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

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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, the decommissioning process is proceeding at San Onofre—a process that includes important 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 four 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. Members of the task force have also had the opportunity to submit additional views on this report, which are attached as Appendix A to this report.

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] These comments and reviews are compiled as 17 items in one document: "Reviews of Drafts and additional commentary, 14 November" (online at

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 far advanced in developing a new system for long-term monitoring and regulation of aging casks. In addition, NRC has already been through re-licensing (for another 40 years) casks at three sites and will soon re-license many other aging casks. This relicensing process has included visual inspections of some canisters along with a more aggressive inspection program that will apply for the future. 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.

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," but there are many other names for the same basic idea—NRC, for example, calls it "reasonable assurance." "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.

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.

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songscommunity.com). A special thanks to David Lochbaum, Frank von Hippel and a team from Electric Power Research Institute (John Kessler, Randy Stark, Shannon Chu, and Neil Wilmshurst) 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,

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 a cask without an onsite pool has been designed and a prototype was demonstrated in the 1990s, but no such full scale commercial system currently exists. 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]

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.

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

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 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. Lots of industries, such as aviation, deal with the reality on a regular basis. 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. There is a tremendous amount of technological innovation in this area, and it would be folly today to predict or demand 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, and thus it would be inappropriate to demand that SONGS—or any particular site—have all the technologies physically on hand. 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

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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),

programs discovered a damaged cask? Some attention is needed, as well, to the non-technological issues. For example, once decommissioning is essentially complete the whole SONGS site will be much smaller than today. 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 in plain English and the CEP needs to focus on whether these answers add up to a coherent strategy.

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.[6]

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

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[6] There is a range of views on this topic. The NRC concluded in 2013 that wet and dry storage are both safe—a conclusion they reached when evaluating whether the US industry should accelerate the removal of fuel from pools into dry storage in light of the lessons learned from the Fukushima disaster. Risk analysis by EPRI is supportive of this general conclusion. My interpretation is that this general conclusion applies to operational reactors—where new spent fuel continues to be produced—and is germane to the question of whether to pay the cost needed for accelerated transfer of fuel out of the pools. For us in the SONGS communities the question is different—is it better to leave fuel that has already cooled even longer in the pools, with the additional expense of maintaining the pools and slowing down decommissioning. On that question, removal from the pools strikes me as clearly the safer option. See Nuclear Regulatory Commission, 2013, "Staff Evaluation and Recommendation for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel (COMSECY-13-0030). And see Electric Power Research Institute, 2010, "Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage after Five Years of Cooling, an Update" (EPRI Report 1025206).

a lot, and that pause would not have happened without the CEP's involvement. It is now time to move on.[7]

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 with a bolted lid 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 for extremely long term storage. 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 there is no clear precedent for gaining regulatory approval. While the legal procedures that would be followed to seek a license are well known, the actual review and approval of that license would be unknown territory for the U.S. industry and regulators—creating the risk that we would be stuck with a system that became entangled with regulatory approvals. For example, it is possible 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 nearly alone in the U.S.

[7] I am mindful that there are different points of view on this. See for example: https://sanonofresafety.files.wordpress.com/2011/11/drycaskstorageissues2014-09-23.pdf

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 where one's own regulators are in control.) 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.[8] 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 vendor, NAC, is not seriously being considered. They have only 16% of the U.S. market.)

Before we move on, we should be sure to obtain a rigorous 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. This recommendation was included in an earlier draft of this report, and based on that recommendation Edison has conducted such an assessment.[9] Edison 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 of Castor against its

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

[9] Edison delivered that assessment as part of its presentation at the 14 October special meeting of the CEP. Edison reported that its assessment was conducted with the benefit of a non-disclosure agreement, but a version of that assessment suitable for public release is included as Appendix B to this report.

rivals.[10] I am satisfied with that assessment. I am also mindful that a serious analysis of this option has required access to proprietary information and thus it would have been inappropriate for the CEP to do that analysis.—a task for which we are not qualified. Indeed, this evaluation occurred at a time when one of the largest contracts for cask purchases in U.S. history was being awarded and all vendors were particularly skittish about confidentiality so as to protect their position in the marketplace. 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 they can reveal from their in-depth analysis that relied, in part, on confidential business information. To my understanding, nothing they have learned differs from the open and transparent summary of the concerns I outline in this report.

[10] I thank David Lochbaum at the Union of Concerned Scientists for articulating this comparison requirement. And I thank EPRI for drawing our attention to risk assessment research in this area. Electric Power Research Institute, 2004, *Probabilistic Risk Assessment of Bolted Storage Casks – Updated Quantification and Analysis Report*, (EPRI report 1009691); NRC NUREG-1864, "A Pilot Probabilistic Risk Assessment of a Dry Cask Storage System at a Nuclear Power Plant."

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 and thus we haven't devoted much attention to transportation. Nearly all casks purchased in the U.S. are designed for long-term storage. 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.

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 recently (2005). 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 existence of two different approaches to fuel supply helps to explain why the US and Europe have radically different strategies for casks. Europe puts a premium on casks that can be transported, opened and the spent fuel removed; therefore they have bolted lids. 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 of pressure to ensure that the O-ring keeps working as designed.

Thus one big difference between the US and European cask inventory is the use of bolted lids. A fraction of U.S. casks have bolted lids,[11] but this approach is much more common in Europe. My read of the literature is that welding is the best approach to closing the lids for long-term storage casks. Looking across the literature I have seen not a single example of lid failure for a cask with a welded lid; I have seen legitimate concerns about the long-term integrity of bolted lids.

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

Another big difference between the U.S. and European cask inventory concerns the materials used. The United States has gone almost entirely to stainless steel casks that are stored in large concrete overpacks. Europe uses this design and also makes significant use of thick walled iron casks. For the stainless steel systems the overpack offers a shield against gamma radiation; in the thick walled iron cask it is the thick wall that provides the shielding. The discussion that follows will focus on the question of whether thick-walled casks are safer than thinner walled stainless steel casks, but a primary reason for selecting thick walls is the desire for gamma radiation protection.

At least one European cask vendor (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.[12] Work on that issue in the United States waned, however, when it became clear that stainless steel options would be more cost-effective.[13] 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.[14]

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, 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

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

[13] 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.

[14] 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.

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—that, along with lower cost, is why the long-term storage market in the U.S. has moved almost completely to welded lids. (From the perspective of U.S. regulators, both welded and bolted lids meet regulatory criteria and are deemed safe.) The low market share for this cask in the U.S. would, in my opinion, 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 of an earlier design 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.[15]

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

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[15] 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

came to transporting the fuel off site or if some aging management problem arose that the vendor wasn't around to help us fix.

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, 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.[16] 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.

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

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 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.)

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.[17] 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.[18] The NRC study includes

[17] 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

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

a literature review—it, along with a recent EPRI report,[19] are the most current reviews published to my knowledge.[20] In recent months, NRC has given extensive briefings on this topic.[21] 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.[22] 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.[23] This helps to explain some confusion as some of these results have been used to argue that casks at SONGS may suffer corrosion cracking.[24] (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.[25] Such research tells us that we should be attentive to risks of

[19] EPRI, 2014. *Literature Review of Environmental Conditions and Chloride-Induced Degradation Relevant to Stainless Steel Canisters in Dry Cask Storage Systems* (report 3002002528).

[20] 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

[21] e.g., Darrel Dunn, 2014, "Chloride-Induced Stress Corrosion Cracking Tests and Example Aging Management Program," 5 August (powerpoint presentation).

[22] 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.

[23] 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.

[24] Notably see the review at https://sanonofresafety.files.wordpress.com/2011/11/drycaskstorageissues2014-09-23.pdf

[25] 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.

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 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.[26]

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.[27]

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[26] 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.

[27] 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

- 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).[28]
- 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

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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.

[28] 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 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.

NRC's role should shift to a more regular one during the period between formal license extensions.

- Several studies reviewed and assessed by EPRI reveal 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 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 <u>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.</u> 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 actually 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.

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.[29] In addition, I have seen it reported and discussed at public meetings 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.[30] I can appreciate that there are different points of view on this important area of scientific research, and because of those differences I have made all of the exchanges of information about this topic a matter of public record, along with every attachment to every email so that others can inspect the record themselves.

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. Moreover, I note that EPRI has recently released a report that examines exactly this scenario. That report looks at the scenario that would unfold after conditions for cracking had been established and after a crack had initiatited. How long would it take for a crack, then, to travel through the walls if the crack were not detected and stopped? EPRI's answer is about 80 years.[31] In addition, the NRC has stated that if they knew that the conditions for cracking existed in the first place they would require mitigation of those conditions. Based on what we know reliably, I do not see these scenarios of SCC and through-wall cracking as credible.

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[29] 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"

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

[31] See Table 3.3 (and 3.4 for a sensitivity analysis). Note that this analysis is for ½" stainless steel and thus the numbers on the table need to be increased 30% for 5/8" stainless steel that would be used at SONGS. EPRI, 2014, *Flaw Growth and Flaw Tolerance Assessment for Dry Cask Storage Canisters* (Report 3002002785).

This is an area of evolving science and regulation. We in the CEP should pay attention to the evolving program for monitoring, detection and possible repair of cracks—and I now turn to that topic.

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 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.[32] The overpack protects against some hazards, such as seismic events, and offers protection against essentially all forms of radiation (gamma, neutron and some 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 C.

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

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[32] 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.

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.[33] What is clear is that NRC has a set of process-oriented regulations that guide license renewal.[34] Although the 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 is subjected to particularly intense scrutiny—for example, when the NRC reviewed the renewal of the license for Calvert Cliffs it focused on the oldest canister. So far, this process has only involved visual inspection; no canisters have been pulled from the concrete overpack and inspected. The results from one of these inspections at Calvert Cliffs in Maryland have been reported publicly within the last year.[35] 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.[36]

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[33] 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.

[34] 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.

[35] EPRI, *Calvert Cliffs Stainless Steel Dry Storage Canister Inspection*, report number 1025209 (2014).

[36] 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."

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, and at our October 14th special meeting we learned about a variety of techniques that do essentially that in a way that does not expose workers to additional radiation. These inspection schemes feed into 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, 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. 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 uncertainties around critical processes—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.[37] 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 and presumably it will be sensible to do more of that in the future.[38] 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.

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 before the end of the year.[39] What I know about it I glean from a 14 March

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[37] While there are uncertainties this has been a topic of extensive research. 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.

[38] One cask—a Castor V/21 design—was transported (empty) 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.

[39] 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.

presentation by the key person at NEI;[40] 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. I have seen a wide array of viewpoints on this matter, with some observers citing "NRC Inspection Reports" showing chloride corrosion within 18 months.[41] 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.[42]
- 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.[43] 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 during initial fabrication the repairs are

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[40] 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. In addition, see a March 18, 2014 letter from Mr McCullum to Mark Lombard, Director of the Division of Spent Fuel Storage and Transportation at the NRC which includes a summary of the NEI 14-03 as an attachment.

[41] 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"

[42] Mark Lombard to Donna Gilmore, 28 August, 5:10pm

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

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.[44]

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 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.[45] 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.[46] 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.

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

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[44] 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.
[45] Thanks to Frank von Hippel for pointing this out in the NRC's Generic Environmental Impact Statement for Continued Storage of Spent Nuclear Fuel
[46] Brett W. Carlsen and Michaele Brady Raap, 2012 "Dry Transfer Systems for Used Nuclear Fuel," INL/EXT-12-26218.

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.[47] 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" 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.[48] 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

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[47] 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.

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

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 C 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 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.[49]

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—although such a leak would be improbable since through-wall cracks would be very tight and it is unlikely that the fuel cladding would also fail, releasing radioactive gases inside the canister. 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 around the fuel (known as "cladding") that holds the fuel together will fail and a variety of other risks. In a review of this document, EPRI underscored that if the cladding is intact then exposure to air, even at high temperatures, would be unlikely to cause the cladding to fail.[50]

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?

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 lid 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

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[49] Email from Jim Madigan to David Victor, 25 August 2014
[50] EPRI, Review of 20 October 2014 draft.

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 means that if there is a problem with the concrete overpack then the canister can be moved to a new one. It may be important to ensure that the site includes extra overpack(s) as a contingency.

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) overpack system to be vastly beyond any plausible risk in that domain.[51] 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.[52]

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. 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.

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[51] 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.

[52] See Manuel Camargo to David Victor, 5 September, 5:18pm, plus attachment "SCE Position Papers on ISFSI location, Tsunami Hazards and other factors."

Appendix A:
Additional Views from Members of the Task Force

(printed in order received)

From Gene Stone, 19 November 2014:

Chairman Victor's final report does now seem to be more inclusive of the different positions held by CEP members. While this draft has removed words such as "hope and faith", the same concept prevails using different words such as "ability to develop new methods as needed", and phrases like "my sense is", using terms like risk analysis, acceptable risk, and low risk are meaningless phrases to make us feel safer. When a family is invested in a community, in their homes, the schools of their children, and places of worship, if a nuclear accident happens those phrases and that type of thinking will be seen as completely unacceptable, not to speak of inadequate. Only real mitigation plans in place will have any meaning at all. Let's hope they will be enough.

On page 22, Victor talks about an adaptive approach to inspection and regulations of dry cask canisters. I would prefer a strictly enforced scientific approach meaning a regularly scheduled mandatory inspection criteria process that would gain the nuclear industry useful information for the new nuclear waste aging management plan . David Victor also says on page 24, speaking of real on site ways of dealing with troubled canisters, that having these ideas in your quiver instead of on site seems to be acceptable to him. He goes on to say, "I don't see the need to have firm and final answers to these questions immediately but clearly these will be part of the long term defense in depth". Again, I prefer a more traditional scientific approach. I prefer real on-site actionable "defense in depth". Having real systems in place when a problem starts seems more practical and ethical, and of course, safer.

SCE and its CEP leadership now have a consistent record of what many consider the spinning of information to fit the SCE agenda. For example on page 3 of his report again regarding "defense in depth", the chairman, after being concerned at first at the lack of defense in depth for dry cask long-term storage, concluded after his "careful research", that the public had not asked about " defense in depth" for waste storage before, and that the nuclear industry and the NRC has done a poor job in defining and getting the word out about "defense in depth" for nuclear waste and dry cask storage. Citing "defense in depth" as cladding on fuel rods, ceramic coatings on the fuel pellets , even the 5/8" thickness of the canister itself and concrete overpack of the casks as if these were "defense in depth", and that they were unspoken of in the past. And he was right they were not spoken of in the past as "defense in depth" because they were not considered nor should we consider them today as "defense in depth". While these have some small measure of defense, they are not in anyway sufficient or adequate for long-term storage of nuclear waste within a heavily populated area like Southern California. My conclusion is that Dr. Victor has been missing over the years in the many discussions about how to deal with long term storage of nuclear waste.

Let us be clear what real "defense in depth" measures that would improve safety for our community would look like. First, choosing the best cask system available. That does not mean fighting over our present day choices, all of which have inadequacies and problems. Unfortunately but necessary resolving this would mean getting DOE, DOD, NRC and the nuclear industry, plus nuclear activists to work together to develop a new long term storage system with a real aging management plan. That would include real time radiation monitoring of inside and outside the cask, the ability to physically inspect the cask, a working method for repair of the cask, a hardened leak proof building for the casks to be stored in to protect the canisters from weather conditions, tsunamis, earthquakes and terrorism , an on-site fuel pool or hot box to deal with a damaged dry cask canister. Money should be set aside for the future to be used for the repair and replacement of these dry cask canisters when needed. And yes, I am aware that real "defense in depth" comes with a cost, but the destruction that a nuclear waste dump could cause to California would be in the many trillions of dollars. So spending a little more now makes a lot of sense to me. California and its citizens deserve a true "state-of-the-art decommissioning" with real on site defense in depth in place. It seems that Southern California Edison and its CEP leadership will be satisfied with much less than that.

Finally we must keep in mind Chairperson Allison MacFarlane's words from Nov 17, 2014 in WASHINGTON, D.C.

The Nuclear Regulatory Commission's rules are not geared for supervising the decommissioning of nuclear reactors, the task that will occupy much of its time in the coming years, the head of the agency said.
http://mobile.nytimes.com/2014/11/18/us/nuclear-agency-rules-are-ill-suited-for-plant-decommissioning-leader-says.html?referrer=

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

From Bill Parker, 2 December 2014:

I have reviewed carefully the "Safety of long-term storage in casks: Issues for San Onofre. Report of the Chairman of the Community Engagement Panel of the San Onofree Nuclear Generating Station " dated 13 November 2014. The report is comprehensive, informative and understandable. There are no "issues of fact" in the report with which I would disagree.

However I may not be as optimistic as the chairman that the nuclear industry and the regulatory authorities will develop and *sustain* the necessary monitoring and repair capabilities necessary for the safely of the public over a period of time that could be as long as a century. Previous accidents in the nuclear industry were more the result of human errors than technical inadequacies. Maintaining a well trained and highly motivated workforce over many decades may well be more of a challenge than the development of technical solutions to address the inevitable consequences of the aging of the dry cask storage materials. The report does not adequately address this management challenge. Monitoring and maintaining a dry cask storage facility over many decades may not remain high on the agenda of management at SCE or the NRC, nor attract the most competent of technical staff. After several decades there may develop an attitude of complacency and over-confidence which may enhance the likelihood of human error.

Chairman Victor has addressed the technical issues of dry cask storage in great detail and academic objectivity, but he, and the task force, may have not adequately addressed long term management issues. This may be the only shortcoming of this otherwise excellent report.

From Ted Quinn, 2 December 2014:

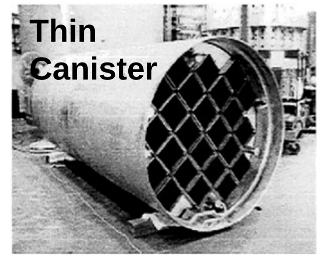
I have read the white paper and attended almost all of the meeting associated with this including the workshop we had in the fall of 2014. I believe the final white paper addresses the key issues of dry cask storage which include safety, maintainability, licensing, supply chain and long term. I firmly believe that the white paper addresses these in a clear and concise manner and does this based on input from all technical and non-technical inputs that have a stake in this. My firm belief is that the area we should focus on is in the long term, addressing the role of the Federal Government in implementing the Waste Policy Act and the recommendations of the Blue Ribbon Commission (BRC) in following up as a joint community. Based on my meetings with DOE (including last month), I firmly believe that the coming year of 2015, is the best time when we can have an impact on moving forward with the recommendations of the BRC, and I fully intend to support this.

From Donna Gilmore, who submitted “Reasons to buy thick casks…” in lieu of commenting on the report itself, 7 December 2014:

[see next page]

Reasons to buy thick nuclear waste dry storage casks

Safety Features	Thin Canisters	Thick Casks
1. Thick walls	1/2” to 5/8”	up to 20”
2. Won’t crack		√
3. Ability to repair		√
4. Ability to inspect exterior		√
5. Early warning monitor		√
6. ASME canister or cask quality certification		√
7. Defense in depth (redundant systems)		√
8. Stored in concrete building		√
9. Licensed in U.S.	*	*
10. Market leader	U.S.	World



The Nuclear Regulatory Commission (NRC) and California Public Utilities Commission (CPUC) should not approve Edison’s decommissioning plan (PDSAR), should not approve use of thin canisters, and should not approve releasing any of the over $3 billion of ratepayer money in the decommissioning fund until nuclear waste storage issues are adequately addressed.

Southern California Edison refuses to allow thick nuclear waste dry storage cask vendors to bid. Edison based this decision on meeting their artificial deadline rather than on selecting the best available nuclear waste storage technology.

On August 26, 2014 the NRC decided tons of nuclear waste may stay at San Onofre and all other nuclear power facilities indefinitely, since no permanent or interim storage sites are on the horizon. *http://www.nrc.gov/waste/spent-fuel-storage/wcd/documents.html*

The NRC, the CPUC and Edison have not adequately addressed the safety and cost impacts of the new NRC indefinite storage decision.

Comments are due to the NRC December 22, 2014 on Edison’s San Onofre Nuclear Post-Shutdown Decommissioning Activities Report (PSDAR). *http://www.regulations.gov/#!docketDetail;D=NRC-2014-0223.*

Go to **SanOnofreSafety.org** for additional action items, sources and details.

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1. Thick walls: Edison is only considering thin walled (1/2” to 5/8”) welded canister systems (Holtec UMAX and Areva NUHOMS 32PTH2).

Thick casks are about 9” to 20” thick. The French Areva TN series forged steel thick casks are use by the French and others, including Japan at Fukushima. The thicker German ductile cast iron casks are up to 20” thick and are the leading international cask. All thick casks use double bolted sealed lids.

2. Cracks: The thin stainless steel canisters may crack within 30 years or less in marine environments due to stress corrosion cracking. A 2-year old Diablo Canyon canister showed all the environmental conditions for cracking. The NRC in August said they did not think conditions for cracking would exist for at least 30 years – they said the temperature of the canister would be too high for salts and humidity to accumulate on the canister. They were wrong.

The thick German seamless ductile cast iron casks do not have crack issues and include a maintainable epoxy exterior and a galvanized nickel-plated interior for additional corrosion protection. More information is needed about the French TN thick steel casks.

3. Repair: Thin canister cracks cannot be repaired. Thick cask seals and lids are replaceable.

A fuel pool is required to replace canisters and casks. Edison plans to destroy the fuel pools with no other adequate plan in place. Pools have already been destroyed at Rancho Seco in Sacramento and at Humboldt Bay. Transporting cracked canisters to another facility with a pool presents numerous safety risks.

No "hot cells" (dry transfer systems) exist in the U.S. that are large enough to transfer fuel between canisters.

4. Inspect: No technology exists to adequately inspect even the exterior of thin welded canisters for cracks or other corrosion. The NRC is allowing vendors 5 years to develop something, but it will be limited. There is **no seismic rating** for cracked canisters yet the NRC plans to allow **up to a 75% crack** in these canisters. They plan to require inspection of only one canister **per plant** after 25 years and then the same canister at 5 year intervals.

The NRC plans to modify their dry storage and transportation standards (**NUREG-1927**) in 2015 with these inadequate guidelines.

5. Early warning: Thin canisters remotely monitor canister temperature. This does not provide early warning before a radiation leak. The NRC requires canister radiation monitoring only a few times a year by an employee with a "monitor on a pole."

Once fuel pools are empty, the NRC has allowed all other radiation monitoring at plants to be shut down (e.g., Humboldt Bay).

Thick casks have pressure monitoring in the lid. A pressure change is an early warning of potential helium leaks. And thick casks have continuous remote radiation monitoring.

6. ASME certification: Thin canisters do not have American Society of Mechanical Engineer (ASME) certification (N3-stamp) and do not meet ASME standards. Thick casks have ASME certification and international quality certifications.

7. Defense in Depth. Zirconium fuel cladding is one of two levels of radiation protection. Damaged fuel assemblies lose this protection. Unless damaged fuel assemblies are sealed, this level of protection is lost. The thick ductile iron casks store damaged fuel rods and assemblies in individual sealed containers prior to loading them into the cask. Holtec uses unsealed cans. Areva does not even use cans -- only unsealed caps. San Onofre has 31 damaged fuel assemblies in the pools and 95 damaged fuel assemblies in canisters.

Thin canisters provide only partial radiation protection and require thick concrete overpacks or casks. The concrete overpacks/casks are unsealed, vented and provide only gamma and neutron shielding. Thick casks do not require concrete overpacks/casks.

Note: no vendor has addressed how to handle **high burnup fuel** cladding that may degrade shortly after dry storage. High burnup fuel burns longer in the reactor, resulting in fuel over twice as radioactive, hotter and unpredictable in storage and transport. It requires more years to cool in the fuel pools for storage and even more years to cool before it can be transported. No U.S. geological repository designs address high burnup fuel.

8. Concrete buildings: Thick casks are stored in reinforced concrete buildings for additional environmental protection.

9. *NRC License: Areva and Holtec thin canister licenses are pending NRC approval for the models Edison is considering.

Thick cask system vendors do not have a current general license and will not request an NRC license without a customer, such as Edison. The expensive licensing process takes 18 to 30 months. If Edison wants the casks, the vendor will apply for a license. The NRC has never turned down a license. Edison thinks the process may take longer than 30 months, but the fuel needs to cool in the pools for many years. The thick casks have international storage and transport licenses and better manufacturing standards. The German vendor, Siempelkamp, is confident it can meet and exceed current NRC requirements.

The Areva TN thick casks have a site specific license at Prairie Island nuclear power plant.

The Castor V/21 German thick ductile cast iron cask was approved by the NRC for storage at the Surrey nuclear power plant years ago, but the license expired. U.S. utilities did not want to pay any increased price for a safer product. Ironically, a Castor V/21 was used to "demonstrate" all other canister designs are safe.

10. Market leader: The thin canisters are the market leader in the U.S. because utility companies based decisions on cost. The thick casks are the market leader in Europe and other countries because those countries will pay more for quality and safety. Prices for thick ductile cast iron casks are now lower than they were many years ago, but unless Edison allows them to bid, we will not know the cost. Steel costs have risen significantly. Cost for the thin systems is just under $4 million each. Prairie Island paid $5.96 million for each TN-40 steel cask.

Nuclear waste dry storage myths

Myth 1. We are not aware of problems with any canisters. That's because they do not have technology to inspect them. Due to lack of gamma and neutron shielding, canisters must be inspected while inside concrete overpacks/casks. Existing technology for other stainless steel products is not directly transferable. The NRC is allowing vendors 5 years to solve this problem. However, solutions will be limited.

Myth 2. We have inspected some canisters. Visual inspection was limited to a small surface area of a few steel canisters, only for canister temperature, and surface dust and salts from a small area of the canisters. No crack or corrosion inspections. Even this limited inspection showed conditions exist for cracking at a 2-year old Holtec Diablo Canyon canister. [1] The NRC said thought this would not happen for at least 30 years.[2]

Myth 3. We have technology to repair stainless steel. That technology does not work for nuclear waste canisters and no solution may be possible.

Myth 4. The public wants the fuel expedited out of fuel pools. Yes, but not into inferior dry storage systems and not without sufficient cooling of high burnup fuel.

Myth 5. Thick cast iron casks are not designed for extended storage and are not designed for welded lids. Germany is using ductile cast iron casks for extended storage and is evaluating them for final disposal. Welded lids can be added to the ductile cast iron casks for final disposal. Japan is also considering them for final disposal.

Myth 6. We have plans for replacing failed canisters using hot cells [dry transfer systems] or fuel pools. There are no hot cells large enough to transfer fuel assemblies from one canister to another. Hot cells are extremely expensive to build and maintain. Also, there are no mobile hot cells in the U.S. The French use a mobile hot cell that is too small for our needs. It may not be feasible to build a mobile hot cell for the size needed in the U.S. Edison plans to destroy the fuel pools after fuel is unloaded to dry canisters. There are no pools at Rancho Seco in Sacramento or at Humboldt Bay. Also, repackaging in a pool could interfere with ongoing pool operations at active plants, could risk unacceptably contaminating the pool, or could challenge the fuel due to the additional stresses associated with rewetting and re-drying operations.[3]

Myth 7. All canisters and casks will eventually fail, so it doesn't matter which one we use. Thin canisters are not maintainable, may have early failure and have no early warning system. We will only know after Cesium leaks into the environment. Additional costs for thin canisters include transfer casks, transport casks, thick overpacks for final disposal (assuming they are even allowed for final disposal) and replacement canisters.

Myth 8. Thick ductile cast iron casks are not approved for transport by the NRC. The NRC has not evaluated the current ductile cast iron casks for transport. Ductile cast iron casks (manufactured by Siempelkamp) are certified for transport by American and international standard setting bodies. A Sandia Lab report shows ductile cast iron casks perform in an exemplary manner and exceed NRC's current standards for embrittlement. Studies cited show DI [ductile iron] has sufficient fracture toughness to produce a containment boundary for radioactive material transport packagings that will be **safe from brittle fracture.** Studies indicate that even with drop tests **exceeding the severity of those specified in [NRC regulation] 1 OCFR7 1 the DI packagings perform in an exemplary manner**. Low temperature brittle fracture is not an issue. The DCI casks were tested **at -29°C and -49°C exceeding NRC requirements**. Conclusions shared by **ASTM, ASME, and IAEA**.[4]

Myth 9. Fukushima dry storage casks were not damaged, so canisters are safe. These were Areva TN-24 thick steel casks stored in concrete buildings. Not thin canisters and none had high burnup fuel.

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[1] Diablo Canyon: conditions for stress corrosion cracking in 2 years, D. Gilmore, October 23, 2014 *https://sanonofresafety.files.wordpress.com/2011/11/diablocanyonscc-2014-10-23.pdf*

[2] NRC 8/5/2014 meeting summary *http://adamswebsearch2.nrc.gov/webSearch2/view?AccessionNumber=ML14258A081*

[3] Dry Transfer Systems for Used Nuclear Fuel, Brett Carlsen, et.al. May 2012, Idaho National Lab, INL/EXT-12-26218 *http://www.inl.gov/technicalpublications/Documents/5516346.pdf*

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

Appendix B:
Edison’s review of the Castor Option

ATTACHMENT

Summary of Review for the Community Engagement Panel (CEP)

I. Purpose:

During recent Community Engagement Panel (CEP) meetings, some CEP members and public participants suggested that SCE evaluate the option to procure the "CASTOR" type Spent Fuel Dry Cask System. In response, SCE Engineering reviewed the options potentially available for the "CASTOR" type dry cask system as marketed by Siempelkamp. SCE's review included evaluating the design, licensing, fabrication, delivery, and loading of approximately one hundred CASTOR dry cask storage units at SONGS (assuming 85 Spent Fuel Canisters and 12 "Greater-Than-Class-C" waste containers) based on a storage system that could accommodate 32 or more fuel assemblies per cask.

II. Background:

On June 7, 2013, SCE announced its decision to permanently cease operation at SONGS Units 2 and 3. In support of that decision, SCE has committed to move the spent fuel from the two spent fuel pools to the Independent Spent Fuel Storage Installation (ISFSI) safely and efficiently to support decommissioning. The goal is to have all spent fuel safely stored in dry fuel canisters by 2019. Currently, there are 2,668 fuel assemblies in the two spent fuel pools that must be moved from the spent fuel pools to the ISFSI.

SCE has diligently reviewed options presented by the three spent fuel canister vendors that currently hold U.S. Nuclear Regulatory Commission (NRC) licenses for canisters: Areva-TN, Holtec, and NAC. These three companies are the only companies with currently licensed products and all three market stainless steel canisters (nearly all with welded lids), that are housed in reinforced concrete over-packs.

SCE initiated the CEP to provide a conduit for information from SCE to the public and vice versa. Some CEP members and other public participants have encouraged SCE to evaluate the "CASTOR" type spent fuel canister. The apparent premise of this recommendation is that the CASTOR system is superior in design to the U.S. designed products. To address the CEP recommendation and public comments, SCE has reviewed the company offering the CASTOR system, (Siempelkamp), the products offered, SCE design basis requirements, and the U.S. licensing requirements.

III. Regulatory Requirements:

- 10 CFR Part 72 contains the licensing requirements for the independent <u>storage</u> of spent nuclear fuel.

- 10 CFR Part 71 contains the licensing requirements for the <u>transportation</u> of spent nuclear fuel.

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- NUREG 1536, "Standard Review Plan for Dry Cask Storage Systems" provides the guidance for use by staff reviewers from the NRC and the NRC's Office of Nuclear Material Safety and Safeguards (NMSS) in performing safety reviews of applications for approval of spent fuel dry cask storage systems. This NUREG generally describes the requirements for use of industry codes and standards that the NRC staff has accepted in the past.

- NUREG 1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel," provides guidance for the review and approval of applications for packages used to transport spent nuclear fuel under 10 CFR Part 71. The document is intended to be used by NRC staff.

- NRC Regulations require the Spent Fuel Canister to be licensed prior to use under a site specific license or under a general license with the Licensee listed in the Certificate of Conformance (C of C).

- There are additional NRC regulations and industry guidance regarding spent fuel storage, which are not specifically listed here.

IV. "CASTOR" General Description:

The "CASTOR" System is presently offered by Siempelkamp under license by the original designer, Gesellschaft fur Nuklear-Service (GNS). The body of the containers is made of a ductile cast iron with a double lid system that is mechanically sealed with studs and "O" rings in two concentric rings which are machined in the mating surfaces. According to Siempelkamp, there are approximately 900 of these casks made for various fuel or debris service worldwide. Within the U.S., 26 units were sold in the early 1980s and are utilized at the Surry Plant in Virginia.

Siempelkamp is offering a newer version of the CASTOR, the "V/19" system, similar to the "V/21" System. The designs used at Surry were the V/21 which holds 21 fuel assemblies that have been cooled for at least five years (hence the Roman numeral V). The X/33 system holds 33 fuel assemblies that have been cooled at least 10 years. Our understanding is that Surry has 25 V/21 canisters and one X/33 canister. Surry has five different types of canisters on site as they were part of the original cask demonstration studies for the U.S. nuclear industry.

CASTOR V/21 and X/33 casks are currently licensed for storage in the U.S. under a site-specific license (SNM-2501) at the Surry nuclear facility. The CASTOR V/21 cask was previously licensed for storage under Certificate of Compliance (CoC) 72-1000 (general license), which expired in 2010. No spent fuel was ever stored in the U.S. under the general license CoC 72-1000.

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V. Analysis:

SCE's analysis was based upon review of historical documents and reports, literature and licensing documents describing CASTOR specifications, regulatory guidance, established (active) U.S. based dry storage technology specifications, and a meeting between SCE and Siempelkamp personnel, held at the SONGS Mesa facility on September 16, 2014. Siempelkamp is a worldwide manufacturer and has capabilities for fabrication; however, SCE identified the following concerns relating to the scope of a SONGS project utilizing the CASTOR system:

- Siempelkamp would need a U.S. Nuclear Utility partner to begin licensing activities with the NRC. Funding and time would be needed from the U.S. Nuclear Utility partner to develop the design and license documents with no guarantee that the NRC would issue a license, placing those funds and schedule at risk.

- Siempelkamp does not currently have U.S. infrastructure to design and license the product; a staff would need to be retained and developed with new people and contract staff. Without the benefit of a long and tenured staff with experience, there would be a learning curve with U.S. regulation.

- Siempelkamp is not equipped to develop Licensing submittals and work with the NRC to gain approval; this process could take 5 to 10 years.

- Siempelkamp does not have experience with fuel movement (including crane maintenance) in the U.S. and would rely on contracted support.

- Siempelkamp is not equipped to perform civil design and ISFSI reinforced concrete work and would rely on contracted support.

- Siempelkamp is not equipped to perform security feature modifications and would rely on contracted support.

- Siempelkamp is not equipped to interact with California regulatory agencies and would rely on contracted support.

- Siempelkamp proposes to use Ductile Iron material (ASTM 874) which is not an ASME Code material. Although the ASME code allows for "Code Cases" for specific applications, and the NRC has a provision in the Standard Review Plan for using various alternative materials, the NRC's review of Siempelkamp's CASTOR system would likely be quite involved, and more so than review of U.S. vendors that utilize ASME material and design rules, with which the NRC is familiar. The use of alternative materials may require material testing programs (ductility, fracture toughness, strength) or other demonstration methods.

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- Siempelkamp proposes to use a single forging method using ductile cast iron material. Ductile Cast Iron was originally proposed by cask vendors as a more economical material for used fuel storage and transportation casks, as compared to casks fabricated with austenitic stainless steel.[4] Although a 'code case' (N670) was found for this material for acceptance by ASME, Reg Guides 1.84 and 1.193 do not allow its use without prior NRC approval. Reg Guide 1.84 explicitly states the Code Case is not acceptable for use.

- Siempelkamp does not have an option to enclose a cast ductile iron container into another container for any reason (i.e., due to damage, leakage, or inadequate strength).

- Siempelkamp proposes that an NRC license for storage and transport could be obtained; however, the NRC never approved the V/21 or X/33 canister for transport. At this time, those canisters at Surry are stranded until some method of transport can be developed. This may be why Dominion (owner of Surry) has not elected to procure any additional CASTOR casks.

- Siempelkamp proposes to use a bolted cover which works very well for European companies that recycle fuel. Since these companies recycle fuel, the use of the canister is short in duration as, while in the U.S., the 'once through' use of fuel results in very long term storage that is better suited by a welded canister. The ductile iron cask does not support a welded lid option. The material, thickness of the lid, and the thickness of the wall would require a very large and involved weld; therefore, SCE would need to rely on a bolted lid connection for a long duration.

- Siempelkamp proposes that the canister design can accommodate the SONGS total canister heat, single assembly heat, high burn up fuel, seismic requirements, etc.; however, the V/21 and X/33 do not meet the SONGS fuel requirements and therefore a new design would be needed that would require additional analysis and or design change to accommodate the SONGS fuel.

- Siempelkamp CASTOR designs that were reviewed by SCE, accommodating higher enrichment/burnup fuel, are heavier than 125 (U.S.) tons when loaded with spent fuel. The existing cask crane capacity is 125 tons. Upgrading the cask crane capacity would be costly and even more complex if the existing structure will not support a capacity upgrade to the crane.

- Siempelkamp CASTOR designs do not utilize a 'multipurpose' canister and thus would require 'direct disposal' via dual purpose canister (DPC) in a repository. It is

[4] EPRI Report NP-4785

unknown if this will ultimately be feasible.[5] The feasibility evaluation assumes cask dimensions and weight consistent with stainless steel DPCs currently stored in SONGS ISFSI, as well as stainless steel DPCs being considered by SCE to store the remainder of fuel in wet storage. The feasibility evaluation assumed dimensions and weight are considerably smaller and lighter than the CASTOR designs. Additional fuel handling, personnel exposure, radwaste generation, and expense will be required to repackage fuel stored in CASTOR casks, if the casks cannot be directly stored in a repository.

- Siempelkamp use of a V/19 or V/21 or similar would result in a much larger ISFSI footprint. Assuming a 19 assembly capacity cask, 141 canisters would be required to store all spent fuel as compared to 87 NUHOMS canisters. A 33 assembly capacity would be more consistent with the Areva or Holtec options.

- Siempelkamp estimates their system could be licensed, casks fabricated, and be ready to support SFP offload by early 2019. This is aggressive based on the issues described above. Even assuming all licensing activities went quickly and assuming one cask is loaded per week with the use of a 19 spent fuel assembly capacity cask (141 casks[6]/141 weeks), the SFPs would be emptied sometime in 2021 or 2022. However, given the issues described above, the overall schedule could go through 2027 (10 years to license, 2 years to offload), which is well beyond the date by which SCE plans to have all spent fuel moved to dry storage.

VI. Conclusion

Based on the risk to the project cost and schedule and considering the issues described above as well as the lack of any current U.S. experience, SCE has chosen not to proceed with further evaluation of the Siempelkamp option.

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[5] "*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

[6] 2668 spent fuel assemblies total in SONGS 2/3 SFPs

Appendix C:
Surveillance Program for SONGS

San Onofre Nuclear Generating Station (SONGS)
Spent Fuel Storage "Surveillance Program"

Purpose:

The purpose of this paper is to describe the current surveillance activities performed by Southern California Edison (SCE) related to the SONGS "Independent Spent Fuel Storage Installation" (ISFSI) as well as future surveillance activities related to license extension.

Current Surveillance Activities:

SCE currently monitors the condition of the fifty-one spent fuel casks located on the SONGS ISFSI. Examples of surveillances include:

- Continuous surveillance of the ISFSI perimeter by the Security force.
- Continuous monitoring of the overpack roof temperature by electronic means with Control Room alarm function
- Routine inspections of the inlet and outlet vents for debris / blockage
- Periodic visual inspections of the exposed surfaces of the concrete overpack
- Periodic radiation surveys of the area
- Periodic inspection of the overpack closure head bolts
- Periodic inspection of the lightening protection equipment

License Extension Activities:

A future license extension request will be reviewed by the NRC using the recently issued NRC standard review plan (NUREG 1927). The "License" and "Certificate of Compliance" are held by the Vendor (currently at SONGS – Areva-TN), and adopted by SCE. The vendor (along with SCE) will utilize all available inputs for development of a license extension request; examples include:

- NUREG 1927 "Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance" (2011)
- NEI 14-03 "Industry Guidance for Operations Based Aging Management for Dry Cask Storage" (Draft)
- EPRI "Failure Modes and Effects Analysis (FMEA) of Welded Stainless Steel Canisters for Dry Cask Storage Systems", (2013)
- NRC "Regulatory Issue Resolution Protocol related to Chloride Induces Stress Corrosion Cracking" (On-Going)
- DOE related initiatives
- Other NEI / EPRI sponsored programs for Aging Management Issues

Future Surveillance Activities

- Future license surveillance requirements will include all of the above as a minimum
- Other surveillance requirements will be developed based on the Aging Management Program (to be developed using guidance discussed above).
- Future licenses may utilize 'Toll Gates' to specify additional inspection evaluation milestones within the licensed extension period.

Stress Corrosion Cracking

One of the more prevalent aging management mechanisms is the Chloride Induced Stress Corrosion Cracking (CISCC). This phenomenon is common to SSC's at nuclear plants close to the Atlantic or Pacific Ocean due to the salt laden atmosphere. The industry has evaluated the impacts, developed surveillance programs, and developed code repair methods for any indications identified in other power plant SSC's.

Repair methods for stainless steel components have been extensively used in the nuclear industry in accordance with American Society of Mechanical Engineers (ASME) Section XI requirements. Similar methods would be utilized with robotics as necessary should a repair to a spent fuel canister be needed.

Background:

SCE has reviewed the designs of the three current spent fuel canister vendors with US licenses; Areva-TN, Holtec, and NAC. These three companies utilize similar materials (stainless steel canisters with reinforced concrete overpacks), air cooling, and an initial license of twenty years (i.e., all similar to the SONGS installation).

The SONGS cask vendor, Areva, will need to apply for a license extension for the existing dry casks before the expiration of the current license in 2023.

The NRC has recently issued the "Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance" (NUREG 1927) in 2011 for review of license renewal applications.

The DOE recently issued the report "Managing Aging Effects on Dry Cask Storage Systems for Extended long-Term Storage and Transportation of Used Fuel" (Rev 1, 2013). This report briefly summarizes that: "Applications for ISFSI license renewals must include the following: a) Time-limited aging analyses (TLAAs) that demonstrate that structures, systems, and components (SSCs) important to safety will continue to perform their intended function for the requested period of extended operation, and 2) A description of the aging management program (AMP) for management of issues associated with aging that could adversely affect SSC's important to safety."