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Preliminary Assessment of the Dose near the Shield Plug at Fukushima Daiichi Unit 2 (1F2)

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INTRODUCTION

Since the accident at Fukushima Daiichi on March 11th 2011, caused by the Great East Japan earthquake and subsequent tsunami, there have been significant coordinated international efforts to better understand the accident progression, phenomenology and consequences. (Ref. 1) Of particular note is the Organisation for Economic Cooperation and Development Nuclear Energy Agency's (OECD/NEA) Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Plant (BSAF Project). (Ref. 2) Phase 1 of this ongoing effort focused on modeling the modeling of the three beyond design basis accidents at the site for the first six days of the accident. Phase 2 of the effort is a forensic effort and focuses on extending the accident simulations out to 21 days and assessing the consequences of the accident. This effort aims to inform the government of Japan and The Tokyo Electric Power Company (TEPCO)'s ongoing effort to decommission and decontaminate the site.

One of the key questions posed by TEPCO in its efforts to decommission the site is the location of released radionuclides (RNs) that result in anomalously high dose rate measurements on and near the shield plugs of all three units. In this summary, we provide insight into the possible location of the source resulting in this high dose. Previous MELCOR accident progression analyses have predicted leakage of the containment through the drywell head, directly below the shield plug. Using this plausible accident scenario, MELCOR is able to predict the radionuclide source to the region below the shield plug and possible deposition amounts within the gaps of the shield plug. Using this predicted source and the transport and shielding code MCNP6 the dose in and around the shield plug of 1F2 was assessed. Unit 2 was chosen since the refueling bay is still intact and therefore a simpler initial problem compared to Units 1 and 3.

Dose Measurements Performed by the Tokyo Electric Power Company

Since the accidents at the Fukushima site, TEPCO has periodically taken dose measurements throughout around the reactor site, within the contaminated reactor buildings and within the primary containment vessel (PCV). Through time as a result of natural decay and scrubbing of deposition surfaces for decontamination efforts there has been a reduction of the dose at the site. This work compares the dose above the 1F2 shield plug before significant decontamination efforts of the floor were begun. The dose rate on June 13, 2012 of the refueling bay near the shielding plug of 1F2 can be seen in Fig. 1. (Ref. 3) From the figure it can be seen that the dose rate at the shield plug is 3-8x higher than the remainder of the refueling bay.

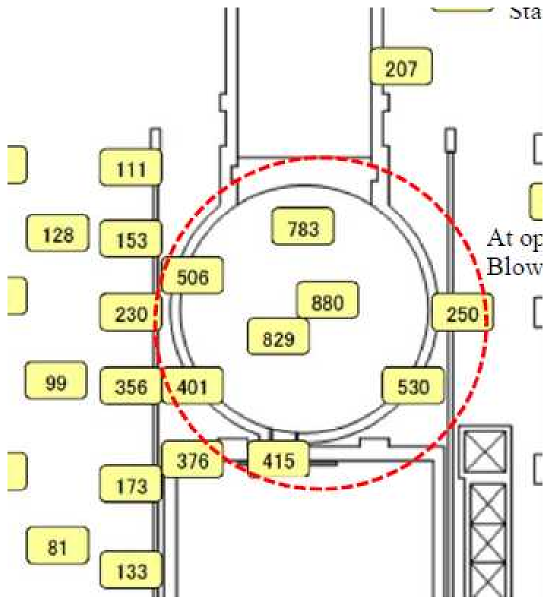

Fig. 1. Dose readings at on and near the shield plug located on the refueling bay of Fukushima Daiichi Unit 2 (1F2) collected on June 13, 2012 by TEPCO, roughly 1 m above the shield plug. (Ref. 3)

MODEL AND METHODS

The full analysis of the dose near the shielding plug requires the coupling of ORIGEN-S/ARP found within the SCALE6.1.3 neutronic depletion code package, with the severe accident analysis tool MELCOR 2.1 and the shielding/transport code MCNP6.1.

The overall method for the dose calculation can be seen in Fig. 2, which shows how the three codes are coupled together and interpreted.

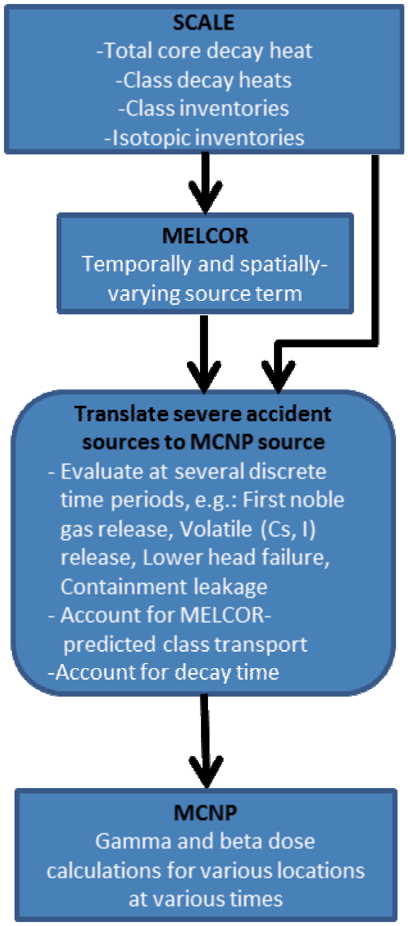

Fig. 2. Code use methodology for source term generation and transport/shielding analysis, showing the coupling of SCALE, MELCOR and MCNP. (Ref. 4)

State-of-the-art nuclear data and problem-dependent cross sections are first generated using TRITON with the latest ENDF/B-VII.1 library. TRITON provides the necessary ARP libraries for subsequent (and faster) ORIGEN-S standalone calculations. (Ref. 5) Using plant operating data from relevant cycles for each fuel assembly, ORIGEN-S/ARP calculations were performed considering the burnup history, power fraction, and enrichment of each assembly. The resultant outputs were then used to build radial distributions of radionuclide inventory and decay power over MELCOR core rings. In the MELCOR 2.1 model that was used in this study five total rings were used.

Using the severe accident and source term analysis code MELCOR 2.1, release rates for the accident events were found for Fukushima Daiichi Unit 1 (1F1). (Ref. 6) These release rates were then used to determine the release fraction through the drywell head from the event. This release fraction was then applied to the inventory of Fukushima Daiichi Unit 2 (1F2) to determine the amount and activity of radionuclides released through the shield plug of 1F2. Future work will repeat this calculation using a MELCOR accident analysis of 1F1; 1F2 was used because it was at the time our most well qualified Fukushima model. Details of the MELCOR 1F1 calculation are shown in the OECD/NEA Benchmark of the Fukushima Accident (BSAF) Report. Table I contains the fractional release of nuclides from the drywell head for the developed source term.

TABLE I. Fractional release of radionuclides from the drywell head into the region directly below the shield plug

Class	Fractional Release
Noble Gases (Xe)	1.84E-04
Alkali Metals (Cs)	1.85E-03
Alkaline Earths (Ba)	2.85E-05
Halogens (I)	1.31E-02
Chalcogens (Te)	4.18E-03
Platinoids (Ru)	3.69E-07
Early Transition Elements (Mo)	3.59E-04
Tetravalent (Ce)	1.10E-07
Trivalents (La)	1.18E-08
Uranium (U)	3.42E-07
More Volatile Main Group (Cd)	3.49E-04
Less Volatile Main Group (Sn)	4.79E-04
Boron (B)	0

When the source term (e.g. released radionuclides) is determined from the accident progression, the resultant nuclides are decayed away using ORIGEN-S and a photon source is calculated. The photon source developed for 1F2 for this analysis can be seen in Fig. 3. The total magnitude of the source at 800 days from the accident initiation is 1.02E+15 photons/s.

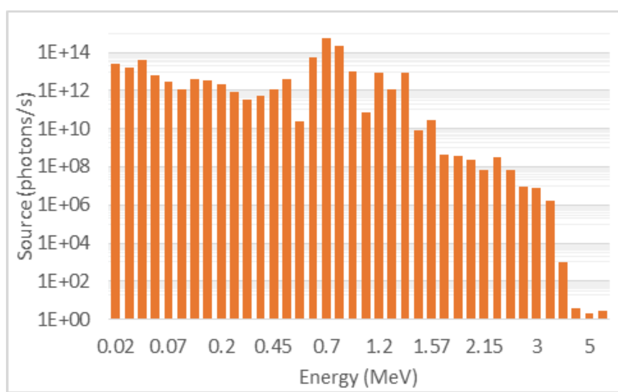

Fig. 3. Photon source for MCNP dose calculation

Using the source term an MCNP model was developed of the shielding plug and the surrounding region, which is approximately 2.0 meters in thickness and 12.0 meters across (the exact Fukushima values are proprietary). (Ref. 7) Included in the model is the uppermost part of the reactor pressure drywell and containment drywell. A qualitative 2D representation of the region modeled can be seen in Fig. 4; also shown are the proposed failure location of the drywell head and subsequent leakage pathways through the gaps of the shield plug. The location of the photon source was assumed to be in two separate locations. First, it was uniformly distributed in the volume above the drywell head, and below the shield plug. Secondly, it was distributed solely within the gaps between the shield plug and the concrete on the outside. This was done to infer the location of the source based on the similarity of the results to measured values. In the MCNP calculations 1 Billion particles were run for each examined case, and a mesh tally that encompassed the whole problem space was employed. In order to calculate the equivalent photon dose in the problem, a flux to dose multiplier was used.

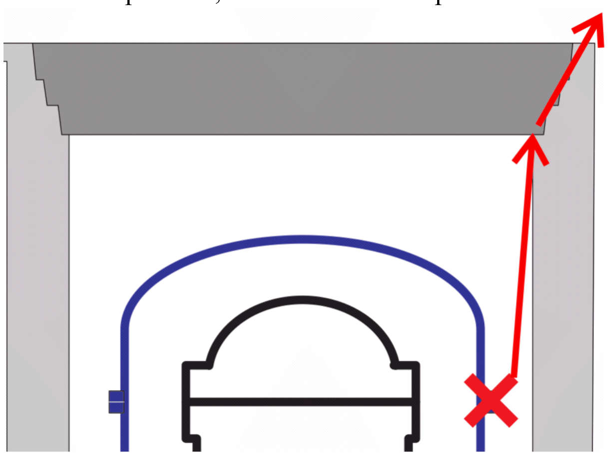

Fig. 4. Representation of the geometry of the shield plug modeled in this analysis showing the drywell head failure location and subsequent leakage pathways.

RESULTS

This section contains the results of two separate dose assessments around the shield plug. The first contains the photon source distributed uniformly between the drywell head and the shield plug, while the second assumes the source is within the gaps between the shield plug and adjacent concrete. While neither of these two simulations contain the real source distribution, they are indicative of the problem's boundary conditions and can inform both future analysis efforts and decommissioning.

Uniform Source above the Drywell Head

The results of a mesh tally of photon dose when the source is located in the volume directly below the shield plug. can be seen in Fig. 5. It can be seen that the dose is high in this open volume, which is primarily filled with air. Looking at the concrete on the edge of this region you can clearly see that almost none of the neutrons are penetrating beyond the outer edge of the concrete. This indicates that the shield plug and the concrete surrounding the containment should be sufficient to shield from high energy photons originating within the concrete surrounding the containment. This indicates that the high dose above the shield plug most likely does not come from below the shield plug. It should be noted that this analysis did not apply any variance reduction techniques to the transport of the source photons. Future work will necessarily include such techniques to verify this result.

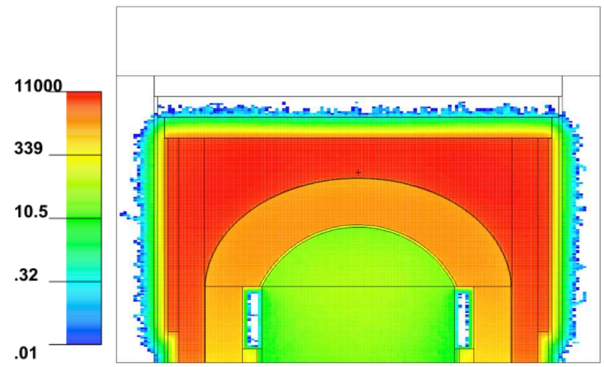

Fig. 5. Radial cross section of predicted dose, when the source is uniformly distributed above the drywell head, dose is shown in mSv/hr

Shield Plug Gap Source

When assuming the photon source is situated within the gaps between the shielding plug and the dose above the shield plug is significantly higher. This can be seen in Fig. 6. Since the source was not scaled as it was moved from the larger volume under the shield plug to the small gaps beside the shield plug, the local dose logically increases. On the areas right above the shield plug gaps and the areas to the left and right of those, the dose is clearly near the ~500 mSv/hr that are seen in the TEPCO measurements.

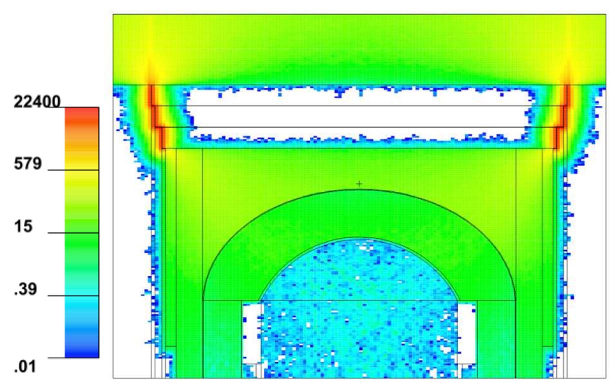

Fig. 6. Radial cross section of predicted dose, when the source is uniformly distributed in the gaps within the shield plug, dose is shown in mSv/hr

Using an axial cross section of the mesh tally 1.0 meter above the shield plug (Shown in Fig. 7), the dose can clearly be seen to be in same range as the TEPCO data. This indicates that the dose found above the shield plug is most likely resultant from radionuclides found within the gaps of the shield plug. In the analysis, the center of the region above the shield plug has a relatively lower dose than the areas directly above the shield plug gaps, this is because the shield plug gaps that are not located in the center of the plug were not accounted for in this model. I tis predicted, a more uniform distribution near ~500 mSv/hr would be found if these gaps in the middle of the shield plug were accounted for.

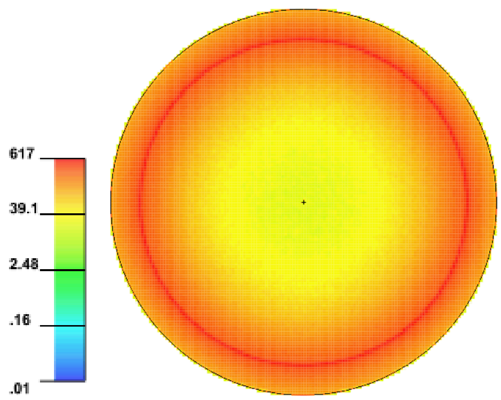

Fig. 7. Axial cross section of predicted dose 1.0 m above the top of the shield plug, when the source is uniformly distributed in the gaps within the shield plug, dose is shown in mSv/hr

An assessment of the relative error for this second source can be seen in Fig. 8. It can be seen that for most of the areas of high importance the relative error is <0.1. While this is not the ideal, it is sufficient for this preliminary analysis. In the future variance reduction techniques will be applied to the analysis and higher numbers of source particles will be run.

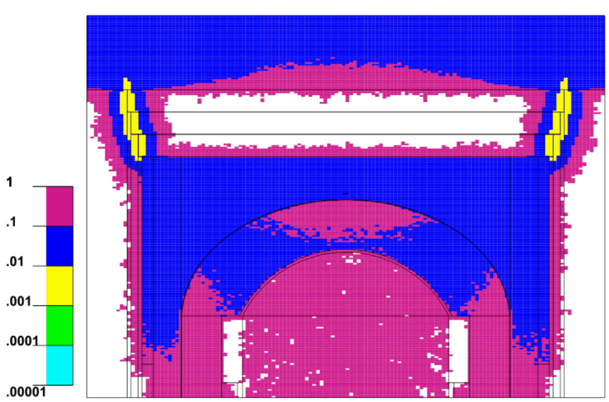

Fig. 8. Radial cross section of relative error of predicted dose, when the source is uniformly distributed in the gaps within the shield plug, dose is shown in mSv/hr

CONCLUSIONS AND FUTURE ANALYSES

It can clearly be seen that the dose found above the shield plug of 1F2 has a clear contribution from radionuclides found within the gaps of the shield plug. This is a key insight for decommissioning purposes, suggesting that it will be nearly impossible to eliminate this dose from scrubbing the area. It was also shown that because of the thickness of the shield plug, there is very little dose contribution from a large source below the shield plug to the area above it. This shows that the dose measurements taken by TEPCO are most likely not indicative of what the dose is below the shield plug. To determine this, a forensic effort would need to be undertaken by TEPCO.

ACKNOWLEDGMENTS

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