Letter with Enclosure

Prepared for: San Onofre 2 & 3

Preparer:	Alan Kepple	E-signed by: Alan Kepple on 2018-06-15 09:46:46
Reviewer:	Alexander Zarechnak	E-signed by: Alexander Zarechnak on 2018-06-18 15:33:20
Approver:	Alan Kepple	E-signed by: Alan Kepple on 2018-06-18 16:20:56

QA Statement of Compliance

This document has been prepared, reviewed, and approved in accordance with the Quality Assurance requirements of the MPR Standard Quality Program.

Created: 2018-06-15 09:46:46
Project-Task No. 02991502-0042

MPR Associates, Inc.
320 King St. • Alexandria, VA 22314
(703) 519-0200 • www.mpr.com

June 15, 2018
0299-0042-LTR-004R2

Mr. Manuel Camargo
Principal Manager, Strategic Planning
SONGS Decommissioning
Southern California Edison
Via email

Subject: SONGS Dry Used Fuel Storage and Chloride-Induced Stress Corrosion Cracking (CISCC)

Dear Manuel:

As we recently discussed, an error was identified in MPR Report 0299-0042-LTR-004R1. Attached is a revised report (0299-0042-LTR-004R2) that corrects this error. Specifically on page 20 of report 0299-0042-LTR-004R1, the sentence "The DOE recently identified a large existing hot cell facility (Test Area North) on the Idaho National Laboratory (Reference 21) that could be dedicated to repackage commercial used fuel canisters." is replaced by the following sentence "The DOE recently identified existing hot cell facilities on the Idaho National Laboratory (Reference 21) that could be used to open and sample used fuel canisters and then to repackage used fuel retrieved from the cask.".

I apologize for any inconvenience this error may have caused. Please let me know if there is anything else MPR can do to assist your efforts.

Sincerely,

Alan C. Kepple

Enclosure

Enclosure to
MPR Letter Dated
June 15, 2018

WHITE PAPER

SONGS Used Fuel Management – Defense in Depth

Situation: The Federal Nuclear Waste Policy Act of 1982 requires the United States government to take possession of used nuclear fuel from commercial nuclear power plants in the U.S., including the San Onofre Nuclear Generating Station (SONGS). Specifically, the U.S. Department of Energy (DOE) was required to provide a national storage facility and begin accepting used fuel by 1998. To date, DOE has not delivered on its mandate to provide such a federal repository. In the meantime, used fuel is accumulating in spent fuel pools and dry cask storage systems at both operating and shut down nuclear power plants across the U.S. Like many other nuclear plants across the U.S., SONGS already has transferred much of its used fuel from cooling pools into dry stainless steel canisters that are sealed and stored in a passive dry storage system known as an independent spent fuel storage installation (ISFSI). In addition, packaging used fuel in stainless steel canisters is the first step to prepare the used fuel for transport offsite since all currently licensed transport overpacks that can ship practical numbers of spent fuel assemblies require the fuel to be packaged in a stainless steel canister. The most feasible near term opportunity to move SONGS used fuel offsite appears to be shipping the used fuel to a consolidated interim storage (CIS) facility, such as those that are being planned in sparsely populated areas of the U.S. such as eastern New Mexico and west Texas.

Focus of White Paper: Even with the prospect of CIS facilities becoming a reality in the next several years, dry fuel canisters continue to age in ISFSIs at sites such as San Onofre. Questions have been raised during discussions at various SONGS Community Engagement Panel (CEP) meetings about how canisters will be monitored over time and, if degradation is detected, how it will be addressed. That’s why Southern California Edison (SCE) requested the Decommissioning Adviser for SONGS (MPR Associates Inc.) to provide an independent review and document the technical basis for the conclusions of the review. This white paper provides the independent review, conclusions, and technical basis associated with defense-in-depth as it relates to dry cask storage at SONGS.

Executive Summary

1. How does dry cask storage of used nuclear fuel work?

Dry cask storage systems for used nuclear fuel protect people and the environment from radiation, using (1) thick concrete for shielding and physical protection (2) a seal-welded stainless steel canister to provide containment for radioactive material and (3) passive cooling which employs a natural convection "chimney effect" which maintains used fuel in a safe condition. Dry cask storage does not use water or fans for cooling.

2. What is the U.S. commercial nuclear industry's experience with dry cask storage and degradation?

There are currently over 2,000 stainless steel canisters loaded with used fuel in service at more than 70 different commercial nuclear sites in the U.S. The oldest stainless steel canisters have been in service for over 20 years and no degradation of any dry cask storage system components has been reported. This includes the Calvert Cliffs Nuclear Power Plant, which is located on the shores of the Chesapeake Bay in Maryland in a marine environment similar to San Onofre.

3. What inspections are planned to detect potential degradation of the used fuel canisters?

Currently, operation of the existing AREVA dry storage system at SONGS is monitored periodically by checking the temperature on top of the concrete storage module, performing radiological surveys and visually inspecting accessible components. Detailed guidelines for dry storage system aging management plans have been developed by EPRI (Reference 10). These guidelines are based on the potential degradation mechanisms for dry storage systems and the inspection and monitoring plans previously approved for the four sites that have obtained license extensions. The EPRI guidelines include detailed acceptance criteria (Reference 10, Section 5) for future visual examinations of the external surfaces of canisters to detect chloride induced stress corrosion cracking (CISCC). The guidelines require surface and subsurface inspection (eddy current or ultrasonic) if the visual indicators of CISSC reach threshold values. If needed, these additional inspections would be performed using automated equipment described by EPRI in Reference 32.

Most recently approved ISFSI aging management plans include periodic visual inspection of the external surfaces of the used fuel canisters. AREVA, SONGS ISFSI licensee, will develop a specific aging management plan for the existing SONGS dry storage system that requires approval by the NRC. SONGS expects to begin performing additional required periodic visual inspections of the external surfaces of the storage canisters in accordance with the NRC approved aging management plan.

4. What would happen if a SONGS spent fuel canister sustained corrosion that led to a crack and that crack grew through the wall of a canister?

If over time a crack grew through the wall of a SONGS used fuel canister, there would be no significant release of radioactive material from the canister, no spread of radioactive contamination offsite and therefore no radiological exposure to the public. The consequence of a leaking used fuel storage canister has been evaluated by tests performed by DOE and by extensive NRC approved analyses of accidents involving leaking canisters. These tests and analyses conclude that a leaking canister will not result in radiological exposure.

5. How would a potentially compromised SONGS used fuel canister be repaired or replaced?

If an unacceptable condition is found on a SONGS used fuel canister, there are a number of possible responses depending on the specific conditions. In some circumstances, such as an isolated crack, a remote weld repair procedure might be the best solution. Under other conditions, the deficient canister could be removed using canister transport equipment and placed in a larger cask on site. In still other circumstances, a deficient canister might be shipped to an offsite facility for repacking, using an overpack for radiological shielding during transportation.

6. What is the expected service life of the SONGS used fuel canisters?

The used fuel canister manufacturers for SONGS (AREVA and Holtec) state the service life for both the AREVA NUHOMS and Holtec UMAX used fuel canisters is 100 years. MPR concludes that the NUHOMS and UMAX canisters at SONGS are likely to maintain containment for more than 100 years based upon selection of Type 316L stainless steel and considering actual experience with the primary canister degradation mechanism (Chloride Induced Stress Corrosion Cracking (CISCC)) at SONGS. The laser peening process that will be applied to the welds on the newer SONGS Holtec UMAX canisters is expected to further extend canister service life.

Table of Contents

Executive Summary ***3***

1.0 Key Issues, Discussion, Conclusions, and Technical Basis ***7***

2.0 References ***26***

A CISCC Experimental Results and Laser Peening Tests ***28***

Tables

Table 1. EPRI Used Fuel Canister Inspection Results..10

Table 2. Offsite Radiation Exposure Estimates 18

Table 3. CISCC Cracking in Koeberg Refueling Water Storage Tanks.............................23

Table 4. Nuclear Power Plant Component CISCC Wall Penetration Times 24

Table A-1. CISCC Average Crack Growth Rates Types 304 and 304LN.............................28

Table A-2. 15-Year CISCC Test Summary 29

Table A-3. CISCC Observed Initiation Time...29

Figures

Figure 1. Spent Fuel Assembly 7

Figure 2. Commercial Dry Spent Fuel Storage Facilities 9

Figure 3. Surface Corrosion Deposits on CISCC U-Bend Specimens.................................12

Figure 4. Used Fuel Canister at SONGS...14

Figure 5. AHSM Concrete Modules at SONGS...15

Figure 6. Schematic Showing UMAX Canister inside Concrete 16

Figure 7. Westinghouse Remote Used Fuel Canister Welding Machine 19

Figure 8. Holtec HI-STAR 190 Transport Cask...20

Figure 9. Hot Cell Facility at BWXT (Reference 22) 20

Figure A-1. Holtec UMAX Peening Test Coupon 31

1.0 Key Issues, Discussion, Conclusions, and Technical Basis

Question 1- How does dry cask storage work?

Dry cask storage basics:

- Radioactive material is trapped in ceramic pellets that are sealed within fuel rods
- Fuel rods are organized into fuel assemblies that are housed in sealed stainless steel canisters
- Canisters are stored in thick concrete overpacks that provide radiation shielding and physical protection
- Collectively, the canisters and overpacks provide shielding, containment, physical protection, and passive cooling

Answer: Dry cask storage systems are designed to safely store used fuel assemblies with passive air cooling. Each SONGS used fuel assembly is about 15 feet long with an 8x8-inch square cross section, and weighs about 2,000 lbs. Each fuel assembly is composed of about 236 individual fuel rods held together by grids as shown in Figure 1 below.

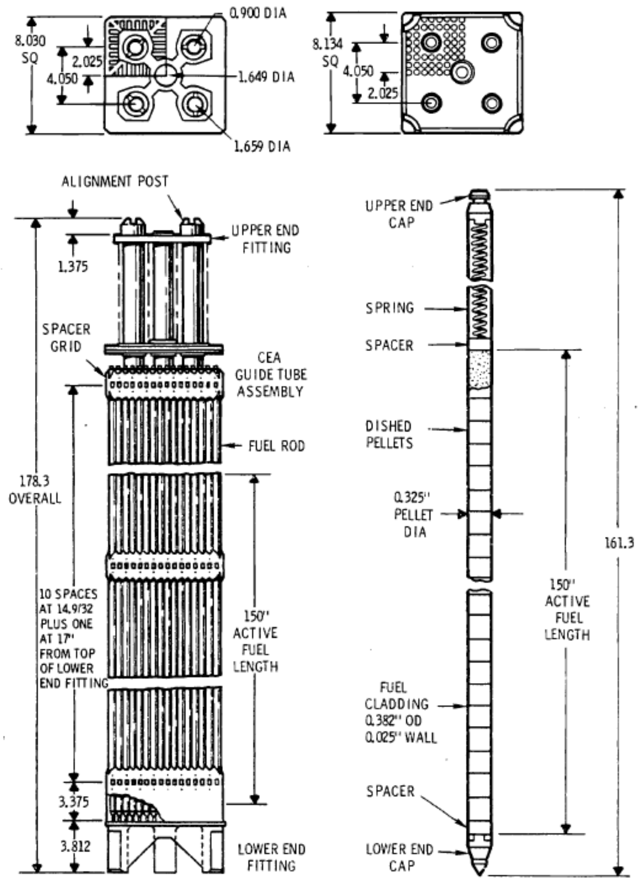

Figure 1. Used Fuel Assembly

Each fuel rod consists of a metal tube (also known as fuel rod "cladding") with about 300 ceramic fuel pellets stacked inside. The metal tube is sealed during manufacture by welding plugs in both ends of the tube. During operation, Uranium atoms inside the fuel pellets are split, producing heat that is used to generate electricity as well as radioactive fission products. Even after the reactor is shutdown, the radioactive fission products trapped in the fuel pellets continue to generate heat due to ongoing radioactive decay. As the radioactive fission products decay, energetic gamma particles are emitted that can damage human tissue (commonly known as "radiation exposure"). In the commercial nuclear industry, multiple layers of defense in depth are used to protect the public from radiation exposure.

To safely store used fuel, three hazardous characteristics of the radioactive fission products need to be managed.

1. **Direct Radiation -** The first characteristic that needs to be managed is the direct radiation (gamma particles) emitted from the fission products in used fuel. Gamma particles are stopped when they interact with matter. For example, 9 out of 10 gamma particles emitted by a common fission product (Cs137) will be stopped by a layer of concrete about 1 foot thick. As a result, dry cask storage systems include shielding (typically 3 or more feet of concrete) between the spent fuel and people. For the AREVA NUHOMS dry used fuel storage system at SONGS, the required shielding is provided by horizontal concrete storage modules. For the Holtec UMAX dry used fuel storage system at SONGS, the required shielding is provided by the concrete monolith that surrounds all 74 canister storage locations, as well as by a thick concrete lid.
2. **Potential Spread of Radioactive Materials -** The second characteristic that needs to be managed is the potential spread of radioactive fission product materials. Spread of these materials is prevented by providing several barriers around the radioactive materials. Most of the radioactive fission product material is in a solid form that is trapped in the ceramic fuel pellets. In addition, the fuel pellets are contained within a sealed tube called fuel rod cladding. Beyond that is the seal welded stainless steel canister. Lastly, the concrete overpack structure presents a tortuous path for the thermal circulation of the cooling air in which the concentration of any particles that have reached this point will be reduced by an estimated factor of 700 (Reference 1).
3. **Decay Heat -** The third characteristic that needs to be managed is the heat given off by the radioactive fission products as they decay. If a means is not provided to disperse this heat, the heat generated could damage the fuel assemblies and the dry cask storage equipment. For both the NUHOMS and UMAX dry storage systems at SONGS, the decay heat is managed by first requiring the used fuel assemblies to be cooled in water pools for about five years until the heat load can be removed by air that is naturally circulated around the exterior of the canisters The air inside the seal welded canisters is replaced with Helium gas which is chemically inert and improves the transfer of heat from the fuel rods to the canister internal surface which lowers the temperature of the used fuel. Both the NUHOMS and UMAX concrete shielding structures are designed with pathways for warm air to escape and naturally cool the canisters.

Question 2 – What is the U.S. commercial nuclear industry’s experience with dry cask storage and degradation?

Answer:

There are over 2,000 loaded stainless steel used fuel canisters in service in more than 70 different commercial nuclear sites in the U.S. as shown in Figure 2 below (Reference 2). No degradation of dry cask storage systems has been identified.

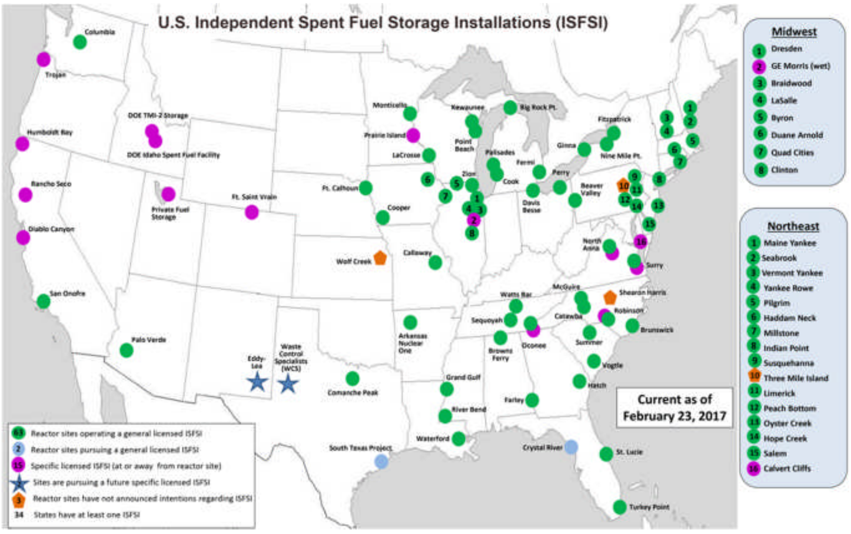

Figure 2. Commercial Dry Spent Fuel Storage Facilities

Based on operating experience, evaluation of potential aging degradation of dry storage systems, and under current NRC licensing requirements, only surveillance type monitoring is performed during the first 20 years of dry storage system operation. Surveillance type monitoring typically includes periodic exterior visual inspections, temperature monitoring, and radiological surveys. Four dry spent fuel storage installations (Surry, Robinson, Oconee, and Calvert Cliffs) have operated for more than 20 years and additional detailed internal visual inspections have been performed at those sites to support NRC license renewal reviews. One of these locations, Calvert Cliffs, is in a marine environment similar to San Onofre. EPRI has sponsored additional informational inspections of canisters in three marine environments: Calvert Cliffs (Reference 3), Diablo Canyon (Reference 4), and Hope Creek (Reference 5). During the EPRI inspections, external surfaces of used fuel canisters at Diablo Canyon, Calvert Cliffs and Hope Creek were visually inspected, surface temperatures measured, and canister surfaces were sampled for salt deposits. Minor corrosion deposits were observed on external surfaces that did not show the concentration of corrosion deposits in areas with high tensile stress (weld areas) that is characteristic of CISCC and is described in the acceptance criteria in Reference 10. Salt deposits on the exterior surface of used fuel canisters is a necessary condition and thus a precursor for chloride induced corrosion. Inspection results are summarized in Table 1 below:

Table 1. EPRI Used Fuel Canister Inspection Results

	Surface Temperature (°C)	Salt Concentration (g/m^2)	Surface Corrosion
Calvert Cliffs (NUHOMS)	44-51	Less than 0.1	A few small rust spots*
Diablo Canyon (Hi-Storm)	49-93	Less than 0.005	No rust spots reported*
Hope Creek (Hi-Storm)	22-57	"Not much Chloride"	No rust on welds*

***Corrosion deposits observed did not meet the Reference 10 threshold for additional inspection**

Question 3: What inspections are planned to detect degradation of the used fuel canisters?

Answer: Operation of the existing NUHOMS dry storage system at SONGS is currently monitored by checking the temperature on top of the concrete storage modules each day, performing radiological surveys, and visually inspecting accessible components to confirm expected conditions. Periodic visual inspection of the canister external surfaces are expected to be added after the NUHOMS dry storage system has been in service for 20 years. This timing will be in accordance with an NRC approved aging management plan to be developed for the SONGS dry storage systems.

Current monitoring includes the temperature of each module, visual inspection, and radiological surveys of the entire ISFSI

SONGS Dry Storage Aging Management

The service life limiting degradation mechanism for used fuel canisters in a marine environment is expected to be chloride induced stress corrosion cracking (CISCC). The other degradation mechanisms for austenitic stainless steel canisters, general corrosion and pitting enhanced by chlorides, are limited to rates (.02-.03 mm/yr.) (Reference 25) that will not penetrate a SONGS canister with a 5/8 inch (16 mm) wall thickness for hundreds of years. CISCC has been infrequently observed in stainless steel materials used in other nuclear plant components as described in Reference 26 over many years of operation. While CISCC experience in nuclear plant components is relevant, the physical protection afforded by dry storage system concrete shielding and the elevated operating temperature of canisters introduce important differences in the local environmental conditions which determine whether or not CISCC can occur. The aging management plan for the NUHOMS dry storage system at SONGS will consider all the known degradation mechanisms for the dry storage system components and incorporate inspections to detect and monitor these mechanisms (References 7 and 8). This plan is being developed by the system designer and NRC licensee, AREVA.

For the new UMAX dry storage system at SONGS, the coastal development permit issued by the California Coastal Commission prior to construction of the new system includes a special condition. Special condition 2.d (Reference 9) states, "Provide..."

> "Evidence that the fuel storage casks will remain in a physical condition sufficient to allow off-site transport, and a description of a maintenance and inspection program designed to ensure that the casks remain transportable for the full life of the amended project"

SCE committed to the California Coastal Commission to provide a maintenance and inspection plan for the UMAX system no later than October 6, 2022.

Visual examination of the external surfaces of sample canisters at intervals of between 1-10 years have been approved by the NRC in aging management plans for other sites. Visual inspections are used to screen for CISCC since active corrosion on stainless steel components is indicated by brownish surface deposits (Reference 10, Appendix E). These visual inspections will be performed in the same way that the EPRI informational inspections were performed on both AREVA and Holtec dry storage systems at Calvert Cliffs, Diablo Canyon, and Hope Creek. If surface corrosion deposits are detected, more detailed inspections including surface and volumetric non-destructive inspections will be performed. Surface and volumetric inspection procedures are currently being developed for used fuel canisters using both eddy current and ultrasonic techniques as described in References 10, 11, and 32.

Aging Management Program Basics:
1. Periodic visual inspection of canisters for early identification of indications of corrosion, using remotely controlled robots
2. If an indication is identified, employ eddy current and/or ultrasonic testing to evaluate the extent of the condition
3. Based on the extent of condition, determine next steps to repair the canister or otherwise mitigate the situation

These inspection methods will be evaluated for the SONGS aging management plans after they have been developed and qualified. If CISCC is detected during the planned inspections, defects will be monitored and evaluated for extent of condition. Plans to repair or replace canisters will be developed based on the inspection findings.

> **Primary Testing Methods:**
> 1. **Eddy current testing** uses electromagnetic induction to detect and characterize surface and sub-surface flaws in conductive materials such as spent fuel canisters.
> 2. **Ultrasonic testing** uses high frequency sound energy to conduct examinations for flaw detection/evaluation through the thickness of the material.

CISCC Indications

CISCC cracking in stainless steel is indicated by a preponderance of surface corrosion deposits in areas with high residual tensile stress, which for canisters are the vicinity of welds. General corrosion and pitting also produce surface corrosion deposits but these deposits are distributed evenly without regard to tensile stress. Surface corrosion deposits similar to those shown in Figure 3 below (Reference 12), that are concentrated in areas of high tensile stress (apex of U-bend specimen), indicate CISCC. If a preponderance of surface corrosion deposits in weld areas are observed on used fuel canisters additional testing would be required to determine if CISCC exists at these locations.

Figure 3. Surface Corrosion Deposits on CISCC U-Bend Specimens

Question 4 - What would happen if a SONGS used fuel canister sustained corrosion that led to a crack and that crack grew through the wall of a canister?

Answer: If a crack grew through the wall of a SONGS used fuel canister, there would be no significant release of radioactive material from the canister (Reference 13), no spread of radioactive contamination offsite, and therefore no radiological exposure to the public. However the inert gas (helium) would be released, air would enter the spent fuel canister, and the used fuel assembly (Figure 1) would begin to slowly corrode (Reference 14). The conclusion that no significant amount of radioactive material would be released from a crack in a canister is discussed in more detail below.

Technical Justification

The following sections describe the industry experience and analyses that support the conclusions that no significant amount of radioactive material would be released from a crack through the wall of a used fuel canister.

The SONGS used fuel canisters provide two important safety functions. The first important safety function provided by an intact canister wall is as a secondary containment barrier that prevents any radioactive material that manages to pass through the fuel rod cladding from subsequently passing out into the environment (Reference 14). The second safety function of the canister is to maintain an inert environment for the used fuel assemblies stored within the canister (Reference 14). After a canister is loaded with used fuel, water is removed and the canister is dried and filled with inert helium gas before the canister is welded closed. The inert environment provided by helium gas prevents corrosion of the used fuel assembly and protects the fuel rod cladding. Helium gas also has significantly higher thermal conductivity than air and by improving heat transfer, reduces the temperature of the stored used fuel.

The used fuel dry storage systems used at SONGS provide multiple barriers between the radioactive material in the spent fuel and the environment and are part of the overall “defense in depth” strategy (Reference 15). The barriers provided by the used fuel dry storage system include the fuel rod cladding, the used fuel canister and finally the surrounding concrete structures. The combined effect of three independent barriers provides a high degree of assurance that no significant amount of radioactive material can reach the environment. Each of the three barriers is described in detail below.

Barriers to Radiological Release

The following sections provide a more detailed description of the physical characteristics of used fuel and the barriers provided in the design of dry used fuel storage systems to prevent release of used fuel radioactive materials. The radioactive materials contained within used fuel assemblies are by-products of the nuclear reaction that splits Uranium atoms. Most of these elements are solid at room temperature but there are some (e.g. Xenon and Krypton) that are gases at room temperature. These inert radioactive gases do not represent a significant source of human radiation exposure, since these gases are quickly diluted if released and are not retained by the human body. The significant long lived fission products from a human exposure standpoint are the solid radioisotopes Cesium 137 and Strontium 90. If these radioisotopes are ingested, they will be absorbed and retained for some period of time in the human body which will significantly increase the time various body tissues are exposed to radiation from these materials.

Figure 1 depicts a typical spent fuel assembly which consists of about two hundred fuel rods depending upon the specific reactor design. Figure 1 also shows a single fuel rod. The radioactive fission products are created and trapped inside the ceramic fuel pellets which are encapsulated by the fuel rod cladding.

Fission products are trapped within ceramic pellets that are sealed in fuel rods as shown at right in Figure 1 above. Together, the pellets and fuel rods provide a significant barrier to release of radioactive material.

Primary Barrier
After reactor operation, most of the solid and gaseous radioactive materials created during the fission process remain trapped within the ceramic fuel pellets and are therefore not readily available to leak out of a defect in the fuel rod cladding. The fuel pellets are hermetically seal welded within fuel rod cladding (tubing) during fuel manufacture. The fuel rod cladding remains sealed on nearly all fuel rods (~99.99%) during reactor operation. As a result, the fuel rod cladding provides a very effective primary barrier against release of radioactive material into the environment. All fuel assemblies are inspected for breached cladding by “sipping” and analyzing the collected gas for fission products before they are loaded into the used fuel canister and removed from the pool.

Second Barrier

The welded stainless steel canisters used in the dry storage systems at SONGS provide a second barrier to release of radioactive materials. After the used fuel assemblies are loaded into a canister, water is removed and the canister is filled with helium gas and welded closed. The SONGS canisters provide a 5/8 inch (16 mm) thick, all welded, highly corrosion resistant stainless steel containment barrier around the used fuel assemblies. The helium gas placed inside the canister provides a chemically inert atmosphere which eliminates the potential for corrosion due to a moist air environment. The effectiveness of the canister as a second barrier is significantly enhanced by the absence of water inside the canister since there is no water available to transport soluble radioactive fission products out of a defect in a fuel rod. A SONGS used fuel canister is shown in the figure below.

Figure 4. Used Fuel Canister at SONGS

Third Barrier

Used fuel canisters at SONGS contain 24 or 37 fuel assemblies. Canisters are welded shut and provide a second layer of defense-in-depth to help prevent the release of radioactive material. To minimize the risk of chloride induced stress corrosion cracking, canisters at SONGS are fabricated from 316L stainless steel, which is highly corrosion resistant.

A third barrier to release of radioactive materials from used fuel in dry storage is provided by the concrete overpack structures that are part of both dry storage systems that will be used at SONGS.   The AREVA NUHOMS design provides a third barrier in the concrete modules – known as AREVA Horizontal Storage Modules (AHSM) – that enclose the used fuel canister as shown in Figure 5 below.

Figure 5.   AHSM Concrete Modules at SONGS

While the AREVA NUHOMS AHSM concrete modules are not hermetically sealed (ambient air circulates through to provide passive cooling) the air flow path provides a significant impediment to release of any solid particulate radioactive material that might pass through the wall of a used fuel canister. The models used to predict release of radioactive materials from operating nuclear power plants include the effects of solid particulate settling. When these models are applied to dry used fuel storage accident scenarios, a significant reduction (such as a factor of 700) in the amount of radioactive material released is attributed to a barrier of this type (Reference 1).

The Holtec UMAX design also provides a similar effective third barrier since the welded used fuel canisters are placed inside individual steel silos in a very large concrete block as shown in the Figure 6 below.

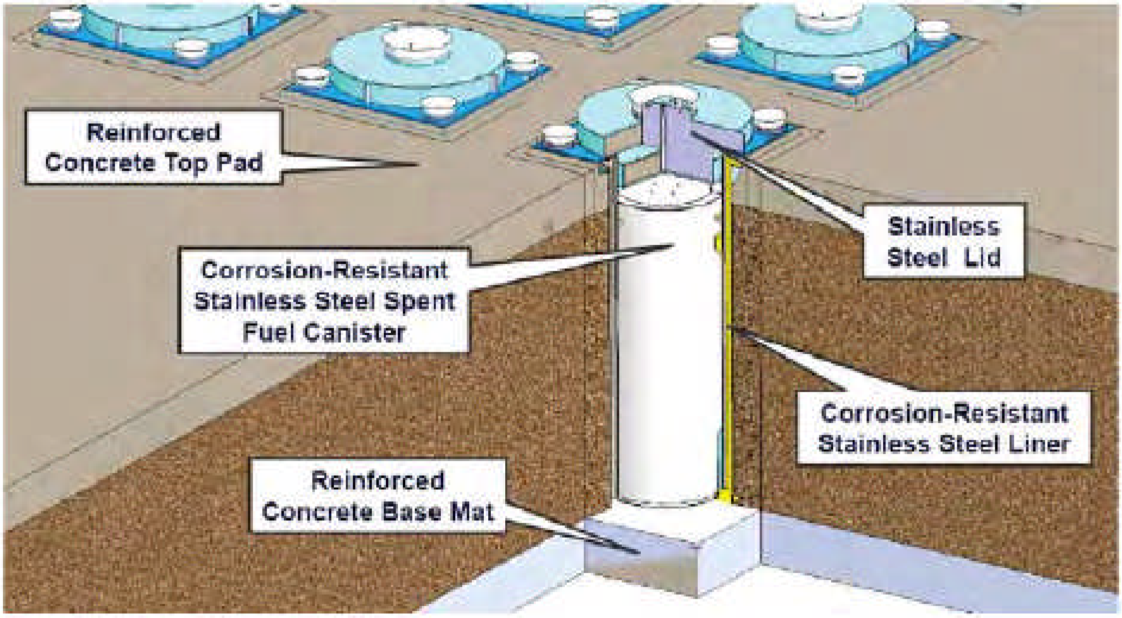

Figure 6. Schematic Showing UMAX Canister inside Concrete

The new, expanded ISFSI at SONGS utilizes a single monolith as compared to individual overpacks in the existing ISFSI. Like all dry cask storage systems, the new ISFSI provides radiological shielding and protects against manmade and natural hazards.

The Holtec UMAX concrete and steel storage silos are also not hermetically sealed (ambient air circulates through to provide cooling) but the air flow path provides a significant impediment to release of any solid particulate radioactive material that might pass through the wall of a used fuel canister.

Experience with Leaking Used Fuel Storage Casks

No leaks have been detected in US commercial power welded used fuel storage canisters to date, however a DOE demonstration storage cask, REA-2023, developed a leak in the mechanical seal between the cask and the bolted closure lid during service (Reference 13). Test data were collected on the REA-2023 and the concentration of oxygen inside the cask was measured as air leaked in. The measurements indicated that it took one to two years for sufficient air to leak into the cask to replace the inert helium gas with an oxidizing environment (Reference 13). Over many years an oxidizing environment inside a used fuel storage canister will degrade the fuel rod cladding and eventually degrade the ceramic fuel pellets (Reference 14) increasing the mobility of the radioactive materials.

Data collected during other tests on the REA-2023 that included used fuel assemblies with defected fuel rod cladding, indicated that only small amounts of radioactive inert gas (Krypton 85) was released from leaking fuel rod cladding (Reference 16). Small quantities of inert radioactive gases do not generally represent a significant source of radioactivity from a human exposure standpoint, since these gases are quickly diluted when released and are not retained by the human body.

Canister Radioactive Material Release

The primary reason that a crack through the wall of a used fuel canister will not release a significant amount of radioactive material is that the fuel rod cladding will remain intact and continue to provide a very effective first barrier to release of radioactive material. By the time used fuel is loaded into a dry storage canister, the used fuel assembly will remain sufficiently cool, even when dry in a canister, that the fuel rod clad cannot be damaged by decay heat. A second reason is that there is very little motive energy available in a used fuel canister to force solid radioactive material through a crack in the canister wall. The underlying source of motive energy in a used fuel canister for forcing any radioactive material through a canister crack is internal canister pressure which only lasts until the canister internal pressure equalizes with atmospheric pressure.

Used fuel is typically held for at least five years in a water pool to allow decay heat to diminish to levels that will protect the fuel cladding from damage even when dry. Shortly after reactor shutdown, used fuel, such as the fuel at Fukushima Daiichi, generates about 100 times as much heat as the used fuel currently stored at SONGS. The radioactive release from the accident at Fukushima Daiichi was made possible by extreme overheating (melting) of the fuel assemblies which not only destroyed the barrier provided by the fuel rod cladding but also melted and released the radioactive materials from inside the ceramic fuel pellets. Because of the lower levels of decay heat in used fuel assemblies in dry storage, fuel melt due to decay heat cannot occur and release large amounts of radioactivity.

As previously described, no significant amount of radioactive material was released from an internally pressurized used fuel storage cask (REA-2023) with a faulty seal in a bolted lid. Bolted lids are routinely removed from small used fuel storage containers in research and development facilities without a significant release of radioactive material. The bolted storage containers routinely used are not hermetically sealed (small through wall cracks effectively exist) but still provide effective containment of the radioactive materials inside.

Used Fuel Dry Storage System Off-Normal and Accident Analyses

The NRC requires that “off-normal” and accident conditions be considered in the safety analyses performed for used fuel dry storage facilities (Reference 17). “Off-normal” conditions are unexpected conditions that can occur infrequently and are less severe than “accident” conditions. The NRC requires analysis of specific “off-normal” conditions as part of dry storage system licensing. One of these specified off-normal conditions for dry storage system is rupture of 10% of the fuel rods followed by a leak in a used fuel canister. The accident scenarios evaluated include highly energetic initiating events such as fires, plane crashes, and severe mechanical impacts (canister drop accidents) which are assumed to rupture a large number of fuel rods and the canister as well as disperse radioactive materials into the atmosphere. The assumed off-normal and accident conditions are much more severe, considering the resulting damage to the used fuel assemblies and dry storage system components, than a through wall crack developing in a canister that is being stored in a stationary ISFSI. A summary of estimated personnel radiation exposure resulting from analyses approved by the NRC for off-normal and accident conditions for Holtec dry storage systems is provided below (Reference 1):

Table 2. Offsite Radiation Exposure Estimates

	Upper Bound Off-Site Radiation Exposure (mrem)	**Best Estimate Off-Site Radiation Exposure (mrem)**
Off-Normal Conditions	0.91	0.00013
Accident Conditions	44	.059

Even under the severe assumed off-normal and accident conditions, the estimated radiation exposure to a member of the public offsite is minimal and much less than the regulatory limits (25 mrem/yr for Off-Normal and 5,000 mrem/yr under accident conditions). Members of the public typically receive more than 200 mrem per year due to natural sources of radiation in the environment. As can be seen in Table 2 above, radiation exposure for only the most severe hypothesized accident approaches the annual dose received by a member of the public in one year from naturally occurring background radiation. As a result, a CISCC through wall crack in a used fuel canister with fuel rods that are essentially intact will not have significant radiological consequences for the public. Refer to the discussion above under "**Experience with Leaking Used Fuel Storage Casks"** for the consequences of a through wall crack in a used fuel canister containing failed fuel rods.

Question 5: How would a potentially compromised SONGS used fuel canister be repaired or replaced?

Answer: If an unacceptable condition was found on a SONGS used fuel canister during inspections, there are a number of possible responses depending on the specific conditions. In some circumstances, such as an isolated CISCC crack, a remote weld repair procedure might be the best solution. Under other conditions, the deficient canister could be removed using existing used fuel canister transport equipment and installed in a larger cask on site. In still other circumstances an unacceptable canister might be shipped to an offsite facility for repacking. A more detailed description of these options is provided below.

Remote Weld Repair- Operating nuclear reactor components have been routinely repaired using remote welding procedures. Some specific examples include the Westinghouse remote welding procedure for main coolant piping to support steam generator replacement and remote welding to repair and replace reactor internal components in Boiling Water Reactors (Reference 18). Equipment to perform weld repair on canisters could be

> Stainless steel components such as piping in commercial nuclear power plants are commonly repaired using welding techniques. Tooling to perform remote welding to repair dry cask storage systems can be developed if needed.

developed using the same basic techniques if needed. An example of remote welding equipment developed by Westinghouse for remote welding of used fuel canisters is shown in the figure below:

Figure 7. Westinghouse Remote Used Fuel Canister Welding Machine

On-site Repackaging- Spent fuel pools are not the only way to provide adequate shielding during used fuel handling and repackaging. A deficient used fuel canister could be installed in a "repair" cask with a larger diameter on site using existing dry used fuel handling equipment without use of a spent fuel pool. This "repair" cask could then be stored in a shielded location above ground or in an oversized storage location such as the one already planned at SONGS as part of the Holtec UMAX system. If it was desirable to repackage a large number of canisters at SONGS, an on-site dry used fuel transfer system could be developed as described in DOE report "Dry Transfer System- Topical Safety Analysis Report" (Reference 19) which describes generic methods for repackaging used fuel assemblies without spent fuel pools at commercial nuclear sites.

Transport to Another Location- The transport cask being licensed by Holtec to ship SONGS used fuel canisters will be technically capable of shipping a cracked used fuel canister. The Holtec transport cask (HI-STAR 190) is being designed to provide a hermetic seal (containment) that will survive hypothetical accident conditions, thereby eliminating the need for the used fuel canister inside the transport cask to be hermetically sealed for shipment. The Holtec HI-STAR 190 is shown in Figure 8 below.

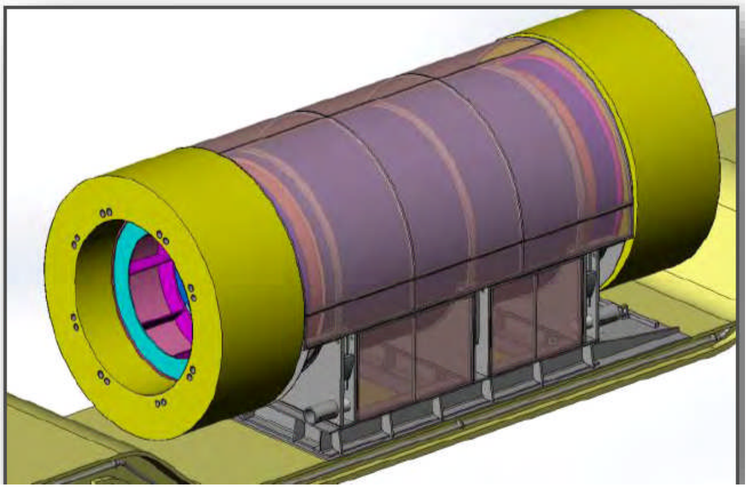

Figure 8. Holtec HI-STAR 190 Transport Cask

Transport casks have been used to ship severely damaged fuel, such as fuel from Three Mile Island, to shielded “hot cell” facilities at DOE National Laboratories (Reference 20). The DOE recently identified existing hot cell facilities on the Idaho National Laboratory (Reference 21) that could be used to open and sample used fuel canisters and then to repackage used fuel retrieved from the cask. A “hot cell” is a facility with thick (3 feet or more) walls that provide enough shielding to protect workers from the radiation emitted by used fuel assemblies. Shielded lead glass windows and remote handling devices allow workers to cut, weld and perform detailed examinations on used fuel in a dry environment inside the hot cell as shown in the Figure 9 below. Hot cell facilities have been used for nuclear research and development for over 60 years.

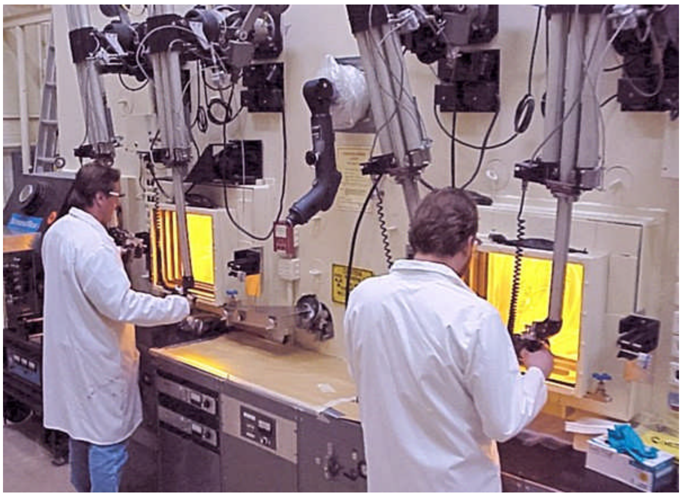

Figure 9. Hot Cell Facility at BWXT (Reference 22)

Since a means of shipping a deficient used fuel canister off-site can be licensed and suitable off-site facilities for repackaging used fuel assemblies exist, a deficient canister could be shipped to another location with a hot cell or a spent fuel pool for repackaging. As previously described, the radiological consequences of a through wall crack developing in a canister are minimal. Therefore there will be adequate time to develop an effective response to any specific deficiencies that might be identified on used fuel canisters at SONGS.

Question 6: What is the expected service life of the SONGS used fuel canisters?

> **Clarifying design life**
> There are a number of intervals that address the life span of spent fuel canisters, as follows:
> - Service life: 100 years
> - Design Life: 60 years
> - Warranty: NUHOMS 10 years, UMAX 30 years
> - NRC license renewal: every 20 years

Answer: The manufacturers (AREVA and Holtec) state the service life for both NUHOMS and UMAX used fuel canisters is 100 years (References 23 and 24). Based upon selection of Type 316L stainless steel for SONGS used fuel canisters and considering actual experience with CISCC at SONGS, MPR concludes that the SONGS NUHOMS and UMAX canisters are likely to maintain containment for more than 100 years. The newer SONGS Holtec UMAX canisters that will have a laser peened surface treatment will likely prove to be completely immune to CISCC. Several different terms are used to describe the expected life time of a dry used fuel storage canister. These different life times are based on different starting assumptions and levels of uncertainty.

a. Service Life is based on nominal expected environmental conditions and represents a best estimate of canister life time including any planned maintenance.
b. Design Life is based on the canister being exposed to the assumed worst case environmental conditions and represents the shortest expected canister life time.
c. Warranty Life is based on canister design life and commercial considerations for the manufacturer.
d. NRC license renewal period- Most dry used fuel storage system licenses are issued for 20 years. When licenses are renewed, the NRC typically reviews site specific inspection results to provide added assurance that the dry used fuel storage equipment is operating as expected.

Canister Aging Concerns

The degradation mechanism for used fuel canisters in a marine environment causing the greatest concern is chloride induced stress corrosion cracking (CISCC). Other degradation mechanisms for austenitic stainless steel canisters include general corrosion and pitting enhanced by chlorides. However these degradation mechanisms are limited to rates (Reference 25, Chapter 4) that will not penetrate a SONGS canister with a 5/8 inch (16 mm) wall thickness for hundreds of years. CISCC has been infrequently observed in stainless steel components used in nuclear power plants. The specific set of conditions applicable to used fuel canisters that may cause cracking are:

1. <u>A susceptible material, such as austenitic stainless steel.</u> Four different austenitic stainless alloys (Types 304, 304L, 316, 316L) are currently licensed for used fuel canisters in the United

States. CISCC susceptibility is different among these four stainless steels. The relative CISCC susceptibility in decreasing order is roughly 304>304L>316>316L (Reference 10). The SONGS canisters are fabricated from the least susceptible, most corrosion-resistant Type (316L).

2. Exposure to water with a sufficiently high dissolved chloride concentration. Since used fuel canisters are stored dry and are protected from rain, exposure to a liquid water chloride solution occurs only as a result of deliquescence. In a marine environment, sea salts are deposited on surfaces. Deliquescence is a process that involves salt deposits absorbing water vapor out of surrounding humid air and forming a thin layer of liquid chloride solution on a surface. Testing has shown that deliquescence in a marine environment occurs when surfaces are at temperatures below about 85°C (185°F) (Reference 25). The surface temperatures measured on the NUHOMS canisters at Calvert Cliffs after fuel has been in storage for about 15 years were reported to be 40°C (104°F) to 51°C (124°F) (Reference 3). The SONGS NUHOMS canisters have been in storage about 16 years and likely have similar canister surface temperatures. The surface temperatures on the SONGS used fuel canisters will decrease slowly as radioactive materials in the used fuel continue to decay.

3. Tensile stress in the material on the surface exposed to the aqueous chloride solution. The minimal stresses generated by internal pressurization of used fuel canisters (less than 50 psi) are too low to promote CISCC. However the welding and forming processes used to fabricate used fuel canisters typically leave residual tensile stresses in the finished canister that are high enough to permit CISCC. The Holtec UMAX used fuel canisters that are being fabricated for use at SONGS will have welds treated with a laser peening process after fabrication to eliminate residual tensile stresses on surfaces that are high enough to permit CISCC. This is expected to make the UMAX canisters immune to CISCC.

4. Sufficient time to initiate and propagate cracks. The CISCC process begins with initiation of a crack at a surface defect. Surface defects, for example a corrosion pit, locally enhance tensile stress. Once initiated, a crack will then grow in the tensile stress field at a rate that is influenced by factors such as the magnitude of the tensile stress, composition of the material, aqueous chloride exposure (time and chloride concentration), and temperature. CISCC has been infrequently observed in nuclear plant components exposed to a marine environment and the rate of CISCC cracking has been studied and testing has been done to measure CISCC crack growth rates. This information is summarized below.

Nuclear Plant CISCC Experience

While no indication of CISCC in used fuel canisters has been reported, NRC Information Notice 2012-20 dated November 14, 2012 (Reference 26), identified examples of CISCC reported in nuclear plant austenitic stainless steel components exposed to marine atmospheric environments that are relevant to stainless steel used fuel canister CISCC performance. However, since there are many more examples of austenitic stainless steel components operating without CISCC in nuclear power plants in a marine environment, literally miles of stainless steel piping, the instances of CISCC cited by the NRC represent a small, highly selected, subset of the entire operating experience. As a result, the CISCC examples cited by the NRC represent unlikely but possible CISCC crack initiation and growth rates resulting from the most aggressive local environments.

1. In 1999, through wall cracks were discovered in 24 inch diameter, 0.25 inch (6.35 mm) wall thickness, Type 304 stainless steel emergency core cooling system piping at St. Lucie Nuclear Power Plant in Florida. The emergency core cooling piping operated in the marine environment for about 16 years. The implied CISCC aggregate rate (CISCC initiation and crack growth) for this instance was 0.4mm/yr. (Reference 25, p 3-5).

2. In 2001, through-wall cracks were discovered in the stainless steel refueling water storage tank (RWST) and in safety injection system piping at the Koeberg Nuclear Power Station in South Africa. The through wall leaks were reported in Type 304L components with wall thicknesses of 5 mm (0.2 inches). These components operated in a marine environment for 16 and 17 years respectively (Reference 10, p A-51). The implied CISCC rates for these instances were 0.31 mm/yr. and 0.29 mm/yr. In 2012, after 27 years of exposure, a through wall crack was reported in a 10 mm (0.4 inch) thick section of the RWST (Reference 10, p A-51) for an implied CISCC rate of 0.37 mm/yr.

CISCC implied crack growth rates at Koeberg have been reported differently by EPRI (Reference 10) and the NRC (Reference 27) (0.91 mm/yr.). The most reliable description of Koeberg RWST through wall cracking, consistent with the rates quoted above, is provided in Reference 10, page A-51. A summary table from Reference 10 is reproduced below:

Clarifying Koeberg vs. SONGS
Comparisons between components at the Koeberg plant in South Africa and used fuel canisters at SONGS in Southern California have been made and are misleading. The Koeberg components operated in a different environment than the SONGS canisters and components at Koeberg were fabricated from a less CISCC resistant stainless steel alloy (Type 304L) than is being used for the SONGS canisters (316L). Also the aggregated CISCC crack growth rate data reported by the NRC in Reference 27 appears to be incorrect.

Table 3. CISCC Cracking in Koeberg Refueling Water Storage Tanks

Tank Section Thickness	Year of First Detection of Leakage in Given Thickness
5 mm	2001 (Both Units)
8 mm	2009 (Unit 2)
10 mm	2012 (Unit 1)
13 mm	No leaks in this thickness in either RWST by end of 2016
15.5 mm	No leaks in this thickness in either RWST by end of 2016

3. In the fall of 2009, three instances of through wall defects in stainless steel piping were reported at SONGS. The defected piping included 24 inch diameter, Type 304, 0.25 inch (6.35 mm) wall thickness emergency core cooling system piping and 6 inch diameter, Type 304, 0.134 inch (3.4 mm) wall thickness gravity feed piping. These components operated in the marine environment for about 25 years. The implied CISCC rates for these instances were 0.25 mm/yr. and 0.14 mm/yr. respectively (Reference 25, p 3-5).

4. In 2005, a through-wall crack developed in an 8 inch diameter, 0.148 inch (3.76 mm) wall thickness Type 304 stainless steel spent fuel pool cooling line at Turkey Point Nuclear Generating Station Unit 3 in Florida. The piping was installed in a room that was exposed to a marine environment. Unit 3 has been operating since 1972 (32 years of exposure). The implied CISCC rate for this instance was 0.12 mm/yr. (Reference 25, p 3-5).

A summary of CISCC rates observed in Type 304 and 304L nuclear plant components exposed to a marine atmospheric environment cited by the NRC is provided in the following table. The time required to penetrate the 5/8 inch (16 mm) wall thickness of SONGS spent fuel canisters at these observed CISCC aggregate crack initiation and growth rates is shown for comparison.

Table 4. Nuclear Power Plant Component CISCC Wall Penetration Times

Plant (System)	Type	Thickness (mm)	Time (years)	CISCC Rate (mm/year)	Implied Time to Penetrate SONGS Canister (years)
St. Lucie (Emergency Core Cooling)	304	6.4	16	0.4	40
Koeberg (Reactor Cavity Liner)	304L	5,10	16,27	0.31,0.37	52, 43
Koeberg (Safety injection Piping)	304L	5	17	0.29	55
SONGS (Emergency Core Cooling)	304	6.4	25	0.25	64
SONGS (Gravity Feed)	304	3.4	25	0.14	114
Turkey Point (Spent Fuel Cooling)	304	3.8	32	0.12	133

Conclusion

The rate of CISCC due to exposure to a marine atmospheric environment is highly dependent on site specific environmental conditions. SONGS has site specific experience with CISCC on Type 304 plant piping (Table 4) which informs estimated canister service life at SONGS. The CISCC observed at SONGS on Type 304 emergency core cooling and gravity feed piping (0.14 to 0.25 mm/yr.) exposed to the SONGS marine environment probably provides an upper limit for CISCC growth rate in SONGS used fuel canisters since the SONGS canisters are fabricated from the more CISCC resistant 316L stainless steel. SONGS used fuel canisters will be exposed to the same general atmospheric conditions, (air humidity, salt content, and temperature) as the

SONGS nuclear plant components. Using the SONGS canister 5/8 inch (16 mm) wall thickness and assuming a crack growth rate at the lower end of the observed Type 304 crack growth rates (0.14 mm/yr.) to adjust for SONGS use of Type 316L material leads to a lifetime projection for a SONGS 316L spent fuel canister exceeding 100 years. The newest SONGS canisters that will have laser peening surface treatment will likely never develop CISCC. More detail on results of CISCC experimental testing and the laser peening surface treatment process are provided in Appendix A.

2.0 References

1. "Best Estimate Dose from Dry Storage Cask Leakage", NRC SMSAB-00-03, dated June 2000.
2. "NRC Maps of Independent Spent Fuel Storage Installations (ISFSI)", NRC web site, https://www.nrc.gov/reading-rm/doc-collections/maps/isfsi.png, February 23, 2017.
3. "Calvert Cliffs Stainless Steel Dry Storage Canister Inspection", EPRI TR 1025209, April 2014.
4. "Diablo Canyon Stainless Steel Dry Storage Canister Inspection", EPRI Report 3002002826, August 2016.
5. "Update on In-Service Inspections of Stainless Steel Dry Storage Canisters", K. Waldrop, NRC/NEI public meeting, January 2014.
6. "Evaluation Method of Corrosion Lifetime of Conventional Stainless Steel Canisters under Oceanic Environment", A. Kosaki, May 2008.
7. "Format, Content, and Implementation Guidance for Dry Cask Storage Operations-Based Aging Management", NEI 14-03, Revision 1, Nuclear Energy Institute, September 2015.
8. "Managing Aging Processes in Storage (MAPS) Report", NRC Draft NUREG-XXXX, Docket ID NRC-2016-XXXX.
9. "Construct and Operate an Independent Spent Fuel Storage Installation (ISFSI) to Store Spent Nuclear Fuel from SONGS Units 2 and 3", Coastal Development Permit 9-15-0228, California Coastal Commission, October 2015.
10. "Aging Management Guidance to Address Potential Chloride-Induced Stress Corrosion Cracking of Welded Stainless Steel Canisters", EPRI TR 3002008193, March 2017.
11. "NDE to Manage Atmospheric SCC in Canisters for Dry Storage of Spent Fuel: An Assessment", DOE report PNNL-224595, September 2013.
12. "Coastal Salt Effects on the Stress Corrosion Cracking of Type 304 Stainless Steel", T.S. Mintz, D. Dunn et al., NACE Corrosion, March 2013, Orlando Fla.
13. "Failure Modes and Effects Analysis (FEMA) of Welded Stainless Steel Canisters for Dry Cask Storage Systems", TR-30020000815, EPRI, December 2013.
14. "Evaluation of Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel", United States Nuclear Waste Technical Review Board, December 2010.
15. "Safety of Long-term Storage in Casks: Issues for San Onofre", D. Victor, SONGS Community Engagement Panel, December 2014.
16. "REA-2023 BWR Cask Performance Test", M.A. McKinnon et al., Third International Spent Fuel Storage Technology Symposium, Seattle Washington, April 8, 1986. PNL-SA-13836.
17. "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility", NUREG-1536, Revision 1, July 2010.
18. "BWR Vessel Internals Project", EPRI TR 108708, March 2000.

19. “Dry Transfer System- Topical Safety Analysis Report”, USDOE report DOE-DTS-TSAR, September 1996.

20. “Program Plan for Shipment, Receipt, and Storage of the TMI-2 Core. Revision 1”, G.J. Quinn, H. W. Reno, R. C. Schmitt, US Government Report EGG-TMI-6536 rev1, 1985

21. “Viability of Existing INL Facilities for Dry Storage Cask Handling”, USDOE Report INL/EXT-13-29035, April 2013

22. “Photograph of BWXT Hot Cell Facility”, BWXT Technologies Inc, web page http://www.bwxt.com/advanced-technologies/laboratory-services/hot-cell-facility

23. AREVA Web Site; http://us.areva.com/EN/home-2341/areva-inc-areva-tn-nuhoms-used-fuel-storage.html

24. Federal Register, Vol 80, No 173; Section III. (12); p. 53694, September 8, 2015.

25. “Literature Review of Environmental Conditions and Chloride-Induced Degradation Relevant to Stainless Steel Canisters in Dry Cask Storage Systems”, EPRI TR 3002002528, May 2014.

26. “Potential Chloride-Induced Stress Corrosion Cracking of Austenitic Stainless Steel and Maintenance of Dry Cask Storage System Canisters”, NRC Information Notice 2012-20 dated November 14, 2012.

27. “Chloride-Induced Stress Corrosion Cracking Tests and Example Aging Management Program”, D.S. Dunn, NRC Public Meeting with NEI, August 5, 2014.

28. “Long Term Exposure Test for External Stress Corrosion Cracking on Austenitic Stainless Steels in Coastal Areas”, Y. Toshima and Y. Ikeno, NACE Corrosion 2000, March 2000.

29. “Evaluation of Austenitic Stainless Steel Dry Storage Cask Stress Corrosion Cracking Susceptibility”, M. Bayssie and D. Dunn, 14th International Conference on Environmental Degradation of Materials in Nuclear Power Systems, Virginia Beach VA., August 23-27, 2009.

30. “Assessment of Tensile Residual Stress Mitigation in Alloy 22 Due to Laser Peening”, A.T. DeWald et al., Lawrence Livermore Technical Report UCRL-JC-154103, January 2003.

31. “Environmentally Induced Transgranular Stress Corrosion Cracking of 304L Stainless Steel Components at Koeberg”, J. P. Basson,

32. “Dry Canister Storage System Inspection and Robotic Delivery System Development”, EPRI TR 3002008234, May 2016.

A
CISCC Experimental Results and Laser Peening Tests

CISCC Experimental Test Data

A number of experimental tests have been performed to develop the current understanding of CISCC in austenitic (corrosion resistant) stainless steels. It is important to realize that most experimental CISCC testing is done, for practical reasons, under conditions that intentionally accelerate CISCC. For example, test samples are often exposed to boiling MgCl solutions or the specimens tested have much higher levels of plastic strain (U-bend test specimens). As a result, this accelerated testing does not provide representative data on CISCC crack growth rates under actual service conditions. Instead this accelerated testing is done to investigate the relative performance of various materials under various conditions.

CISCC Growth Rate Tests (Kosaki)

A CISCC test for used fuel canisters was performed by the Japanese Central Research Institute of Electric Power Industry (CRIEPI) in 2008 (Reference 6). This test involved testing with 1/5 scale model canisters (13 mm wall thickness) in a normal marine environment as well as testing of small specimens under accelerated conditions. Testing under normal conditions was performed on a beach on Miyakojima Island. Accelerated tests were performed by exposing test materials (304, 304L, 316LN) to a 60°C (140°F) NaCl steam mist. A summary of the CISCC crack growth rates measured under normal marine conditions is provided in Table 1 below:

Table A-1. CISCC Average Crack Growth Rates Types 304 and 304LN

	Crack Growth Rate (mm/yr.)
Normal Marine Conditions	0.04 to 0.6

The normal marine condition test results reported above are generally consistent with CISCC rates observed on stainless steel Type 304 components in service in nuclear plants in marine environments.

15-Year Test of Austenitic Stainless Steels in Marine Environment (Toshima)

Type 304, 304L, 316 and 316L welded test specimens were exposed to marine environments in Chiba and Okinawa for 15 years starting in 1984 (Reference 28). The results of the test are summarized in Table 2 below:

Table A-2. 15-Year CISCC Test Summary

	304	304L	316	316L
Intergranular Cracking	X	No	No	No*
Trans granular Cracking	X	X	No	No*

*No CISCC was observed in Type 316 material used for SONGS used fuel canisters after 15 years of exposure

Accelerated U-Bend CISCC Initiation Test (Bayssie and Dunn)

An accelerated test of stainless steel U-bend specimens was sponsored by the NRC and included Types 304, 304L and 316L at three temperatures (40°C(104°F), 85°C (185°F), 120°C(248°F)) (Reference 29). CISCC initiation times were observed under the accelerated test conditions to provide an indication of the relative performance of the three stainless steel types at three temperatures. Crack growth rates were not measured in this test. CISCC was accelerated for this test by subjecting the test specimens to dry salt deposition followed by cyclic exposure to high humidity. U-bend test specimens were also used to accelerate testing. U-bend specimens have a higher level of plastic strain compared with material in a typical canister weld. No deliquescence or CISCC initiation was observed at the higher test temperatures (85°C and 120°C). A summary of the Bayssie and Dunn measured CISCC crack initiation times is provided in Table 3 below.

Table A-3. CISCC Observed Initiation Time

	304 (weeks)	304L (weeks)	316L (weeks)
Accelerated Test Conditions	4	16	32*

*The Type 316L material, used for the SONGS used fuel canisters, performed significantly better than the 304 material used for the SONGS piping that cracked (CISSC)

Holtec UMAX Canister Surface Stress Improvement (Laser Peening)

As previously described, CISCC requires tensile stress on the surface of a susceptible material for stress corrosion cracks to initiate and grow. Because of the low pressure inside the used fuel canisters, the only significant tensile stresses on the canister wall are residual stresses resulting from canister fabrication processes (welding and plate rolling). Even carefully controlled welding processes can create tensile stresses on the surface of welded materials due to shrinkage of the molten weld metal as it cools. In addition to stress corrosion cracking of susceptible materials, tensile stresses on the surface of materials can also promote fatigue cracking. For many years, the surfaces of materials susceptible to stress corrosion or fatigue cracking have been treated with peening or burnishing to eliminate tensile stresses on surfaces to inhibit cracking. Both peening and burnishing locally deform a metal surface in a way that creates a thin layer of compressive stress on the surface of a material. An example of a commonly used method of peening is shot peening which involves directing a stream of particles accelerated by compressed air against the surface of a material. Each particle impacts the surface with enough force to cause the material to locally deform. The effect of the many individual impacts creates a thin layer (0.040 inches thick) of compressive stress on the surface of the material. Other processes (laser and waterjet peening) have been used to peen surfaces in nuclear reactor plants. Cracks due to either stress corrosion or fatigue cannot form or grow through a layer of compressive stress. The effectiveness of peening largely depends on the depth and uniformity of the compressive stress layer.

Before work on the Yucca Mountain geologic spent fuel repository was suspended, the US DOE performed tests of surface peening and burnishing on used fuel canister welds to prevent stress corrosion cracking. A laser powered peening process was tested which created a deep (0.160 inch) layer of compressive stress on the surface of welded test coupons (Reference 30). SCE and Holtec conducted tests using the same laser peening process that was previously tested by DOE on prototypical UMAX canister materials and welds and confirmed that the laser peening process also creates a deep (0.160) layer of compressive stress on UMAX canister weld surfaces. Accelerated stress corrosion cracking tests were then performed on the peened UMAX weld coupons that confirmed that the laser peening process was effective in preventing CISCC. Figure 1 below shows a UMAX weld test coupon that was peened on half of the surface and then exposed to a boiling MgCl solution (standard CISCC accelerated test). CISCC cracking occurred in the area that was not peened and no cracks were found in the peened area.

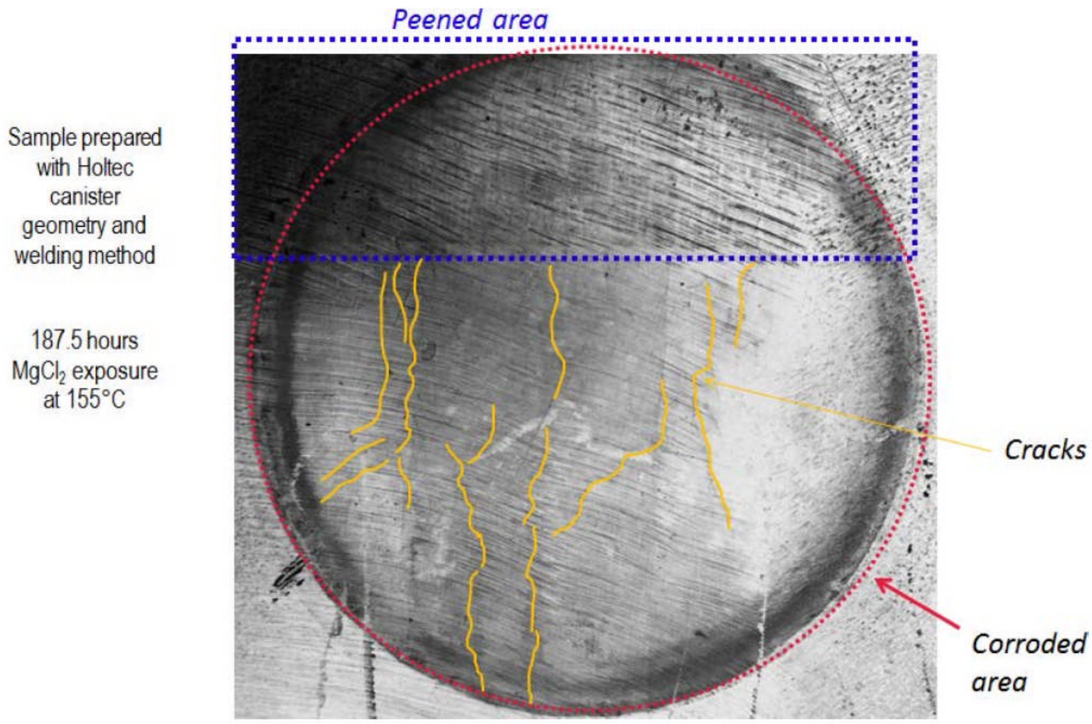

Figure A-1. Holtec UMAX Peening Test Coupon