talk past each other. [4]

Kessler 10/28/2014 8:56 PM
Comment [3]: This is true in the US, but a demonstration of a prototype was performed at the Idaho National Laboratory in the 1990s: See EPRI report TR-113530: *Cold Demonstration of a Spent Nuclear Fuel Dry Transfer System*, 1999.

Recommendation: An early draft of this report included the recommendation that the CEP meet with the two viable cask vendors and ask them what "defense in depth" means and how they, as vendors, will service these casks for the long haul. In response to that recommendation, that meeting was held on October 14th, 2014. That meeting revealed that there is a tremendous amount of useful information that is not visible to the public eye yet highly germane to how we in the public should assess the safety and security of spent fuel storage on site. As this process unfolds, we should focus not just on the repair and replacement of casks over the long haul but also the strategy for monitoring of casks for corrosion and cracking—a process that must be difficult since the surfaces of the stainless casks that matter most are inside the concrete overpack and not directly visible by workers. We need to ask these questions of the vendors themselves because it is clear that the vendors play a pivotal role in the regulatory and management process. At the same time, we should ask Edison to articulate over the coming year how "defense in depth" will work and how the industry is preparing for long-term management. It would be helpful to have clear graphic diagrams of credible hazards and the responses, as well as a sense of the probabilities that are assigned to these different hazards. It is very easy for the public to focus on particular, emotive scenarios—for example, terrorist attack with high explosives—while not appreciating the many layers of active and passive defenses that radically diminish those risks. Absent better information about what is being done—within the limits, of course, of the secrecy needed to keep adversaries from learning about our defenses—it is hardly surprising that the public is not better informed about real levels of risk. This problem of risk management, preparedness and communication is as old as the nuclear power industry itself.

Recommendation: When the CEP revisits this issue in early 2015 we should consider holding a workshop with NEI, EPRI, NRC, and national watchdog groups that are focused on this issue industry-wide. One of our roles in the CEP could be to help articulate in plain English how "defense in depth" will work at SONGS. That would help all of us focus on the elements of that strategy—including the uncertainties—that are really important. My assessment is that the uncertainties

Kessler 10/28/2014 8:58 PM
Comment [4]: EPRI may or may not be able to provide input to what "defense in depth" means as it is partially a policy-based definition.

[4] I thank Gene Stone, in particular, for helping to articulate this issue.

involved—such as long-term aging of the fuel inside the casks, integrity of cask walls, repairs of the walls and overpack if needed—are all completely manageable, do not require fundamentally new types of material and other sciences, and are within the realm of what good organizations know how to do already. We also need to ask vendors, Edison and the NRC about protection of the canisters against direct attack, such as by terrorists.

Recommendation: The CEP and many other bodies should continue their work to press DOE for long-term storage sites as well as consolidated interim storage.[5] When the CEP revisits this issue in early 2015 we should be sure to discuss where and how the CEP can help put pressure on the federal government to remove spent fuel, especially from decommissioned sites such as SONGS.

Second, because we face long-term storage on site, we must recognize that regardless of which vendor is chosen, the casks will age. Eventually, the casks will need replacement; some may need repairs along the way. Other events may occur that require special monitoring and handling. This is hardly surprising since all such materials age over the long haul. Yet, at the same time, the rest of the plant is being decommissioned and the overall site is being shrunk so that it encompasses just the "ISFSI" pad on which the fuel and canister systems sit.

Recommendation: As the decommissioning process proceeds, the CEP and outside experts should look at the major events for which contingencies are needed. This articulation should be about strategy and vision, not nailing down the particular technologies that should be in place 50 years from now. It would be inappropriate at this stage to demand to know exactly what kinds of technologies will be used for those tasks. For example, removing fuel from a cask might be done in a pool or in what's known as a "hot cell." At our meeting on October 14th we learned that new technologies are emerging that might make pools and hot cells unnecessary. Moreover, it seems likely that the key pieces of technology will be shared among many sites. What is needed is a vision for the key major tasks and a sense of the timescales involved. For example, if a critical technology such as a hot cell might be needed, what is the time horizon needed to build or obtain one? What would be done in the interim if monitoring programs discovered a damaged cask? Some attention is needed, as well, to the non-technological issues. For example, if the site is shrunk will there be enough space on the ISFSI for these tasks to be performed? If critical technologies such as hot cells or back-up casks are shared among multiple sites, how will they be moved around if the rail spurs are removed during decommissioning? If the trust fund ends in half a century once decommissioning is complete, what contingencies are needed for long term funding? It is my assessment that there are plausible answers to such questions, but they need to be articulated.

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[5] Lee Hamilton and Brent Scowcroft (chairmen) et al., *Blue Ribbon Commission on America's Nuclear Future*, Report to the Secretary of Energy (January 2012),

Third, I remain convinced that the safest option for us starts with getting the fuel out of pools and into casks as soon as that's practical. In the pools all the fuel is sitting in two locations and is kept cool with active systems—pumps, circulating water, etc. In casks it is divided into more than 100 new independent containers—each designed to withstand massive shocks—and relies only on passive cooling. All else equal, decentralized passively managed systems are safer than centralized active schemes.

Recommendation: While we should study the many options and continue to articulate views about the best strategies, we must also remain mindful that there are tradeoffs with delay. We need to encourage Edison and the various vendors to make diligent decisions and then get on with the business of decommissioning.

Fourth, when this work began, Edison was focused on two vendors for stainless steel casks. Both of those vendors already have a large presence in the U.S. market. It has been very useful for us to pause and look more widely at the range of options—including European vendors of canisters not currently licensed in the United States and which were not under consideration by Edison. We have learned a lot, and that pause would not have happened without the CEP's involvement. It is now time to move on.[6]

My assessment is that the SONGS co-owners are wise to be focusing on just the vendors of stainless steel casks who have a significant presence in the U.S. I appreciate that some folks want SONGS to look at vendors from Europe who use a different technology with very thick iron walls rather than thinner stainless steel. Having looked at the totality of the evidence—in particular, a thick walled cask called "Castor" from a German company Siempelkamp Nuclear Services—I don't see that option as viable for the long haul here in the U.S. Technically, the cask with thick ductile iron walls has some advantages when compared with stainless steel casks that are ubiquitous in the U.S. nuclear power industry, but the ductile iron material used in those casks have some substantial disadvantages as well. Moreover, the bolted lid used on that particular cask has additional disadvantages. The paramount concerns I have are twofold:

a. First, is a matter of regulation. While the Nuclear Regulatory Commission has a process in place to approve new cask designs, Castor's general license expired in 2010 and no new license application has been filed. Because this cask is quite different from those widely used in the industry and there is no precedent for storing the type of fuel from San Onofre in the Castor cask, Thus gaining regulatory approval, if at all, for this cask is not an entirely straightforward matter. While the legal procedures that would be followed to seek a license are well known, the actual review and

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dful that there are different points of view on this. [redacted]: [redacted]

Kessler 10/28/2014 9:08 PM

Comment [5]: NRC staff concluded – and the NRC commissioners agreed – that both wet and dry storage are safe and there is no need to accelerate the transfer of spent fuel from pools into dry storage. See NRC's COMSECY-13-0030: STAFF EVALUATION AND RECOMMENDATION FOR JAPAN LESSONS-LEARNED TIER 3 ISSUE ON EXPEDITED TRANSFER OF SPENT FUEL: "The staff concludes that the expedited transfer of spent fuel to dry cask storage would provide only a minor or limited safety benefit (i.e., less than safety goal screening criteria), and that its expected implementation costs would not be warranted. The staff therefore recommends that additional studies and further regulatory analyses of this issue not be pursued, and that this Tier 3 Japan lessons-learned activity be closed."

EPRI also conducted an analysis of the pros and cons of accelerated transfer: EPRI report 1025206: *Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage After Five Years of Cooling, An Update.* EPRI, Palo Alto, CA: 2010.

Kessler 10/28/2014 9:12 PM

Comment [6]: NRC's regulation 10 CFR 72.214 lists the current approved storage system types. There are a couple of bolted metal systems that have received licenses and are in service in the US. One site in the US, Surry, uses CASTOR V/21 casks. Several sites use more modern bolted metal cask designs, such as the TN-32, TN-40, and TN-68 bolted metal casks. EPRI can get a more exact number of bolted metal casks that are in operation, but it is approximately 400. The first bolted metal system – a CASTOR V/21 went into service in 1986, and has received a license renewal for a total storage period of 60 years. However, the majority of bolted metal casks that are currently licensed and deployed are of the AREVA TN type.

approval of that license would be unknown territory for the U.S. industry and regulators. It is possible, as well, that the Castor system will face troubles with seismic approval since, to my knowledge, the system has never been licensed at a site that has the strict seismic requirements at SONGS. The Castor cask is so different in design, size and weight from the stainless steel casks that dominate the U.S. market that it is *possible* that the cask would never be approved for transport or disposal in the U.S. That creates, for us in the SONGS community, the risk of delays. Worse, it creates the risk of getting stuck with casks that are not approved for transport or have no ultimate home in a nuclear waste repository or a consolidated interim waste storage facility when those facilities are ultimately built. That would be a worst case outcome for us in the San Onofre communities since the one thing I have heard from everyone is that they'd like the waste removed as soon as practical.

b. Second, opting for that cask—or for any design other than the dominant stainless steel casks—would put us alone in the U.S. industry and thus unable to benefit from lessons learned at other U.S. facilities. (The German cask does have a large share of the international market, but in a highly regulated industry what matters most is the share of the market in which one lives.) It would leave us particularly vulnerable if Castor's manufacturer went bankrupt or otherwise decided not to continue investment in the U.S. market—leaving San Onofre as possibly the only site in the U.S. deploying that technology. What if, for example, problems arose with Castor's bolted lid—indeed, there are documented problems with bolted lids in other settings. If San Onofre were the only site with these casks then San Onofre would be fully exposed to the risk, including the cost, of devising a solution It is my understanding that the European nuclear industry is taking the lead on issues surrounding bolted lids, but in many countries in Europe that industry is on the precipice of being shut down. I appreciate that other analysts seem to be less worried about being abandoned by the vendor because there is a long history of bankruptcies and abandonments in the industry.[7] But my point is different: safety with long-term storage comes from good design, "defense in depth," and working with technologies that many other peer companies use at the same time. As of June 2013—which was the last full inventory of U.S. casks that I have seen—Castor had less than 1% of the U.S. market. Of the three cask vendors the best options are with Areva TN or Holtec—the two companies that dominate the U.S. market. These are exactly the two vendors that the SONGS co-owners are evaluating for final decision on cask vendor. (The third

Kessler 10/28/2014 9:14 PM
Comment [7]: This is incorrect as described in the previous comment. There are several hundred bolted metal casks that have received NRC licenses and have been deployed in the US.

Kessler 10/28/2014 9:15 PM
Comment [8]: See the previous comments.

[7] See Marvin Resnikoff's review of an earlier draft of this memo, "Resnikoff Critique of Victor Piece, not dated".

vendor, NAC, is not seriously being considered. They have only 16% of the U.S. market.)

Recommendation: Before we move on, we should ask Edison for its final assessment of the Castor option, including an assessment of the possible regulatory delays and the risk that SONGS would be stuck as one of the only purchasers of this system.[8] Their comparison, following the request of the CEP, looked at Castor against the three U.S. vendors and included an assessment of possible regulatory delays, risks that heavier and more numerous casks might create more opportunities for dropping of a cask during fuel movement, the number of fuel assemblies and thus the total number and footprint of the cask system, and other factors that allowed for a real apples to apples comparison.[9] We in the CEP must remain mindful that a serious analysis of this option has required access to proprietary information and thus it would be inappropriate for the CEP to do that analysis—a task for which we are not qualified. Indeed, this evaluation would occur at a time when one of the largest contracts for cask purchases in U.S. history is being awarded and all vendors will be particularly skittish about confidentiality as information could affect their prospects at SONGS and at other sites. We in the CEP have pressed Edison, appropriately, to share what it has learned yet we need to remain mindful of the limits to what can be revealed given the confidential business information included in such an analysis. To my understanding, nothing they have learned differs from the open and transparent summary of the concerns I outline in this report.

Kessler 10/28/2014 9:15 PM
Comment [9]: The TN series of bolted metal casks could be included in this assessment.

Kessler 10/28/2014 9:26 PM
Comment [10]: Two rather detailed PRA studies were conducted approximately ten years ago. One was completed by EPRI for a bolted metal cask design; the other was completed by NRC for a welded SS canister design. Both PRAs found a very low risk of latent cancer fatalities to members of the public.
EPRI report 1009691: *Probabilistic Risk Assessment of Bolted Storage Casks – Updated Quantification and Analysis Report*, 2004.
NRC NUREG-1864, "A Pilot Probabilistic Risk Assessment of a Dry Cask Storage System at a Nuclear Power Plant."

[8] Edison delivered that assessment as part of its presentation at the 14 October special meeting of the CEP. That assessment was limited because of non-disclosure requirements, but the preliminary assessment that did not face such limits is attaches at Appendix A to this report.
[9] I thank David Lochbaum at the Union of Concerned Scientists for articulating this comparison requirement.

Main Report

Question 1: Why are U.S. utilities using thinner walled stainless steel casks rather than thicker walled ductile iron or forged steel?

For better or worse, the United States long ago decided to have a "once through" nuclear fuel cycle. We put fuel in reactors and burn it partly and then refuel the reactor with fresh fuel. The spent fuel is then cooled on site, put into casks, and as a final step sent to a permanent long-term repository. Of course, that last step hasn't happened yet. By contrast, other countries—notably France—recycle essentially all spent fuel; many other countries recycle some portion of their fuel. Germany, the country where the Castor cask is most widely used, also reprocessed all its fuel until 2005; Germany is now in the process of shutting down its entire industry. In those reprocessing countries, fuel is put into reactors and burned partly; then it is cooled in pools, put into casks and sent to reprocessing facilities where fresh fuel is fabricated in part from the old fuel. I won't get into the question of whether "once through" or "reprocessing" are better economically or in terms of safety, but the reality for us is that it leads to radically different strategies for casks.

In the American system, the cask is designed to be a permanent home for the fuel. We put fuel into the cask, seal it, and then keep it there forever. That strategy means that we in America want to select materials for the cask that have extremely long lifetime (usually stainless steel—more on that below) and we want to weld the whole thing shut so that it is hard for anyone to open the cask.[10] Europe, by contrast, puts a premium on casks that can be opened and re-used and that have monitors and other systems inside the cask that can be routinely inspected and repaired. European casks, as well, rely on bolted lids that can safely be opened and closed because the trip into the cask for spent fuel is a brief affair. Because the bolted lid relies on removable sealing between the lid and the cask—for example, O-rings—such designs also require more active monitoring to ensure that the O-ring keeps working as designed. Such risks of lid failure should be dramatically lower when the lid is sealed with a weld, although I have not yet seen a true "apples to apples" comparison of lid failure risks over the long term. Having looked across the literature I have seen not a single example of a welded lid failure and some evidence of legitimate concerns about the long-term integrity of bolted lids.

These fundamental differences make it very hard to compare European and American casks. Both of the vendors under consideration for SONGS casks (Areva

[10] A small minority (11% by my calculation) of U.S. casks have bolted lids. Most are welded shut and essentially all new cask designs envision welding.

Kessler 10/28/2014 9:36 PM
Comment [11]: This 11% number is closer to being correct. But it still translates into the use of several hundred bolted lid systems in use in the US. Some bolted lid casks are still being purchased. Thus, there is both licensing and operational experience in the US of bolted lid casks.

Kessler 10/28/2014 9:28 PM
Comment [12]: The casks that are opened and reused are exclusively meant for transportation. Re-opening and reuse of casks meant for long-term storage followed by transportation is not done.

Kessler 10/28/2014 9:29 PM
Comment [13]: EPRI would like to know what type of monitors are being referred to. To EPRI's knowledge, no monitors are placed *inside* the casks.

Kessler 10/28/2014 9:33 PM
Comment [14]: Bolted lid casks are nearly universally used *for transportation purposes*. Even welded steel canisters will be placed inside a bolted lid transportation overpack during transportation. So the "reliance" is for transportation rather than storage.

TN and Holtec) have large overseas operations. But these vendors use different casks overseas than in the United States, and the regulatory approval processes are different in each major market

At least one design (Castor) uses very thick (about 14 to 20 inches) ductile iron walls, along with bolted lids. Iron may have some advantages over stainless steel in terms of integrity of the cask alone, but that is a hypothesis rather than anything proven. Thickness doesn't automatically mean safety, especially when it concerns long-term aging that might involve embrittlement. The Department of Energy has raised serious concerns about whether thick-walled casks have sufficient integrity—when Edison reviews the Castor design with Siempelkamp it should explicitly ask about these concerns. These concerns, along with the expectation that iron casks would be cheaper and thus favored by industry, led to some of the first research (by EPRI) on how iron casks would survive "drop tests" and other possible rough handling. At the time, one of the chief concerns related to embrittlement of the material and other hazards of manufacturing and aging.[11] Work on that issue in the United States waned, however, when it became clear that stainless steel options would be more cost-effective.[12] Outside the United States iron casks kept a greater market share and there has been more research on how iron casks actually perform. For example, there is a review paper written by the Department of Energy that points to research done in Japan and other countries, where these casks more heavily utilized, and that paper suggests that these embrittlement problems may not be a concern.[13]

For us, the critical point in all this is that thick walled casks have not taken off in the U.S. Some of those troubles may relate to cost—it is my understanding that the Castor cask is presently much more expensive than the stainless steel options that dominate the U.S. market and would presumably also create additional costs such as the need for a larger fuel storage pad, although we don't have an actual bid that would reveal the real cost. (That high unit cost may relate, in part, to low market share.) Some of the concerns relate to whether such a cask would ever be accepted in a permanent fuel repository. The Castor cask has never been licensed in the U.S. for transport or for permanent storage. If the concerns about embrittlement are not satisfactorily addressed to U.S. regulators then I would be surprised if a ductile iron cask were approved for transport in the U.S. Moreover, there is now substantial evidence that bolted lids may "creep" over time and the seals may leak—which is why the long-term storage market in the U.S. has moved almost completely to welded lids. The low market share for this cask in the U.S. would, in my opinion,

Kessler 10/28/2014 9:38 PM
Comment [15]: All bolted lid metal casks are rather thick. The thickness is primarily for gamma shielding purposes rather than to act as a corrosion barrier.

Kessler 10/28/2014 9:37 PM
Comment [16]: EPRI would like the reference for this statement.

Kessler 10/28/2014 9:40 PM
Comment [17]: There is not a significant difference in the size of the storage pads between welded and bolted lid systems.

Kessler 10/28/2014 9:42 PM
Comment [18]: The main reason for the switch to welded steel canisters is economic. Both bolted lid and welded steel canister designs meet the regulatory criteria.

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11 *Predrop Test Analysis of a Spent-Fuel Cask*, EPRI NP-4785 (1986).

12 Today, the stainless systems appear to be more cost effective. See National Research Council, 2006, *Safety and Security of Commercial Spent Nuclear Fuel Storage*, p. 63. Thanks to Donna Gilmore for pointing me to this source.

13 See Jeffrey A. Smith, Dick Salzbrenner, Ken Sorenson, and Paul McConnell, 1998, *Fracture Mechanism Based Design for Radioactive Material Transport Packagings Historical Review*, SAND98-0764.

create a big gap in how U.S. regulators could obtain the information needed to give their approval. The main U.S. facility that has about two dozen Castor casks has a site-specific license and thus little can be gleaned from that experience that might tell us about licensing of newer Castor designs at other sites such as SONGS. I find it instructive that the owner of that site has not purchased any more of the Castor design. Absent a license for transport or permanent storage, if utilities bought these casks they would potentially need to move the fuel from the cask into a new, final storage cask—which is exactly the opposite of the "once through" fuel strategy and would expose workers to additional radiation hazards as the fuel is transferred.[14]

Kessler 10/28/2014 9:44 PM
Comment [19]: Fundamentally, all of the bolted lid casks share common characteristics such that information gleaned for one type of bolted lid cask will likely be applicable to other bolted lid designs.

All this creates a "chicken or egg" problem for Castor. It is imaginable that the U.S. industry might follow a radically different path and use thick-walled casks. But nobody wants to go first—in part because there are good technical reasons to use stainless steel with concrete overpacks. And since the vendors know what the industry thinks, nobody makes a big investment in marketing and servicing these casks in the U.S. (Worse, the European vendors are about to face a severe crisis since electricity demand in Europe is flat; few new reactors are being built; and some countries, such as Germany and Sweden, are shutting all their reactors. That reality should make us worried about depending heavily on vendors whose financial lifeblood is in Europe unless they have other serious options elsewhere in the world.) This reality will not be altered by what we do at SONGS, and if we purchased Castor casks we might find ourselves stuck in the middle—neither chicken nor egg. That could mean that we would need to "repurchase" all of our casks when the time came to transporting the fuel off site or if some aging management problem arose that the vendor wasn't around to help us fix.

Kessler 10/28/2014 9:45 PM
Comment [20]: Quite a few US ISFSIs already use bolted lid systems. SCE would not be the first.

For our purposes, what is crucial to know is that these thick walled casks have essentially zero market presence in the U.S. In fact, the Castor design isn't currently licensed for use in the U.S. and thus even if SONGS were to purchase them there would be a period of uncertainty (and delay) in getting those casks into service. Edison's assessment is that would introduce 5-10 years in delay just for licensing,

[14] It is important to note that none of the U.S. stainless steel casks have been accepted in a U.S. repository, either, because such a repository does not exist. As far as I can tell, the Department of Energy is not far along in the process of setting the actual rules for storage, transport and disposal cask designs because it has not imminently faced the need to accept fuel for final disposal. That said, the fact that literally thousands of similarly designed stainless casks have accumulated at U.S. facilities all but guarantees that that design will be approved for final disposal. In the industry, this issue is known as "dual purpose canisters" (DPC), and I thank Frank von Hippel for drawing my attention to it. While there has not been urgency about licensing DPC because no repository exists, this topic is being studied and there appear to be no technical barriers to making it work. See notably: "*Perspectives on Dual-Purpose Canister Direct Disposal Feasibility Evaluation*," E.J. (Tito) Bonano, E.L. Hardin and E.A. Kalinina, Sandia National Laboratories. NEI Used Fuel Management Conference, St. Petersburg, FL., May 6-8, 2014

and none of the external reviewers of this report suggested that assessment is off base. In email traffic with members of the CEP the NRC has said that its licensing process could run only 18-30 months.[15] But that assessment is a procedural one—it is just the time required for a license to be reviewed by the NRC on the basis of materials and procedures that are already familiar to the NRC and is based on the assumption that no substantial problems arise during the review that would halt the review or require a re-submission by the vendor. It is quite plausible that SONGS would suffer the much longer-term estimate of a decade of delays in light of all the uncertainties at NRC and the complete lack of operational experience with these casks in the U.S. along with the many questions that have been raised about whether thick walled ductile iron is viable. My assessment is that the safest options for the long haul require buying casks that lots of other utilities use provided that Edison and the communities have confidence that these casks are matched with "defense in depth." That assures us that we can learn from the real experience across the U.S. industry and that we have lots of partners in case issues arise with casks over time. Even if the vendor of our casks were to go bankrupt, the large number of similar casks across the U.S. industry would guarantee that other vendors would appear to help us manage these casks safely as they age.

I have asked Edison for their assessment of the potential for the Castor cask, which I attach as Annex A to this memo. It summarizes many of the issues raised above. There are still a few unturned stones—for example, the manufacturer's response to the concerns raised about ductile iron and the need for a fresh assessment of the likely delays in obtaining regulatory approval. But as soon as those concerns are resolved—which can be done through a direct meeting between Edison and the vendor—I would consider this matter resolved. I am mindful that there have been calls, as well, for a public meeting with the vendor but if the vendor is not a viable option I don't see the purpose in such a public event.

Question 2: What is the track record with cracking of stainless steel similar to that used in casks?

Stainless steel has been used extensively in the nuclear industry and thus the experts are learning a lot about how it ages under stress.

The Nuclear Regulatory Commission (NRC) has focused heavily on how aging materials might fail and has an active program in this area. However, when we look at information from this program we must remember that most of NRC's focus is on stainless steel in pipes, vessels and other uses in ACTIVE nuclear reactors. These pipes operate under extreme pressure (hundreds or thousands of pounds per square inch, psi) in direct contact with water; they are cycled between hot and cold, high pressure and low, and thus will experience a LOT more wear in those extreme flexing environments than the stainless steel that is relevant for casks. The evidence

[15] email from Mark Lombard to David G. Victor, 22 Sept 12:35pm.

from stainless steel used in refueling water storage tanks (RWST) may be more relevant, but again the pressures and temperatures are different from casks. RWST tanks typically have lower pressure than many of the stainless steel pipes in a reactor, which could make them similar to the conditions in casks; but they come into regular contact with cold water, which makes them quite different from much warmer casks. Cold temperatures are a key factor in creating the onset of corrosion cracking. Much has been made of a failure of one RWST tank at the Koeberg power plant in South Africa, but we here in the U.S. have very little information about the quality and inspection of that stainless steel and its welds. (Below I look at this issue of through-wall cracking in more detail.)

Kessler 10/28/2014 9:46 PM
Comment [21]: EPRI will check to see what information it has on this.

My assessment is that we learn useful things by looking at how stainless steel ages in many different settings. But at the end it is crucial to apply those lessons with an eye to the actual physical conditions of the spent fuel canister. Within a cask the wall is dry; the pressure is low and constant and the temperature nearly constant. I have seen press reports about how stainless steel pipes have failed at San Onofre—and at other facilities around the world—that have included the implication that the same material would fail in the same way when used for casks. But logically that doesn't follow at all.

What really matters, therefore, is an assessment of risks for stainless steel used in cask systems. In that regard, I have found it particularly helpful to review a massive recent (2013) EPRI study that looks, on a 120-year time horizon, at ways welded stainless casks could fail.[16] This study is part of a pair of studies along with an ongoing EPRI program on materials aging in nuclear plants. This risk management approach is the right way to analysis risks across the whole system, but first let me comment on what I have learned about stainless steel itself.

In parallel with the EPRI study, NRC itself funded some research focused on one particular kind of failure—so-called stress corrosion cracking (SCC) due to chlorides and other materials deposited on the surface of the casks.[17] The NRC study includes a literature review—the most current one published, to my knowledge.[18] In recent

Kessler 10/28/2014 9:49 PM
Comment [22]: EPRI has also published a literature review report recently: EPRI report 3002002528: *Literature Review of Environmental Conditions and Chloride-Induced Degradation Relevant to Stainless Steel Canisters in Dry Cask Storage Systems,* 2014.

[16] EPRI, 2013, "Failure Modes and Effects Analysis (FMEA) of Welded Stainless Steel Canisters for Dry Cask Storage Systems." EPRI report 3002000815. Online at epri.com

[17] NRC, 2014, "Assessment of Stress Corrosion Cracking Susceptibility for Austenitic Stainless Steels Exposed to Atmospheric Chloride and Non-Chloride Salts" NUREG/CR-7170.

[18] In addition, one member of our task force has issued a review of the literature, which can be found at: Donna Gilmore, 2014, "San Onofre Dry Cask Storage Issues," September 23. Online at https://sanonofresafety.files.wordpress.com/2011/11/drycaskstorageissues2014-09-23.pdf

months, NRC has given extensive briefings on this topic.[19] Among the findings from the NRC study is that risks depend on the type of stainless steel, the filler material used in the welds, the ambient temperature and humidity, and a host of other factors. This is clearly an area of ongoing research, and at this stage it is very difficult to interpret what the NRC results mean for any operational spent fuel storage site.[20] The study reports fundamental results—for example, the rate of corrosion and cracking for a given temperature and exposure to corrosive salts—but was not designed to connect those results to real environmental exposures at real sites.[21] This helps to explain some confusion as some of these results have been used to argue that casks at SONGS may suffer corrosion cracking.[22] (The crucial "may" in that sentence has been turned into the impression of "will" when re-reported in the press.) In writing this report I have spent a lot of time examining this claim. When pressed on this point, the NRC itself has underscored that such results can't be used in isolation from knowledge about the actual environmental conditions at the plant as well as any mitigating measure that NRC would require if corrosion-prone conditions actually existed.[23] Such research tells us that we should be attentive to risks of stress corrosion cracking, as with an array of other risks, but doesn't tell us much about the specific level of risk.

Because it is unwise to pluck results out of studies that look at cracking under hypothetical conditions, here I will focus on the EPRI study because it is based on a full failure analysis through which the EPRI team looked at every mode that could lead to canister failure and then identified the relevant risks in each mode. They do that with an eye to every different configuration of welded lid stainless steel casks currently in service in the U.S. When we look at how the industry updates its procedures in light of information we should expect to see studies like the 2013

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[19] e.g., Darrel Dunn, 2014, "Chloride-Induced Stress Corrosion Cracking Tests and Example Aging Management Program," 5 August (powerpoint presentation).
[20] The same can be said for many other studies on corrosion in stainless steel, which tend to focus on other applications (notably piping) rather than the settings most germane to casks. For example, I am grateful to Donna Gilmore for pointing me to: R. Parrott et al., 2010, "Chloride stress corrosion cracking in austenitic stainless steel – recommendations for assessing risk, structural integrity and NDE based on practical cases and a review of literature," ES/MM/09/48 U.K. Health and Safety Laboratory.
[21] Looking across this research it is clear that the industry and scientists are still learning about these casks. The first stainless steel cask was put into service in 1989 and only a few (3-5) cask systems have been through their first round of relicensing after the initial 20 year period.
[22] Notably see the review at https://sanonofresafety.files.wordpress.com/2011/11/drycaskstorageissues2014-09-23.pdf
[23] Mark Lombard to Donna Gilmore, 28 August at 5:10pm. It is clear to me that when the CEP meets with the cask vendors we should ask them what "mitigating measures" actually exist.

EPRI analysis adjusted periodically as new data comes in. That's crucial to a long-term plan that is adaptive to new information. What I see at EPRI and elsewhere is a big effort, delivering results, to do exactly that.[24]

The EPRI report is a complicated study, but let me highlight a few key observations and findings:

- While the license period is 20 years the typical useful service time for casks is probably more like 40-50 and could extend to 120 years;
- There are two trends that move in opposite directions. On the one hand, the risk of corrosion and damage to casks rises over time as environmental exposures accumulate and as materials age. On the other hand, the consequences of cask failure—in particular, cracking—decline over time because the half-life of the materials that could most readily escape through a crack (i.e. gases) is relatively short. I have never seen these two trends plotted against each other, but clearly a full-blown risk assessment would do that. There are many other trends that vary over time as well. Temperature of the casks, for example, declines slightly as the fuel inside cools—a trend that, overall, seems to suggest that risks may rise with time because SCC is more likely in colder temperatures.[25]
- The dominant risks come from hazards OUTSIDE the casks, such as salt and biological corrosion. That insight suggests that the first line of monitoring should come from inspection of the outside of the casks on a regular basis (more on that below).[26]

Kessler 10/28/2014 9:51 PM
Comment [23]: EPRI would appreciate a copy of the Holtec CEO presentation if it is available.

[24] Full disclosure: I am one of the independent directors on EPRI's Board of Directors. As with the other independent directors, one of my tasks is to hold EPRI accountable to its public mission as a non-profit research entity; these long-term aging programs are one of the areas where I have focused.

[25] One, as yet not reviewed or published, paper has reported that at Diablo Canyon the conditions at the bottom (cooler) part of the Holtec canisters have conditions that allow for one kind of salt deposition that could be a precursor to the chemical processes that lead to stress corrosion cracking. See Charles R. Bryan and David G. Enos, "Understanding the Environment on the Surface of Spent Nuclear Fuel Interim Storage Containers," Probabilistic Safety Assessment and Management PSAM 12 June 2014, Honolulu. At our October 14th event we addressed this question to the CEO of Holtec who reported on the full results of the inspection program at Diablo and another site. He shows that salt deposition was minor—far below the level of concern. He also stated that one of the key variables is temperature—hotter canisters do not create the conditions needed SCC and thus Holtec's strategy is to adjust air flow over the canisters to keep them hot. This is an area of evolving science and monitoring and the CEP should remain attentive to developments in this field.

[26] However, others in the industry as well as outsiders should re-evaluate that observation. As the casks age it may be that other hazards, such as manufacturing defects, are significant concerns as well. This has been an issue with critical nuclear

- Many of the cracking modes that have been the subject of concerns with stainless steel elsewhere in reactors—such as fatigue and the production of corrosive materials through "radiolysis"—are "non-credible" (see EPRI report, section 4.2.6).
- The process of license renewals is producing substantial amounts of useful information about aging—for example, the license renewal for casks at Calvert Cliffs has provided much information about the impacts of fatigue. We should be happy that we in the SONGS communities are making cask purchase decisions and will be developing aging management programs later in the game. We will learn a lot from the others who precede us.
- There are three basic failure modes for cask walls that need attention (see section 4.3). Two of them are particularly unlikely. For the casks in our marine environment at SONGS the failure mode that seems to be of greatest concern is through-wall cracking that begins with corrosion on the surface from salt. That this problem exists does not mean that it can't be readily mitigated. Mitigating this problem requires periodic inspection of the canisters as well as monitoring of the composition and concentration of the deposits that accumulate on the surface of the canister. At this stage, it isn't clear to me what "periodic inspection" might really mean in practice—nor how much we can learn by looking at aging results at other sites versus the amount of real inspection that needs doing at SONGS itself. As fundamental knowledge rises the need for inspection may decline; as casks age the need for inspection may rise. More on that below.
- The best solutions to these problems come from monitoring and prevention. Particularly important will be the regular monitoring of temperatures and radiation around the concrete overpack as they can signal the conditions that would be pre-cursors to canister failure and also canister failure itself. As is widely done in the industry, these routine inspections should probably be done in layers—by Edison and the vendor on site and then with routine verification by third parties and the NRC. My sense is that the NRC part of this equation is currently focused on the 20 year license period but that NRC's role should shift to a more regular one during the period between formal license extensions.
- A variety of expert studies reviewed and assessed in two EPRI studies shows that there is "no credible ... pathway" to criticality of the fuel inside canisters. In the worst case analysis of an implausible scenario—substantial cracks in a cask followed by the intrusion of water sloshing around inside the cask—it is still impossible for the fuel to become critical (page 4-26). Results from an actual cask that has been allowed to leak slowly for 2 years show, as well, that intrusion of water and the formation of hydrogen gas can't reach explosive levels (section 4.4.3, page 4-25). I learned two things from this

Kessler 10/28/2014 9:51 PM
Comment [24]: Is this the FMEA report?

Kessler 10/28/2014 9:52 PM
Comment [25]: It is unclear which EPRI studies are being cited.

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components at other facilities—such as with reactor forgings at the Doel plant in Belgium. The extensive review of an earlier draft of this memo revealed that this is an area of ongoing active research, including by EPRI.

work. First, there is simply zero basis for the highly emotive statements that I have seen in the press and various other locations for the view that long-term storage of the fuel on site at SONGS has put "another Fukushima" or "another Chernobyl" in our backyard. We do the public a disservice with such emotive language since it creates images that are not in any way rooted in the technical assessment of the real risks. I would prefer the fuel gone, but the explosive consequences of highly concentrated critical fuel and accumulation of explosive hydrogen gas that were the root causes of Chernobyl and Fukushima has absolutely nothing in common with our situation here at SONGS. Second, we in the SONGS communities stand to learn a lot from the broader industry experience with aging casks provided that we actually use casks that are similar to the industry standard. Particularly important for us is the data coming from the other sites in the U.S. that are further along and from the collective research and operational studies at EPRI, NEI, NRC and some of the national labs. I have been struck that this is one of many reasons for the "safety in numbers" logic when choosing a cask vendor.

As these casks age there may need to be a more active non-destructive evaluation (NDE) program for inspection that would evaluate casks on-site beyond just visual inspections. To date, all of the license renewals given by the NRC have involved visual inspections rather than pulling canisters from overpacks. At Calvert Cliffs there were in-place visual inspections of two canisters; at Prairie Island there was limited visual inspection and photographic archiving of the results. It is my understanding that NRC is developing new procedures that would involve more regular visual monitoring, and it may be that enough information can be gleaned from visual inspection to be confident that SCC and other hazards are not present—and to intervene if they are.

Kessler 10/28/2014 9:54 PM

Comment [26]: The Calvert Cliffs design is a welded stainless steel canister inside a concrete overpack system, whereas the Prairie Island uses a bolted lid system. Hence, the Prairie Island inspection was fundamentally different.

In addition to NDE there may need to be a more active modeling program to assess and predict corrosion and aging over time; in turn, those efforts could guide physical monitoring and NDE with greater precision. My sense is that the building blocks for all these efforts are in place, but it isn't clear how far along the industry and NRC are in developing such a strategic plan that would be adaptive to new information. We should ask the vendors and we should ask the experts, perhaps in the context of a workshop held in tandem with a CEP meeting when the CEP next looks closely at spent fuel which is likely to be early in 2015. We should be sure that we inquire, as well, about how inspection and repair will happen without exposing workers to undue harm. What is clear from the research is that this field encompasses a well-understood realm of chemistry and metallurgy and the relevant responses are within the realm of what industries that work with stainless steel already do.

Finally, I want to underscore that I am deeply concerned about some claims and numbers that have been widely reported and re-reported in the press because I have found no robust basis for those numbers. In particular, I note that there are claims that cracks could begin as early as 30 years. However, none of the data reviewed above provide any evidence for that number, and the number itself seems to emerge from an unrecorded verbal exchange at a meeting with two NRC officials. Yet having reviewed all the presentations by those officials on that topic, and having included them in an extensive array of email exchanges, I do not find any robust support for that number. I have found one official summary of the meeting at which this 30-year number was discussed and the summary makes it clear that the estimate is based on an assumption that conditions were favorable for the appearance of SCC even though the NRC has explicitly stated that no such conditions are known to exist.[27] Moreover, it has been widely reported that the cracks would then go through the walls of the canister in 16 years—or faster. That number seems to be based on the experience with a storage tank at a nuclear reactor in South Africa even though the design and purpose of that tank is quite different from a spent fuel canister. Again, there is an unrecorded verbal exchange that has never been documented.[28] I can appreciate that there are different points of view on exactly what was said and exactly the conditions that apply to each statement, and I have therefore made all of these exchanges a matter of public record, along with every attachment to every email so that others can inspect the record themselves. But based on an extensive review and re-review of all the evidence I don't see any support for these rapid corrosion, cracking and through wall penetration scenarios.[29] One of the areas that still needs clarification concerns the mitigation measures that would be required by NRC if there were evidence of the combination of conditions that could lead to SCC. NRC has stated that if they knew of such conditions they would require mitigation; they have also stated that they are developing a new monitoring program to make sure that such conditions are detected long before they become problematic. We in the CEP should pay attention to this new program as it is developed over the coming 5 years.

Kessler 11/5/2014 11:00 AM
Comment [27]: EPRI has just released a new, publicly available report on crack growth rates: EPRI report 3002002785: *Flaw Growth and Flaw Tolerance Assessment for Dry Cask Storage Canisters*, 2014. Crack growth rates are a function of relative humidity and temperature.

It is clear that if corrosion occurs and then cracks appear they would affect the seismic integrity of the canisters. For that reason, along with many others, there needs to be a robust program for monitoring, detection and repair—and I now turn to that topic.

Kessler 10/28/2014 9:59 PM
Comment [28]: This is not clear to EPRI because cracks are likely to be oriented perpendicular to the weld direction. Thus, the cracks may have only limited effect on the structural integrity of the canisters.

Question 3: How would cracks be detected and addressed—especially since casks are stored in overpack and not readily monitored directly?

See answer to question 4.

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[27] See Kristina Banovac to Anthony Hsia, "Summary of August 5, 2014 Public Meeting…" dated 9 September 2014 and included as an attachment in the email "Al Csontas to David Victor, 19 Sept 8:35pm, with two attachments"

[28] For a summary of the numbers see page 2 of the attachment in Donna Gilmore to David Victor 22 Sept 7:35pm.

[29] Of course, this is far from the last word on this topic. For example, one area of agreement is that there are disturbing differences between the different standards organizations on this topic. See "Donna Gilmore to David Victor, 24 Sept at 1:09pm"

Question 4: If a crack were detected in a cask, what is the timeline for removing fuel from the cask, replacing or repairing the cask and putting the fuel back into cask? Without an onsite spent fuel pool, how would this be done safely and efficiently?

I think questions 3 and 4 are two of the most important questions that the CEP has asked me to investigate. While question 3 focuses narrowly on how we detect problems with the casks and question 4 focuses on the timeline for action after detection, both of these questions are central to a larger question of how the SONGS site will implement "defense in depth." What are the layers of monitoring and defense that will help us detect and fix problems before they become serious, and how will site managers respond if such problems arise?

My read of the literature is that the industry has not articulated what "defense in depth" means in practice but that <u>there is a lot more going on in this realm than is immediately apparent.</u>

My impression is that "defense in depth" is unfolding on three fronts. First, the cask system is designed for layers of defense with the concrete overpack distinct from the cask that sits inside.[30] The overpack protects against some hazards, such as seismic events, and offers protection against some forms of radiation (gamma, neutron and alpha particles). The cask itself is the key line of defense that keeps fuel rods from being exposed to the atmosphere. The collection of concrete overpacks and casks are, in turn, surrounded by a berm at SONGS and layers of active defensive systems—a scheme described in more detail in a document from Edison attached as Appendix B.

Kessler 10/28/2014 10:00 PM
Comment [29]: Essentially *all* forms that affect dose to humans.

Kessler 10/28/2014 10:00 PM
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Second, the NRC offers some periodic oversight—in particular during the renewal of cask licenses after 20 years. I say "some" because it is not yet clear to me how aggressively NRC oversees this process, and with an array of license extensions in the near future—12 in the next six years alone—we will learn a lot more about how this process really works. I am comfortable with that approach because by the time the existing casks at SONGS need to start the relicensing process (beginning about 2020) we will know a lot about what works and doesn't.[31] What is clear is that NRC has a set of process-oriented regulations that guide license renewal.[32] Although the

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[30] And within the cask, depending on the design, there are multiple layers of defense as well. We should ask the cask vendors how each of these systems perform under different circumstances—for example, in an extreme seismic event how will the fuel racks inside the cask perform and will they protect the fuel and cladding against failure.

[31] The existing casks at SONGS are relatively young and are still in their first 20-year license period. According to NRC rules, the casks on site today will need to file for a renewal in 2021 and obtain it no later than 2023.

[32] e.g., U.S. NRC, 2011, "Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance," NUREG-1927.

specific obligations are general—for example, licensees must, among many other things, "evaluate potential aging effects"—the renewal process includes extensive flowcharts and procedures aimed at the weakest links in the canister system. Overall, it is performance-oriented, as it should be, so there is flexibility for each site to develop its own plan. One striking aspect of the process is the idea of a "critical canister." Prior to license renewal the canister most likely to suffer damage—for example, the canister that is coldest and most exposed to corrosive salt—is subjected to particularly intense scrutiny. So far, this process has only involved visual inspection; no canisters have been pulled from the concrete overpack and inspected. If that canister is found wanting then perhaps others would be inspected until the NRC is satisfied that another 20 years extension is warranted. The results from one of these inspections at Calvert Cliffs in Maryland have been reported publicly within the last year.[33] That plant is particularly important for us as a precedent since, like San Onofre, it is in a marine environment. Indeed, the focus of the inspection was on exactly the issues that have been of concern to the San Onofre community: whether, with aging, the canisters would face conditions leading to corrosion or cracking. My understanding is that results from two other inspections—at Diablo Canyon in California and at Hope Creek in New Jersey will be reported later this year. My impression is that the inspection strategies are still an evolving science. For example, we may not know enough to have the ability to robustly identify the best "critical" canister in every setting and thus a blend of critical and random canisters might lead to more useful information, including eventual improved algorithms to identify the real, true critical canisters.[34]

Kessler 10/28/2014 10:03 PM
Comment [30]: At present, the canister subject to the most scrutiny in a recent license renewal effort at Calvert Cliffs was the oldest, "hottest" canister. However, for future inspections, NRC is reconsidering which are the "lead" canisters.

As more of these extensions are granted and the industry gains real experience of real hazards to the canister I assume that the "critical canister" concept will be adjusted—perhaps it is multiple canisters that should be inspected in some environments. Maybe some should be actually pulled out and scrutinized away from the overpack—although we would need to understand how that might be done without exposing workers. In addition, the regulatory system is based on what NRC calls "Time Limited Aging Analysis Evaluation (TLAA) and an Aging Management Program (AMP) that can be tailored to individual canisters. Perhaps, at some sites,

[33] EPRI, *Calvert Cliffs Stainless Steel Dry Storage Canister Inspection*, report number 1025209 (2014).
[34] I am grateful to David Lochbaum for this information: "For example, the Dresden nuclear plant experienced the failure of an in-vessel component called the jet pump in 1980. The NRC required owners to periodically inspect "critical" regions of their jet pumps. In January 2002, the Quad Cities reactor experienced the failure of a jet pump. It broke in a "non-critical" area -- the inspected "critical" areas were fine. See http://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML021160530. Another example, Oconee and other PWR owners were inspecting J-groove welds of penetrations through reactor vessel heads. These areas were thought to be the "critical" zone. In spring 2001, workers at Oconee found through-wall cracking from the "non-critical" area. See http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/2001/in01005.html."

no inspections would be needed because the body of knowledge is such that the hazards are well understood. It strikes me that this is the right kind of regulatory system—one that is adaptive to new information and is performance-oriented so that it can be adjusted to local circumstances and real world experience. The system is designed to avoid the need to open canisters and look inside—a process that is quite difficult and probably should be avoided whenever possible since it can add extra risk to workers.[35] When I look across the totality of the NRC program it is also clear that the NRC is focused, as it should be, on places where there are still substantial uncertainties—it is risk averse where we know less and concentrated on getting research done to narrow those uncertainties. For example, there are uncertainties about how fuel pellets swell over time and how they respond to water; there are uncertainties about when and how radioactive gases might be released from the pellets stored inside canisters.[36] This information and adjustment strategy strikes me as important not just because it can lead to better regulation but also because it is focused on ways to gain information that can be used across the industry. For example, there are periodic studies that do actually open canisters and look inside—many of those are cited in the NRC regulations (see p.20). Wherever possible, SONGS should be doing exactly what everyone else in the industry does—that maximizes the opportunity to learn from other plants and minimizes risk.

Kessler 10/28/2014 10:06 PM
Comment [31]: The CASTOR V/21 cask was brought to INL empty. Each of the 21 assemblies that were placed into the cask were shipped separately.

Kessler 10/28/2014 10:04 PM
Comment [32]: EPRI notes there are many reports related to experimental data and modeling on the issue of both fission gas release from the pellets into the cladding plenum, and some work on fuel pellet swelling.

Third is a plan emerging in parallel from the Nuclear Energy Institute (NEI). This plan, known as "NEI 14-03," is expected to be released in final form for NRC review this month and approved by NRC before the end of the year.[37] What I know about it I glean from a 14 March presentation by the key person at NEI;[38] when the final version is released I will send around copies to the whole CEP. Some of the key points from NEI's work that are most germane for us in the SONGS communities include:

- To date, there have been three detailed inspections of actual canisters at actual coastal sites analogous to SONGS—none of them indicate any

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[35] One cask—a Castor design—was transported from Surry to Idaho National Lab for inspection. In tandem, two Areva TN casks were used to transport the fuel to Idaho, at which point it was transferred via "hot cell" into the Castor cask for analysis. Clearly for research purposes it is important to have some canisters with bolted lids. And as the whole fleet of canisters and spent fuel ages I assume that more such cask openings will be done. That would be a prudent research strategy.

Kessler 10/28/2014 10:06 PM
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[36] see especially pages 2-3 of: *Annual Status Report: Activities Related to Extended Storage and Transportation*, U.S. NRC, SECY-13-0057, dated May 31, 2013.

[37] Since this plan is not an official NRC activity I am not sure, as a legal matter, that NRC actually approves the plan. What is clear is that NRC and NEI both have a strong interest in each other agreeing on a common strategy.

[38] Rod McCullum, 2014, Dry Cask Storage License Renewal: Industry Guidance for Operations-Based Aging Managing (NEI 14-03), NEI, March 12 presentation, https://ric.nrc-gateway.gov/Docs/Abstracts/mccullumr-w20-r1-hv.pdf. For a draft outline of the plan, see: http://pbadupws.nrc.gov/docs/ML1408/ML14087A229.pdf.

significant problems with chloride corrosion. I have seen a wide array of viewpoints on this matter, with some observers citing "NRC Inspection Reports" showing chloride corrosion within 18 months.[39] Yet the NRC itself has said that if they knew of any such chloride corrosion concerns they would require mitigation of the hazard before licensing the cask at that site.[40]

- The NEI approach will be based heavily on "toll gates"—that is, periodic checks on the performance of the casks that is an "extra layer of assessment" beyond what is done through regular checking and assessment (slide 13). As this work is developed, we in the CEP should focus on whether the "toll gates" approach comes into play only after the first relicensing (20 years) or whether it can and should be implemented earlier. SONGS might be an ideal location to implement it earlier as part of a larger industry-wide research program.
- The overall approach would make license renewals more streamlined (something that matters to the industry) and safety-focused (something that matters to the communities around these plants). I think we benefit from a licensing process that can focus like a laser on the parts of the system that might become vulnerable with aging—and then apply lessons from one site across the rest of the industry, including SONGS—rather than a system that is ad hoc and plodding.

I am mindful that other observers have less respect for what NEI is doing in this area.[41] But this is not an opinion that I share nor, I think, warranted by the evidence.

At this stage I don't know if we can provide definitive answers to question #4. My impression is that the only defects that are likely to arise with long-term aging of the casks are minor defects on the surface of canisters and possibly with concrete overpacks. In the case of canister defects the repairs are rapid—a matter of days to clean and resurface an affected area or perhaps weeks to arrange a new weld. The NRC has stated that the industry has already proven that it has methods for identifying and repairing stainless steel cracks in difficult environments and has proven the ability to develop new methods as needed.[42] At our October 14th special meeting of the CEP we also learned that exactly those methods are already being used to repair stainless steel components elsewhere in nuclear reactors—for example, a repair of nozzles at the Palo Verde nuclear station. What's not clear to me is the strategy that would be followed in a worst-case situation—where a cask started leaking for some highly unlikely reason. We put that question to the vendors

Kessler 10/28/2014 10:07 PM
Comment [33]: This is the case during initial fabrication only – not during actual use.

[39] See Marvin Resnikoff's review of an earlier draft of this memo, page 2 (related to page 6 of the draft). "Resnikoff Critique of Victor Piece, not dated"
[40] Mark Lombard to Donna Gilmore, 28 August, 5:10pm
[41] See Marvin Resnikoff's review of an earlier draft of this memo, "Resnikoff Critique of Victor Piece, not dated"
[42] Email replies from Mark Lombard (26 August 2014) in response to questions raised by Tom Palmisano and Ted Quinn and points made in a 25 August petition by Gene Stone and Donna Gilmore.

at the October 14th meeting and heard three answers that are not necessarily incompatible. One might involve putting the canister into transport cask, sealing it from the environment, and then leaving it "as is." From a regulatory and technical perspective that approach appears to be prompt and straightforward. A second strategy might start with the first and then move the transport cask to another site where there is a "hot cell" or a pool—and then the fuel would be repackaged into a new canister. I note that hot cells of adequate size do not currently exist "off the shelf" and a pool would not exist on site once the rest of SONGS is decommissioned. (But pools exist at other sites—every operational reactor has one.) The NRC has published a design for repacking a cask in a small shield building without an onsite pool.[43] Two researchers at the Idaho National Laboratory have published a terrific review of systems for dry transfer of used nuclear fuel that includes an appendix documenting 13 existing and proposed systems.[44] At the October 14th event one of the cask vendors reported on new technology, available shortly, that will not require hot cells or pools for repackaging spent fuel. A third response might involve on-site repair that would clean the damaged surface and make minor changes in the shape of the surface to relieve stress. My sense is that all three responses are viable and that all three arrows, along with others, would be in the SONGS quiver as the casks age.

Kessler 10/28/2014 10:09 PM
Comment [34]: This fact seems to support the idea of keeping the pool available, which means there would be no rush to empty the pool.

In short, as we have looked closely at this topic it has become clear that there is actually a tremendous amount of work on the issues related to isolation, possible repair and repackaging of damaged canisters. I don't see a need to have firm, final answers to these questions immediately but clearly these will be part of long-term "defense in depth." Having an on-site pool for such a remote contingency is probably quite impractical and would lead to an ISFSI that has a much larger footprint than the public favors---various comments from the public suggest to me that the public wants the footprint as small and secure as feasible. The transport cask option—or a similar arrangement with a spare overpack sleeve—might be the best one, but that could require pre-positioning such casks in the U.S. for such contingencies, just as the industry shares other types of pre-positioned material.[45] All of these are questions that are amenable to analysis using existing methods and probably require an industry-wide strategy to address. I have also learned to appreciate that the lack of full answers, right now, to all these contingency questions is unsettling to some people who are not used to how technology in the industry evolves and who, frankly, do not trust the industry or the regulators. For that reason, and many others, it is crucial that the full range of "defense in depth"

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[43] Thanks to Frank von Hippel for pointing this out in the NRC's Generic Environmental Impact Statement for Continued Storage of Spent Nuclear Fuel
[44] Brett W. Carlsen and Michaele Brady Raap, 2012 "Dry Transfer Systems for Used Nuclear Fuel," INL/EXT-12-26218.
[45] For example, this sharing of critical emergency resources is now done across the industry in response to the "FLEX" rules that NRC adopted after the Fukushima disaster.

strategies—including a clear articulation of what is in place right now and what's needed in the future—is essential.

For the concrete overpacks, the timing of repairs is not critical assuming that defects are caught in time—which is what the NRC and NEI schemes would assure. According to Tom Palmisano at Edison, there is one documented case of a concrete overpack suffering minor external damage—something that was readily detected and repaired.[46] This type of activity doesn't strike me as rocket science and the industry is already adequately focused on the problem of concrete aging. In the worst case, an overpack could be replaced easily with the cask simply moved to the new overpack on the same pad.

Very far down the road at the end of the lifetime of the casks—which might be 50 to 100 years if not longer—then a temporary pool might need to be constructed on site to allow offloading of fuel and reloading of the new canisters. Or, more likely, a program would be set up in which canister replacements are staggered as they age—perhaps using a "hot cell" or some other technology that doesn't exist. It is hard to predict what kinds of improved technologies will exist in 50 years, and it might be an especially poor idea to establish regulatory rules today—such as requirements for on-site pools—that would discourage innovation in better technologies. I don't see that contingency as material to our decisions today since the need for such a pool would be easy to anticipate with many years of advance notice.

After reviewing all these materials I see a "defense in depth" program that has physical, informational and strategic elements. The physical layers of defense start with the cask. Additional defense against some hazards comes from the overpack. The informational elements include monitoring the casks—especially temperature and radiation—as signs of failure, along with ongoing monitoring of corrosion and decay. The strategic elements, which are perhaps the most crucial for the long-term, are just taking shape—they include research on aging and industry-wide sharing of experiences. When I started this research project, frankly, not much of this was evident and that has created the false impression that less is going on in this domain than needed.

When I look across all the elements of "defense in depth" I draw three conclusions. First, the next time the CEP looks at spent fuel management we should ask Edison to articulate for us in plain English what "defense in depth" means for the SONGS site. The document at appendix B of this memo is an excellent start to helping us understand the procedures, but what exactly will be done, when and how? Answering this question really is a matter for the whole industry—vendors, utilities, NEI, EPRI, and the NRC along with the research community—in addition to Edison

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[46] Tom Palmisano statement to the CEP meeting concerning damage and repair to an overpack at Idaho National Laboratory.

itself. As we grapple with these issues in the CEP we should be paying more attention to the broader industry-wide efforts.

Second, I have seen in the press much discussion of the need to wait to buy the "right" casks because this is an expensive purchase and we should "purchase them once." (I am paraphrasing comments from many officials.) I don't think this is the right way to think about the challenge. We have casks that are widely used in the industry that deploy the latest technology and are licensed by the NRC. Those are our options. Waiting doesn't change the laws of physics and chemistry that dictate how materials like stainless steel age. What's needed is the smartest cask decision today and then a smart aging and "defense in depth" scheme for the future.

Third, we should ask Edison to explore nominating SONGS to be one site where the industry does long-term aging research. Clearly that would be beneficial to the industry but it would also help assure us in the SONGS communities with the largest amount of real data on the real status of casks at this site. As a practical matter that might involve pulling additional canisters for surface inspections and more detailed monitoring of concrete overpacks. I don't know if the SONGS site would be a viable one for actual internal canister inspections since the site itself may not be an effective place to open canisters and moving canisters from SONGS to some research location may be impractical. But we should explore what might be done on the site with research, whether the costs could be reasonably recovered in the trust fund, and how this site might fit into the industry-wide aging management program.

Question 5: What is the internal pressure of a cask during storage, and how would leaks from helium over-pressure be detected? Are we safer with casks that have pressure monitors built in or with welded casks that do not contain those monitors?

The EPRI 2013 study cited above includes detailed information on cask designs. It appears to me that the internal pressures vary by design and are as high as 100 pounds per square inch (psi). Compared with many other uses for stainless steel in piping, where pressures rise to thousands of psi, these pressures strike me as quite modest. At SONGS the casks with the unit 1 fuel are pressured with Helium to 1.5 psi; the casks for units 2 & 3 fuel are 6.5 psi.[47]

The helium injected at pressure into the casks before they are sealed is extremely important as it helps keep the fuel cool and prevents contaminants, including water, from entering the cask. A helium leak would be detectable, in the extreme, with measured release of radioactive materials. The EPRI 2013 study makes it clear that one of the central issues in assessing the impacts of a cask failure is the rate at which helium escapes and is replaced by air or other contaminants. As air replaces the helium the temperature of the fuel rises and that raises the risk that the wrapping

[47] Email from Jim Madigan to David Victor, 25 August 2014

Kessler 10/28/2014 10:12 PM

Comment [35]: It is unclear whether this would actually be the case. As you note in the following sentence, if there were through-wall cracks, they would likely be very tight such that the helium leak rate would be quite slow. It is also likely that there would be no cladding failures such that there would be no radioactive release of fission gases.

around the fuel (known as “cladding”) that holds the fuel together will fail and a variety of other risks. These risks decline as the fuel ages and cools. It is still unclear to me whether we obtain sufficient information from temperature and radiation monitoring or if additional systems (of what types?) would provide for a much better assessment of the integrity of the canisters. Here, the nuclear industry is hardly alone. Aviation has long experience with material stresses and aging and has an extensive program for non-destructive evaluation—for example, measuring changes in magnetic flux, which can reveal flaws that are otherwise not visible. What has been learned from that industry that might be relevant here?

Kessler 10/28/2014 10:15 PM
Comment [36]: If the cladding is “intact” (no cracks or pinholes), then exposure to air – even at somewhat higher temperatures is unlikely to cause cladding failure.

How much equipment is needed on the cask itself to monitor pressure and safety? At first blush the right answer might be “as much as possible,” and that is one reason that the Castor system might be attractive. My sense is that is not the correct answer for three reasons. First, we must remember that the Castor system has a removable, bolted lid—an application that makes sense in Europe but is probably unwise for extremely long-term storage that is envisioned here in the U.S. A lid with moveable bolts and O-rings needs more monitoring—and that is why the NRC requires a pressure monitor on the lid but doesn’t for welded shut lids. In some of the public discussions with the CEP there have been comments regarding the possibility of just welding the Castor lid, but that’s not such a simple matter since the led wasn’t designed to be welded and thick iron is hard to weld reliably in a field setting.

Second, with helium under pressure inside the casks and good monitoring of other parameters outside the cask we can gain essentially the same information—including early warning of failures. In particular, measurements of temperature are essential because variations in temperature can reveal information about shifting of the fuel inside. The visual inspection program outlined above—along with other inspections added as the whole fleet ages—will also provide critical early warning of failures. This logic is based on the idea—so far, robust, but in need of periodic review—that the most important hazards come from outside the canister and thus most of the essential monitoring can occur outside.

Third, safety systems such as through-wall monitors bring risks of their own. In my professional life I do a lot of research on how real organizations manage complex systems. In that work, one of the books that has influenced me the most is Charles Perrow’s *Normal Accidents*. Written by a sociologist, that book looks at why some complex systems are easier to manage safely than others and one of the central conclusions from his study is that sometimes active safety systems actually makes things less safe. When you drill a hole through the wall of a reactor vessel or a cask and install a sensor you get information about what’s going on inside, but you also get a new failure point. Thus systems that are purely passive and welded shut are probably a lot safer than those that are bristling with through-wall sensors and can be opened and closed. I think that insight applies especially for systems that need to be safe for the very long haul and in environments where we don’t know exactly how the sensors and lids would age.

Question 6: What is the track record with corrosion in concrete overpacks? How can corrosion be detected and addressed?

The concrete overpacks play a crucial role for "defense in depth" in the U.S. system for storing spent fuel on site. They are the first line of defense for some hazards—including hazards, such as terrorist attack, that have become central topics of public concern. They provide physical protection for the canisters as well as partial radiation shielding and they help manage the heat flow away from the canisters as the fuel cools slowly over time. The fact that the overpack is physically distinct from the canister is probably a big advantage in the U.S. system for long term storage when compared, say, with the thick-walled European casks that are "all in one" systems with no overpack. If there is a problem with the concrete overpack then the canister can be moved to a new one.

Kessler 10/28/2014 10:17 PM
Comment [37]: See the EPRI comment about the two PRAs that were conducted - one for a bolted lid design and the other for a welded SS canister design. Both PRAs resulted in very low health risks.

As noted above, to my knowledge there is just one incident of a concrete overpack suffering material damage from aging. Since the most vulnerable to corrosion elements of the concrete overpack are directly visible I don't expect that any significant issues will arise with this, and if they do it is a trivial task to remove a canister and put it in a new overpack. There may be some licensing issues with that if, for example, a new overpack would need to be built and that expanded the footprint of the "ISFSI" pad on which the casks are stored, but addressing those issues would be straightforward.

The CEP has already looked into the questions related to seismic risks and found that the design of the current (Areva TN) system to be vastly beyond any plausible risk in that domain.[48] The underground Holtec system, which is the other leading contender for the SONGS contract, has similar performance. The CEP has only briefly discussed the issue of tsunami risk and I have seen no credible evidence that such risks are material to the choice of storage technology nor the location of the spent fuel pad.[49]

Kessler 10/28/2014 10:18 PM
Comment [38]: Regarding the statement in the footnote about seismic activity and a cracked canister, see EPRI's previous comment about the crack orientation that would likely not result in a significant loss of canister structural integrity.

Question 7: With fuel assemblies stored inside casks and not observable directly, how will we know if fuel assemblies—including HBF—degrade or damage with age? How will missing knowledge on this question be filled in and practices adjusted?

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[48] This issue arose at the first CEP meeting in March 2014. On the CEP's behalf, CEP member Bill Parker researched it and reported back to the Panel on 22 May by email and also with a statement at our CEP meeting that same day. I note that the seismic rating does not seem to apply to cracked canisters, but that is one of many reasons why a cracked canister would be promptly repaired or replaced.

[49] See Manuel Camargo to David Victor, 5 September, 5:18pm, plus attachment "SCE Position Papers on ISFSI location, Tsunami Hazards and other factors."

I think this question has been answered in the answers to questions 3 & 4. For some fuel failures this information will be revealed through variations in temperature measured outside the cask. Other failures—where the fuel remains in place—would not be detectable, but it is not clear why that situation would pose any hazard. It may be that ultimate disposal of failed fuel assemblies might be different—if the fuel is removed from the storage casks and put into some final disposal cask at a waste repository. In that situation, the fuel would be “canned” and handled slightly differently, but that practice is already well understood in the industry. Some of the high fuel assembly canisters do not accept “cans” and thus damaged fuel would be put into canisters that are rated for canned fuel.