From: Jason Schaperow , RES
To: Diane Jackson , NRR
Date: Mon, Dec 6, 1999 9:07 AM
Subject: Draft Memo on Spent Fuel Pool Accident Uncertainty

Attached is my draft memo on spent fuel pool accident uncertainty. As I just mentioned on the phone, it has not been concurred on by any of my management. However, I would appreciate your feedback at this stage.

Thanks.
Jason

Save this document.

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MEMORANDUM TO: Samuel J. Collins, Director
Office of Nuclear Reactor Regulation

FROM: Ashok C. Thadani, Director
Office of Nuclear Regulatory Research

SUBJECT: OPPORTUNITIES TO REDUCE UNCERTAINTY IN CONSEQUENCE ASSESSMENT FOR SPENT FUEL POOL ACCIDENTS

As part of its generic study of spent fuel pool accidents, undertaken to develop generic, risk-informed regulatory requirements for plants that are being decommissioned, the Office of Nuclear Reactor Regulation (NRR) had requested the Office of Nuclear Regulatory Research (RES) to perform an evaluation of the offsite radiological consequences of a severe spent fuel pool accident. Accordingly, RES completed an in-house analysis of offsite radiological consequences, and on November 12, 1999, RES forwarded to NRR a report containing the detailed technical basis of this analysis. The primary objective of the analysis was to determine the effect of extended storage in a spent fuel pool, and the resulting radioactive decay, on offsite consequences. The analysis showed about a factor-of-two reduction in prompt fatalities if the accident occurs after 1 year instead of after 30 days. The analysis also showed that beginning evacuation three hours before the release begins reduces prompt fatalities by more than a factor of ten. Further reductions in consequences (e.g., latent cancers) were limited by the large contribution from long half-life isotopes.

Subsequent to the November 12, 1999, analysis, RES took the initiative to identify further opportunities to reduce uncertainty to develop a more realistic evaluation of offsite radiological consequences of spent fuel pool accidents. Our review of the accident scenarios and the progression of each scenario reveals these opportunities. Our review, which is documented in the attached report, indicates opportunities in four areas: (a) the length of time between the beginning of the evacuation and the beginning of the fission product release, (b) the fission product release rate and magnitude, (c) the fission product deposition on site, and (d) the long-term relocation criterion. Our conclusion is that a more detailed evaluation of the thermal hydraulics and accident progression is expected to show that spent fuel pool accidents have no early fatalities and smaller long-term consequences than earlier assessments. The attached report includes specific recommendations for performing a more detailed evaluation of the thermal hydraulics and accident progression. This report is for your use in developing the final draft of the generic study of spent fuel pool accidents. Also, we would like to elicit your judgment regarding which of these recommendations we should pursue.

In a November 5, 1999, meeting with the staff, the Advisory Committee on Reactor Safeguards (ACRS) raised issues related to the assessment of offsite consequences for spent fuel pool accidents. For example, the ACRS suggested that, for a fuel assembly that heats up to the point of releasing fission products, the ruthenium release fraction might be larger than that assumed in previous spent fuel pool consequence assessments, because some air which enhances ruthenium release might be present in the fuel assemblies during the release. In a recent discussion with NRR staff, we agreed to review the issues raised by the ACRS and provide recommendations by January 14, 2000 for their disposition.

Attachment: As stated

cc: C. Paperiello
G. Holahan
J. Hannon
R. Barrett

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Opportunities to Reduce Uncertainty in Consequence Assessment for Spent Fuel Pool Accidents

Introduction

As part of its generic study of spent fuel pool accidents, undertaken to develop generic, risk-informed regulatory requirements for plants that are being decommissioned, the Office of Nuclear Reactor Regulation (NRR) had requested the Office of Nuclear Regulatory Research (RES) to perform an evaluation of the offsite radiological consequences of a severe spent fuel pool accident. Accordingly, RES completed an in-house analysis of offsite radiological consequences, and on November 12, 1999, RES forwarded to NRR a report containing the detailed technical basis of this analysis. The primary objective of the analysis was to determine the effect of extended storage in a spent fuel pool, and the resulting radioactive decay, on offsite consequences. The analysis showed about a factor-of-two reduction in prompt fatalities if the accident occurs after 1 year instead of after 30 days. The analysis also showed that beginning evacuation three hours before the release begins reduces prompt fatalities by more than a factor of ten. Further reductions in consequences (e.g., latent cancers) were limited by the large contribution from long half-life isotopes.

Subsequent to the November 12, 1999, analysis, RES took the initiative to identify further opportunities to reduce uncertainty to develop a more realistic evaluation of offsite radiological consequences of spent fuel pool accidents. Our review of the accident scenarios and the progression of each scenario reveals these opportunities. Our review, which is documented below, indicates opportunities in four areas: (a) the length of time between the beginning of the evacuation and the beginning of the fission product release, (b) the fission product release rate and magnitude, (c) the fission product deposition on site, and (d) the long-term relocation criterion.

Length of Time between the Beginning of the Evacuation and the Beginning of the Fission Product Release

For the purpose of evaluating offsite radiological consequences, spent fuel pool accidents can be broken down into three types, namely, loss of cooling flow, small break, and large break. In the loss of cooling flow accident, heat from radioactive decay raises the temperature of the spent fuel pool water until boiling occurs. After the water level drops to below the top of the fuel, exposed fuel can heat up beyond the boiling point of water. Then, fuel assemblies with the highest decay power density could heat up to the point of releasing their fission products by self-heating. Fuel assemblies with lower decay power density could subsequently heat up to the point of releasing fission products through a combination of self-heating and heat transfer from the higher decay power assemblies.

For a loss of cooling flow accident, heat up and boil down of the water to the top of the spent fuel assemblies can take a long time, because of the low average decay power of assemblies in the spent fuel pool (some of the assemblies may have been in the spent fuel pool for as long as 40 years) and the depth of the spent fuel pool. *Preliminary Draft Technical Study of Spent Fuel Pool Accidents for Decommissioned Plants* (Memorandum from G. Holahan to J. Zwolinski of

June 16, 1999) stated that it would take more than five days to heat up and boil down to the top of the spent fuel assemblies. Five days should provide sufficient time for a complete evacuation.

In the small break accident, a break occurs that is large enough to lower the water level in the spent fuel pool more quickly than a loss of cooling accident but more slowly than a large break accident. Other than the step involving heat up of spent fuel pool water to the boiling point, the progression of a small break accident would be the same as a loss of cooling flow accident. In the small break accident, the rate at which the water level decreases depends on the hole size. For example, for a 2-inch-diameter hole in the bottom of a pool that is 30 feet wide, 35 feet long, and 40 feet deep, the water level would decrease to the top of the fuel in about 16 hours. This length of time, together with the additional time it takes for the level to decrease to uncover a significant amount of fuel and the time it takes for even the highest decay power fuel in the pool to reach temperatures high enough to release fission products, should provide sufficient time for a complete evacuation.

In the large break accident, a break occurs that is large enough to drain the spent fuel pool quickly in comparison with the time required to heat up the highest decay power fuel in the spent fuel pool to reach temperatures high enough to release fission products. (Because it can take a number of hours for the highest decay power fuel to heat itself up, a large break would be that size that would drain the water in an hour or less. An 8-inch-diameter hole would reduce the water level to the top of the fuel in an hour.) Other than the steps involving reducing the water level, the progression of a large break accident would be the same as the small break accident. Although the progression of a large break accident would happen more quickly than the other two accidents, the *Preliminary Draft Technical Study of Spent Fuel Pool Accidents for Decommissioned Plants* indicates that it would take a number of hours for even the highest decay power fuel in the spent fuel pool to reach temperatures high enough to release fission products. The MACCS calculations documented in the November 12, 1999, memorandum show that beginning evacuation three hours before the release begins would essentially preclude early fatalities. Therefore, no early fatalities are expected from this type of accident.

For the loss of cooling flow and the small break accidents, no early fatalities are expected because of the long time available for evacuation. For the large break accident, although the time available for evacuation appears to be sufficient, it is less than for the other types of accidents.

Although long-term consequences (e.g., latent cancers) would not be affected by evacuating early, they could be eliminated if the long time available were used to put water onto the fuel. Putting water onto the fuel would cool the fuel before it reached the high temperatures that cause fission product release.

Recommendation: Perform a realistic assessment of the heat up time for the highest decay power fuel in the pool to confirm that, in the case of a large break accident, sufficient time is available to evacuate the close-in population and possibly to eliminate offsite releases.

<u>Fission Product Release Rate and Magnitude</u>

Previous consequence analyses have assumed that the fission product release rate is high and that all of the assemblies in the pool release their fission products. However, the overall release rate is limited by the global heat up of the highest decay power assemblies and the spreading of the heatup to the lower decay power assemblies. For example, for the loss of cooling flow and the small break accidents, the global heat up of the highest decay power assemblies is limited by the gradual rate of decline of water level; only fuel above the water level could be hot enough to release its fission products. Also, the overall release magnitude is limited, because of the small potential for the heat up to spread to lower decay power assemblies as discussed below.

The decay power densities for the assemblies in a full BWR spent fuel pool in Table 1 were provided by NRR staff for the RES thermal hydraulic analysis of critical decay time using the FLUENT computation fluid dynamics code. The 800 fuel assemblies shown in first row of Table 1 are the final core offload and have a decay power density of 11.0 kw/Mt. The 267 assembles discharged during the final refueling outage have a decay power density of 4.8 kw/Mt. The *Preliminary Draft Technical Study of Spent Fuel Pool Accidents for Decommissioned Plants* stated that, following a complete loss of coolant, the fuel assemblies with decay power density above 6 kw/Mt have the potential to heat themselves up to the point of releasing their fission products. Therefore, only the assemblies in the final core offload have the potential to heat themselves up. For the BWR spent fuel pool with 4200 assemblies in Table 1, this corresponds to less than one-fifth of the assemblies in the pool.

Fuel assemblies	Number of assemblies	Decay power density at 1 year after final shutdown (Kw/Mt)	potential for assembly to heat up by self-heating	potential for heatup to spread to these assemblies
final core	800	11.0	Yes	Yes
one-third of core discharged in last refueling	267	4.8	No	Yes
one-third of core discharged in next-to-last refueling	267	2.9	No	No
earlier discharges to the pool	2866	less than or equal to 2.1	No	No

Table 1. Decay power densities and potential for propagation (1 year after final shutdown).

The fission product release will begin when the assembles in the final core offload reach temperatures above 1500 K. Because all of the assemblies in the final core offload will not reach 1500 K at the same time due to variations in burnup and location in the pool, the fission product release from these assemblies will be staggered resulting in lower overall release rates. (Table 1 assumes that the burnup of all assemblies in the final core offload is 40 Gwd/t. Because one-third of the final core will have a burnup of 60 Gwd/t, one-third 40 Gwd/t, and one-third 20 Gwd/t, the decay heat in these 800 fuel assemblies also will vary.) First, the highest burnup assemblies in the final core offload will reach 1500 K. If the radioactivity has not decayed sufficiently, then the lower burnup assemblies in the final core offload also may reach 1500 K by self-heating.

NUREG/CR-4982 indicated that, for the heat up to spread to lower decay power density fuel, the lower decay power density fuel must have decay power density in excess of 4.0 kw/Mt.

Table 1 shows that only assemblies in the final core offload and in the final refueling discharge have decay power densities in excess of 4.0 kw/Mt. This would suggest that the heatup would spread to the 267 assemblies in the final refueling discharge. Therefore, 1.3 cores would release their fission products, and this release may be spread out over hours or days. In contrast, the November 12, 1999, assessment assumed that 3.5 cores released their fission products over 30 minutes. A lower release rate would provide additional time to complete evacuation to further reduce short-term consequences. Although long-term consequences (e.g., latent cancers) would are not affected by evacuation, a lower release rate would provide additional time to take action to reduce the offsite release which would reduce both short-term and long-term consequences. Action that could be taken during a prolonged release includes putting water or another material onto the fuel. Putting water onto the fuel would reduce the release by cooling the fuel below temperatures that cause fission product release. Putting another material onto the fuel would slow down the overall pool heat up, and resulting fission product releases, by reducing exothermic oxidation of the hottest assemblies. Also, this material would act as a filter for fission products released from the fuel assemblies.

Finally, previous consequence analyses have assumed that all of the assemblies in the pool release their fission products. For example, the November 12, 1999, assessment assumed that 3.5 cores released their fission products. Reducing the amount of assemblies releasing fission products from 3.5 cores to 1.3 cores would result in a proportional reduction in the offsite release and thus reduce both the short-term and the long-term offsite consequences. The offsite consequence results in NUREG/CR-6451 indicate that a reduction in the number assemblies releasing their fission products can be significant.

Recommendation: For each type of accident (i.e., loss of cooling flow, small break, and large break), evaluate the global release rate from the highest decay power density assemblies and the time for the heatup to spread to the lower decay power density assemblies to quantify the additional time available for completing evacuation and taking action to reduce the offsite release. For each type of accident, also perform a realistic thermal hydraulic evaluation to confirm the decay power densities of 6.0 kw/Mt and 4.0 kw/Mt for self-heating and spreading, respectively, to confirm that only 1.3 cores would release their fission products.

<u>Fission Product Deposition On Site</u>

Radioactivity is released by vaporization of fission products from the fuel. The released fission product gases are carried away from the fuel by steam or air and cool off. Because of the cooling, fission product gases (with the exception of any remaining noble gases) condense into micron-sized aerosols. The noble gases have short half-lives and are, therefore, small contributors to spent fuel pool accident consequences. Because the fission product gases become aerosol after they are away from the fuel, the potential exists for significant deposition inside the spent fuel building or for complete removal by spent fuel building filters. Aerosol deposition mechanisms include settling, diffusiophoresis, and thermophoresis. The rate constant for the first order process of fission product aerosol settling in the containment for a reactor accident is on the order of .5 per hour. Using this rate constant and a fission product aerosol holdup time of two hours in the spent fuel building, half of the fission products released from the fuel would deposit on site. A factor of two reduction in the offsite release would reduce both the short term and the long-term offsite consequences.

Recommendation: For each type of accident, perform an evaluation of fission product removal by deposition and filtration.

Long-Term Relocation Criterion

The November 12, 1999, analysis used the same long-term relocation criterion to limit offsite radiological consequences as that used in the Surry model for the NUREG-1150 study. This long-term relocation criterion is that the population in a sector that is relocated can return home if an individual's dose over the next five years is less than 4 rem. Preliminary sensitivity calculations with the MELCOR Accident Consequence Code System (MACCS) indicate that long-term radiological consequences would be reduced if the dose criterion is reduced. For example, reducing the criterion from 4 rem to 3 rem, reduces the societal dose for the population within 100 miles of the spent fuel pool from 4.5 million rem to 3.8 million rem.

Recommendation: Re-evaluate the basis for the 4 rem relocation criterion.