March 17, 2003

MEMORANDUM TO: Roy Zimmerman, Director
Office of Nuclear Security and Incident Response

FROM: Ashok Thadani, Director ***Original signed by A. Thadani***
Office of Nuclear Regulatory Research

SUBJECT: PRELIMINARY VULNERABILITY ASSESSMENT RESULTS

Attached is a brief report which provides insights and preliminary results from analyses of spent fuel pool events performed as part of ongoing work in the integrated vulnerability assessment. While some of these results are very recent, we provide them so that you may be appraised of our best current understanding. These analyses have been performed using state-of-the-art methods and treat the scenario in a consistent integrated manner. We believe these analyses are a significant improvement over past predictions of accident response. RES plans to continually update you as new analyses are completed. In the long term, we plan to issue a report on the consequences of spent fuel pool accidents which will supplant the analyses in NUREG-1738, Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, February 2001.

These analyses were performed to address the full and partially drained pool configurations for an operating reactor and have addressed, where applicable, comparisons with the generic study performed in NUREG-1738. Calculations address

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Ex. 2

By contrast, in NUREG-1738 all of the fuel was assumed to release a significant fraction of its fission product inventory. The timing of the release predicted in our preliminary analysis is much less severe (starts later and extends over longer interval) than assumed in NUREG-1738. This reduction in the radionuclide release alone has significant impacts on offsite consequences.

Ex. 2

the building or its remnants.

Ex. 2

~~Ex 2 entirety~~
Portions Ex 2

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In this report, we have also provided some initial insights on fuel loading and makeup sources of water, and we expect further work to provide more of the same along with greater clarification and confirmation of these points.

The analyses described herein represent a substantial improvement in the way we perform evaluations of spent fuel pool accidents. More work is essential to confirm and expand these analyses but this preliminary evaluation is providing a strong base for our ongoing vulnerability assessment. We will provide you with additional information as we proceed, and we are planning to conduct an external peer review before the final report is issued.

Attachment: As stated

cc w/o att.:
CPaperiello
WKane
WTravers
GHolahan
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Preliminary analyses of spent fuel pool events suggest that these more realistic treatments of heat transfer mechanisms and integrated treatments of atmosphere composition and fluid flow produce more favorable predictions (compared to some past predictions including NUREG-1738) of fuel coolability and fuel degradation when coolability is not assured. NUREG-1738 calculations indicated that about 4-5 years of decay is needed before air cooling, for a fully drained pool, is sufficient to preclude a zirconium fire. Our calculations suggest fuel is air coolable, for a fully drained pool, at much earlier times.

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The risk tradeoff of these design impacts will be addressed as we proceed.

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The integral calculations show a very large reduction in the magnitude and rate of the radiological release to the environment from that assumed in the generic NUREG-1738 analyses and earlier analyses.

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Future work is expected to provide insights as to whether Ex. 2 could provide even greater benefits for coolability and prevention of fuel damage.

The preliminary analyses have provided numerous insights and an improved understanding of the more realistic range of fuel damage and offsite consequences resulting from terrorist attacks. We have identified some of the insights on preventing and mitigating the consequences of spent fuel pool events. These calculations need to be expanded, reviewed and confirmed (including experimental confirmation) and modified to include a consideration of uncertainty. Ex. 2

Nonetheless, we think this ongoing work with its preliminary results, along with improved analyses of reactor events and alternative consequence modeling, is already providing a vastly stronger foundation for our vulnerability assessment.

PRELIMINARY VULNERABILITY ASSESSMENT RESULTS

1. BACKGROUND AND OBJECTIVES

In response to the terrorist attacks on September 11, 2001, the NRC has undertaken an assessment of the vulnerabilities of nuclear facilities to a variety of threats. Evaluation of the vulnerabilities and the potential consequences of attacks on facilities guides the agency in assigning priorities, identifying possible compensatory or mitigating actions and ensuring security is appropriately addressed for both operating facilities and future designs. As a part of the agency's activities, RES has underway a detailed study of the vulnerabilities posed by attacks on [ ] operating nuclear power plants. The RES assessment of the operating plants Ex. 2 * includes characterization of the vulnerability of the reactor and the spent fuel stored on-site in the spent fuel pool. Vulnerability is being evaluated as an integrated risk assessment; a probability of occurrence is attached to the individual elements of the analysis and scenario, those events leading to damage of structures, systems, fuel damage, offsite release of radionuclides and public health consequences and environmental impacts.

The objective of this brief paper is to summarize the results of preliminary analysis performed to date with regard to the prediction of accident progression and offsite consequences. Further, this paper focuses on the results of one area of analysis:

> Analysis of the phenomena associated with cooling, heatup, and possible degradation of fuel in the spent fuel pool together with potential offsite consequences in the event fuel heating is sufficient to result in fuel failure and significant radionuclide release.

With respect to the analysis of spent fuel pool heatup, these analyses done as part of the vulnerability assessment have implications for the evaluation of other non-vulnerability related scenarios, such as those considered in NUREG-1738, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants." The methodology developed for this vulnerability assessment is a substantial improvement upon the methods adopted for the generic decommissioning study and it is expected that future analyses of spent fuel pool accidents, regardless of the accident initiator, would benefit from the more mechanistic and realistic assessment of fuel thermal response, zircalloy oxidation and possible radionuclide release. Comparison of the ongoing analyses with the analysis in NUREG-1738 is provided.

2. SPENT FUEL POOL ANALYSIS

The general methodology being used to evaluate spent fuel pool cooling under conditions where water has drained from the pool is based on a two tiered approach to evaluate the thermal hydraulic and natural circulation conditions. In order to evaluate details of natural circulation flow through the fuel assemblies and rack cell structures, a CFD code is being used because of its inherent capabilities to simulate multidimensional flow, detailed flow losses through a complex geometry and free shear flow conditions associated with buoyant plumes. The CFD code is also being used to assess mixing of the plume exiting the pool with the bulk building atmosphere and the boundary condition associated with the airflow to the pool. To simulate the overall system response we use the MELCOR severe accident analysis code which includes modeling of the transient draindown, boiloff, natural circulation, zircalloy oxidation, material heatup, melting and relocation as well as potential fission release and transport. The MELCOR code analysis, using the conventional control volume code approach, will use the insights from the detailed CFD model to benchmark its basic thermal hydraulic model of volumes, flow paths and resistances.

To further guide the development of the MELCOR integral spent fuel pool model, we have also devised an approach wherein we construct a simple separate effects model, as shown in Figure 1, simulating 5 fuel assemblies, with a central assembly and its 4 adjoining neighbors. With this separate effects model we can investigate basic phenomena of air and steam cooling, impact of flow resistances on natural circulation cooling and issues attendant to the failure and melting of the cell walls (boral or boraflex dividers). The first set of calculations were done with a model simulating details of the spent fuel pool assemblies and cell racks of a specific PWR for which existing detailed information was readily available. This racking is a high density design, generally representative of numerous domestic BWR and PWR plants as well as foreign reactors.

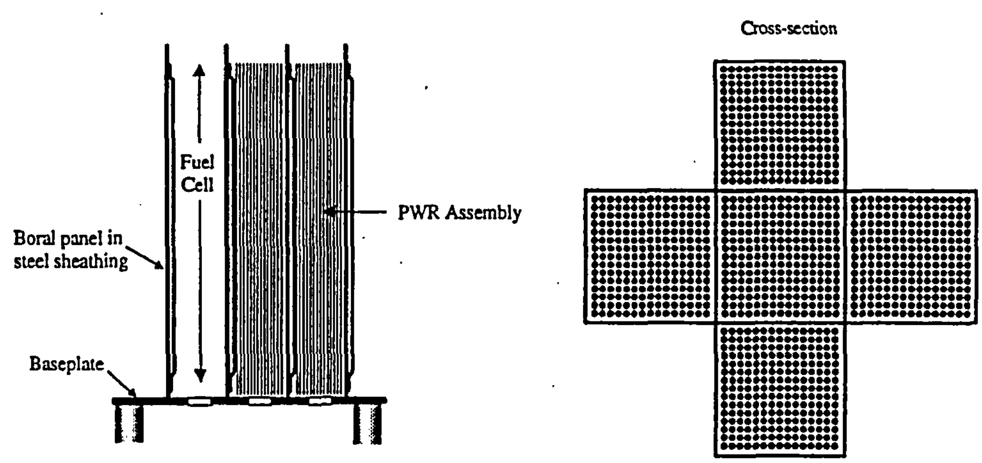

Figure 1. Separate Effects Model

The first calculations were performed to test the model and assess the effectiveness of air cooling for various decay times. [

Ex. 2

] The results of air cooling calculations, assuming the water has drained from the pool are shown in Figure 2.

[

Ex. 2

]

The curves in Figure 2 show the thermal response of fuel cladding for [Ex. 2]

indicates, for the separate effects calculation, that fuel which has [Ex. 2] could be air cooled; its temperature would rise above the initial temperature but would stabilize and reach a new equilibrium at a temperature below that at which zircalloy oxidation would cause an uncontrollable increase (i.e., "zirc fire"). Fuel failure could be expected to occur at a temperature of [Ex. 2] and fission products would begin to be released but significant releases would not occur until somewhat later. The sharp upward temperature ramp, [redacted] is due to the exothermic energy addition associated with cladding oxidation. [redacted]

Because natural circulation cooling with air is influenced by the resistance (e.g., form and wall losses) of the flow path, we looked at potential locations where the localized resistances of the path may be more severe (Figure 3).

[redacted]

[redacted] This can be compared to the coolability for other assemblies [redacted] shown in Figure 2 and described above [redacted] The conclusion one could draw from this analysis is that [redacted]

The design of the rack may possibly be optimized in the future [redacted] although we recognize that other design constraints may [redacted] exist. There is a point here relevant to the NUREG-1738 study concerning flow blockage, in that flow blockage was cited as a reason for concluding that in some instances fuel may never

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Additional analyses, not described in detail here, have also been performed to examine the extent to which the limiting of oxidant (air starvation) was reducing the rate of cladding oxidation. MELCOR modeling accounts for the composition of the atmosphere (oxygen, nitrogen, and steam) and thus includes the effects of oxygen deprivation.

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Ex 2

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Even in the case of [ ] there Ex. 2 may be substantial time for corrective action to restore the water inventory or cooling of the fuel. A series of simple calculations were performed, in this case simulating a complete pool, (no longer using the separate effects model), to assess the time for the water to drop to various key elevations. These calculations were done roughly simulating the inventory and decay heat level in a BWR spent fuel pool [ ] Figure 5 is Ex. 2 a depiction of the [ ]. An observation can be Ex. 2 made relative to this pool based on our existing information(which is being confirmed). Unlike the configuration assumed for pools in decommissioning reactors [ ]

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In the case of simple boiloff, with no hole or drainage, there are before the Ex. 2 fuel is uncovered.

Level draindown calculations were performed for various assumed hole sizes in the spent fuel pool. The draindown calculations were then used to assess makeup flow rates. Discussions with local firefighting experts confirmed that, as an example, pumper trucks commonly used in the Baltimore-Washington area have a rated capacity of 1000 -1500 gpm. (Some trucks have capability up to 2000 gpm). Losses (line losses and elevation changes) will reduce that capability. The ability to draw from a distant source (e.g., pond, river, or tank) and deliver flow may be limited on the suction side by the fixed piping carried or available but discharge over relatively long distances is feasible. Trucks can also be aligned in series to Ex. 2 increase capability over longer distances. Ex. 2

A part of the examination of spent fuel pool coolability and the potential for fuel damage Ex. 2 (and concomitant radionuclide release) is the integral analysis Simulation is necessary to capture the potential for fission product mitigation, and to model the mixing and inlet air flow to the spent fuel pool. then significant fission product deposition may occur even though the fuel has released its volatile radionuclide inventory. This would, in turn, significantly reduce offsite consequences. Where the separate effects model was used to simulate details for a 5 assembly array of fuel, the integral model will simulate the 3000 some assemblies which comprise the pool inventory. Based on the general distribution of fuel assemblies a MELCOR model was constructed Ex. 2 Ex. 2

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The integral model has as an objective, in addition to the calculation of the onset of fuel damage, the prediction of the extent to which propagation of fuel damage may occur given heatup of the highest decay heat assemblies. Since the decay heat levels may vary widely within the pool across major regions, it is plausible that relatively smaller regions, even if they reach high temperatures associated with rapid zirconium oxidation, may not heat adjoining large colder regions. At a minimum, it is reasonable to posit that the time for the fuel through out the pool to release its fission products may be influenced by the relative distribution of power within the pool. In the NUREG-1738 study it was assumed, from a bounding standpoint, that all of the fuel released its fission product inventory simultaneously, regardless of power level, over an interval of 30 minutes. In NUREG-1738, it was also assumed that radionuclide release began in about 1 hour. The integral analysis will provide a much more realistic characterization of the timing of the radionuclide release together with a more realistic evaluation of the magnitude of that release.

For the first preliminary analysis, it was assumed that [redacted] in order to shed light on timing and propagation behavior [redacted] We have not as yet determined [redacted] The scenario chosen for this calculation is a [redacted] draindown with air cooling. This type of scenario is most like those addressed in NUREG-1738 and is considered to be important for the vulnerability assessment. Unlike the NUREG-1738 study, in this analysis we further assume the drainage of water to occur not instantaneously but rather as a transient process [redacted]

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The timing of the release of radionuclides from the damaged fuel in the spent fuel pool is also greatly changed from the NUREG-1738 assumptions in that it is less severe. The first offsite release of radionuclides occurs as compared to the assumed release start of 1 hour in NUREG-1738. In NUREG-1738, it was assumed that the release took place over an interval of 30 minutes, the preliminary analyses predicted the bulk of the release occurs Ex. 2 Ex. 2 Ex. 2

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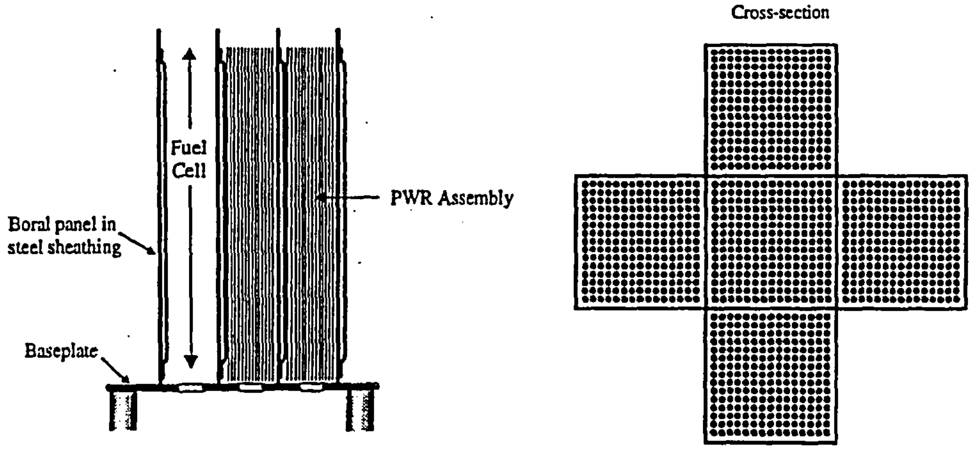

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