From: Jason Schaperow / RES
To: Diane Jackson / NRR
Date: Wed, Dec 8, 1999 4:44 PM
Subject: Memo on Spent Fuel Pool Consequences

Attached is the final draft of our memo on spent fuel pool consequences that is due by December 10. We expect to sign it out tomorrow (December 9).

CC: Charles Tinkler, Farouk Eltawila

B/46

MEMORANDUM TO: John N. Hannon, Chief
Plant Systems Branch
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation

FROM: Farouk Eltawila, Chief
Safety Margins and Systems Analysis Branch
Division of Systems Analysis and Regulatory Effectiveness
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) has 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, a report containing the technical basis was forwarded to NRR. The primary objective of the analysis is to determine the effect of extended storage in a spent fuel pool, and the resulting radioactive decay, on offsite consequences. The analysis predicts a factor-of-two reduction in prompt fatalities if the accident occurs after 1 year instead of after 30 days. The analysis also shows 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) are limited by the large contribution from long half-life isotopes.

In a November 23, 1999, meeting with NRR staff, RES agreed to identify further opportunities to reduce uncertainty to develop a more realistic evaluation of offsite radiological consequences of spent fuel pool accidents. An RES review, which is documented in the attached report, indicates opportunities in four areas: (a) the length of time between the beginning of the accident and 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. Reducing uncertainty in the first two areas depends on the ability to do a more realistic evaluation of the thermal hydraulics including severe accident progression in the spent fuel pool. This type of analysis is challenging due to the lack of prototypical experimental results and limitations of current modeling techniques. A significant expenditure of resources is required to further refine the thermal hydraulics.

NRR has also requested RES to perform an evaluation of the critical decay time using computational fluid dynamics (CFD). CFD is used predict the natural circulation flows in a three dimensional model which includes the spent fuel pool and surrounding building. Critical decay time is defined as the minimum time the fuel in a pool must age to ensure that maximum clad temperature during a complete loss of coolant accident does not exceed a critical value. This analysis is underway and preliminary results and issues have been provided to NRR. A report documenting this study is planned for January 2000. The preliminary and final results, will

provide NRR valuable information about the critical decay time and the important phenomena governing the natural circulation flows in the spent fuel pool and surrounding building.

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. This is due to the potential for some air being present which enhances the ruthenium release. In the November 23, 1999, meeting with NRR staff, RES agreed to review the issues raised by the ACRS and to provide recommendations by January 14, 2000, for their disposition.

Attachment: As stated

cc: G. Holahan
J. Wermiel
R. Barrett

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

Introduction

In a November 23, 1999, meeting with NRR staff, RES agreed to identify further opportunities to reduce uncertainty to develop a more realistic evaluation of offsite radiological consequences of spent fuel pool accidents. An RES review, which is documented below, indicates opportunities in four areas: (a) the length of time between the beginning of the accident 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 Accident and the Beginning of the Fission Product Release

For the purpose of evaluating offsite radiological consequences, three types of spent fuel pool accidents are postulated, 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.

The *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. Therefore, for a loss of cooling flow accident, it appears that sufficient time would be available to take mitigative action and offsite protective measures without preplanning.

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 10 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 the highest decay power fuel in the pool to reach temperatures high enough to release fission products, may be sufficient to take mitigative actions and offsite protective measures.

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. A 6-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 the

highest decay power fuel in the spent fuel pool to reach temperatures high enough to release fission products. This may be sufficient time to take mitigative actions and offsite protective measures.

The MACCS calculations documented in the November 12, 1999, memorandum show that beginning evacuation three hours before the release begins essentially precludes early fatalities. Therefore, the review of accident progression indicates that sufficient time may be available to evacuate early enough to preclude early fatalities in all three 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.

Fission Product Release Rate and Magnitude

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 limited potential for the heat up to spread to lower decay power assemblies.

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. One year after final shutdown, only the assemblies in the final core offload have decay power densities higher than 6 kw/Mt. For a full BWR spent fuel pool with 4200 assemblies, this corresponds to less than one-fifth of the assemblies in the pool.

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. A lower release rate would provide additional time to complete evacuation to further reduce short-term consequences.

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.

Fission Product Deposition on Site

Because the released 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.

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.