Gamma Radiation Damage To Fukushima Units 1- 4 Spent Fuel Pools

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1-20-13

We at SimplyInfo.Org have written several papers on the spent fuel pools (SPL) at Fukushima Daiichi. The papers contain general information, cooling systems, water supply systems, photos of fallen debris into the pools and potential tearing of the stainless steel liner. At the present time we have contacted Sandia National Laboratory (SNL) to share our information and talk about the MELCOR analyses that were performed. At our request, SNL is in the process of performing another analysis with current decay heat load data and conditions in the SFP. In the interim period prior to release of the SNL analysis, we are conducting further research and our own assessment. A report on unit 4 SFP will be released as soon as the analysis data is available. This report will be crucial to give the current status of the SFP and is anticipated to support our theory. ***The theory involves the unit 4 SFP as being safe from effects of loss of cooling or draining of the SFP.***

Another area we have been studying is the extremely high gamma radiation field that is emanating from the storage racks in unit 4 SFP. TEPCO chose to discharge all of the fuel in the unit 4 reactor to prepare it for a ***shroud*** change out. In an unprecedented decision, TEPCO off loaded the fuel from the reactor to the SFP then put it all in a tight and close position in the SFP. When the fuel is off loaded following a reactor shutdown, it is always, as a general rule, loaded in the SFP in a checkerboard fashion to keep it from creating focused higher gamma heat loading.

This decision places the unit 4 SFP in the highest risk category for damage to the stainless steel liner or adjacent concrete structure and could result in cracking of the liner or spalling and overheating of the concrete that could result in formation of cracks where water could migrate out of the SFP.

One very critical fact is that the spent fuel pool liner, ¼ inch stainless steel, is the smallest barrier of protection the fuel assemblies have. The Primary Containment Vessel is nearly 4 times thicker and the reactor vessel 10 times thicker. Another fact is that the spent fuel pool liner is closer than any of the others and the gamma heating and radiation is acting on the ***thinnest*** metals and concrete.

This link from the Dept. of Energy contains another very critical fact about what has been done in the SFP's as a result of going to a high density loading configuration.

http://www.osti.gov/energycitations/servlets/purl/6272964-1AVlrK/native/6272964.pdf

- Most storage rack configurations used to provide a 1 to 1-1/2 foot allowance around the sides of the pool.
- The high density storage configuration is an exception in that the design allows racks to be placed ***within 1/2 inch of the walls of the pool***.

One critical calculation is absent from the assumption that it is ok to put fuel assembly racks ½ inch from the fuel pool walls. When the racks are placed that close, the extreme gamma heat and radiation levels will degrade the concrete behind the SFP liner as well as the liner itself. The degradation can result in spalling, chipping and crack formation as well as creating a hot spot on the fuel pool liner due to loss of pool heat sink.

The following information has been compiled from our research on gamma heating/radiation damage to stainless steel and concrete which was used in the unit 4 SFP

Radiation/Irradiation

http://www-pub.iaea.org/MTCD/publications/PDF/te_1025_prn.pdf

- Irradiation due to either fast and thermal neutrons emitted by the reactor core or gamma rays produced as a result of capture of neutrons by members (particularly steel) in contact with concrete, can affect the concrete
- Fast neutrons are mainly responsible for the considerable volume increase, caused by atomic displacements, that has been measured in certain aggregate (e.g., flint)
- Nuclear heating occurs as a result of energy introduced into the concrete as the neutrons or gamma radiation interact with the molecules within the concrete
- Gamma rays produce radiolysis of water in cement paste that can affect concrete's creep and shrinkage behavior to a limited extent and also result in the evolution of gas.
- Prolonged exposure of concrete to irradiation could result in decreases in strength and modulus of elasticity
- Approximate threshold levels necessary to create measurable damage in concrete have been reported in limited research studies. ***For nuclear plants that have operated longer that 30 years, these levels are 1 x 10 e20 neutrons/cm for neutron fluence and 2 x10e20 rads of dose for gamma radiation.***

[3.26] HILSDORF, H.K., et al., "The Effects of Nuclear Radiation on the mechanical Properties of Concrete", ACI SP-55, Douglas McHenry Int. Symp. on Concrete and Concrete Structures, American Concrete Institute, Detroit, MI (1978).
http://nisaplm.jp/html/img/04_reseach/PDF/Concrete%20Durability-8.pdf

- There are three typical interactions between gamma rays and materials
- Gamma rays collide with orbital electrons, one orbital electron is ejected and then the gamma ray disappears. This phenomenon is called **photoelectric** effects.
- When the gamma rays energy is much greater than the binding energy of electrons, gamma rays collide with electrons to eject the electrons and loose a part of the energies to change the travelling directions. This is called **Compton scattering**.
- When the energy of gamma rays is greater than 1.02MeV, they disappear around atomic nuclei and a pair of electron and positron is produced. This is called **pair production**.
- Water, a main component of concrete is thus expected to be decomposed by gamma rays to convert to hydrogen, oxygen and hydrogen peroxide [15]. Since water contents are much greater in cement paste than in aggregates, it is considered that gamma rays have more influence on cement paste than on aggregates

Mechanism of Concrete Deterioration

- Nuclear radiation causes expansion of aggregates and slight shrinkage of cement paste
- Concrete, the mixture of cement paste and aggregates, expands by the irradiation and its expansion is usually larger than the volume-averaged expansion of the aggregate and cement paste, which suggests the formation of cracks around the aggregate
- Under high temperature conditions, water in cement paste will be released in the form of vapor.
- Under radiation conditions, water will be released by gamma heating in the form of vapor and by radiation
- Decomposition in the form of ***hydrogen and oxygen gases***.

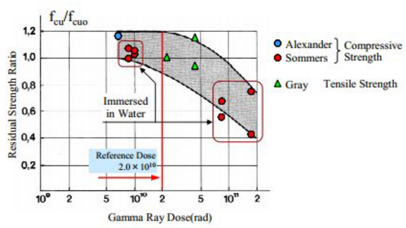


Figure 2 Compressive and Tensile strength of Concrete Exposed to Gamma Radiation fcu, related to Compressive Strength of Untreated Concrete, fcuo [1]
(Legend symbols were changed and some notes were added to the original.)

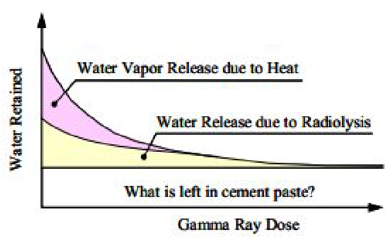


Figure 8. Gamma Ray Dose vs. Water Retained in Concrete.

Determining The Damage

From; Assessing Radiation Damage in Spent Fuel Pools http://soe.rutgers.edu/files/Nuke.pdf

- The three strongest types of radiation are gamma, neutron, and beta, all of which damage the austenitic stainless steel liner on a micro and macro level
- Heating of the SFP liner and subsequent heating of the concrete adjacent to the liner can elevate temperatures to a point of concrete thermal damage, spalling, chipping and degradation
- Each type of radiation comes from a different source and has different effects
- Information about the effects of radiation on stainless steel is widely available
- There is no comprehensive paper cataloging the cumulative effects of all of the types of radiation found in the environment of a spent fuel pool
- There is limited data on spent fuel pool concrete degradation
- Austenitic stainless steels in the 300 series are usually used for waste pool liners in the nuclear power industry
- When iron or steel is heated to a high enough temperature, its crystal-structure changes from ferrite to austenite and the metal takes on different properties
- After the heated carbon steels cool, they leave the austenitic state, but steels with high enough chromium and nickel concentrations remain fully austenitic upon cooling

Concern about damage to the spent fuel pools has lead to studies on finding faults and to repair them.

- Nondestructive examination (NDE) is an up and coming field that is developing way to view materials and degradation without further damaging the material.
- Each pool has its own unique energy levels, so we need a variety of data to determine the effects of different energy levels on the steel
- Not all spent fuel pools have the fuel stored at the same distance from the steel liner and do not experience the same dosage of radiation
- Spent fuel pool walls receive radiation over a very long period of time, and though this is important, the exact conditions are difficult to sustain in a lab.
- SFP cracking due to stress corrosion cracking and loss of material thickness due to pitting and crevice corrosion

Damage to the SFP liner as a result of gamma heating and radiation, or corrosion that degrades the function of the liner has resulted in development of liner repair techniques to restore the liner to a functional condition. The following link and information is an example of how this technology is being applied for the SFP liners.

Robotic Repair Technique Targets Fuel Pool Liners

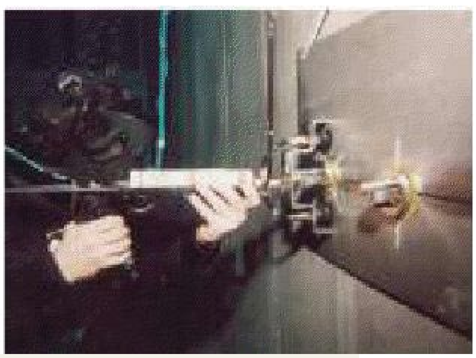
EPRI is collaborating with EDF to evaluate a polymer-based repair technique that could be deployed robotically to repair leaks in spent fuel pool liners.

http://mydocs.epri.com/docs/CorporateDocuments/Newsletters/NUC/2012-11/Liner_repair_Nov2012.pdf

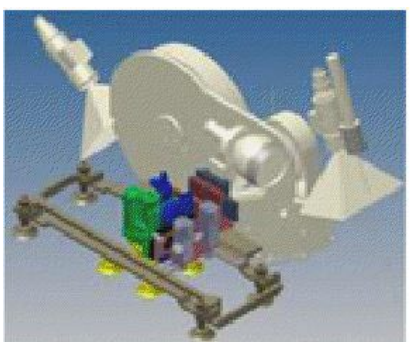
- The spent fuel pools used at nuclear power plants are an integral part of safe nuclear plant operation, serving both to shield against radiation and to cool the fuel rods
- These pools are lined with ¼-inch thick stainless steel sheets that are welded together and anchored to concrete walls
- The potential for leaks from these welded seams is raising concerns and has prompted the development of advanced inspection and repair techniques
- In one effort, EPRI and EDF are jointly developing the prototype of an innovative robotized technique that could be used in-situ for in-service repairs

Fuel pool leaks from the stainless steel liners in spent fuel pools may contain radioactive nuclides such as tritium and strontium-90. These substances could affect the structural integrity of the concrete and the steel reinforcing bars in fuel pools, and potentially contaminate the groundwater. EDF also has been investigating leak repair in "**two manual dives**"

- one to place the tool and inject the silicone into the mold (see photo at right)
- a second to disassemble the chassis.



Manually applied polymer based solution



General design of a robot able to apply repair strip

Repair strip applied manually on lap weld.

CONCLUSION

We have learned many things about our research on gamma heating or radiation damage that can be caused by the fuel racks being so close to the spent fuel pool (SFP 4) walls. This review has raised a host of questions which, at the time of this writing are unanswered as follows:

- Analysis to support moving the racks containing the fuel assemblies so close to the wall and adjacent to the concrete (1/2 inch) has not been able to be found. Not even in the documents to support a more dense SFP fuel loading.
- Operation in an unanalyzed condition at the NPPs (nuclear power plants) must be evaluated to support the continued operation, which must be done to Japan's NPPs
- SFP 4 has had the total fuel loading from the last period of operation centrally placed in the pool. To our knowledge this has not been done at any other reactors and introduces a critical element of trying to complete assessments on the severity of heating and intense gamma radiation induced on the wall in that location
- At this point our assumption is that concrete degradation is occurring in the SFP, concrete overheating, spalling, chipping and chemical changes are ongoing
- The annular space between the concrete and the liner is being impacted by potential hydrogen, Co2, hydrogen peroxide or other gas concentrations which produce new challenges
- In addition to the gamma fields there are also spontaneous neutrons which are generated and may escape the racks and interact with the steel liner or concrete structure
- We have established our choice of the boundary conditions within the concrete around which more detailed analysis can be done. The limit is 2 x10e20 rads of dose for gamma radiation. The estimated radiation level of a fuel assembly which has been discharged from the reactor core is on the order of 1 x 10e6Rem/Hr
- We must take into consideration all of the accumulated radiation exposure that has been received since the beginning of operation for unit 4

These questions and the current conditions will play into the future status within the SFP at unit 4. We hope that TEPCO will embark on immediate efforts to answer these among other questions to prove the safety to the Japanese people and globally.