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November 30, 1999

Ms. Tanya Eaton
Project Officer
U. S. Nuclear Regulatory Commission
Division of Systems Analysis
MS OWFN 11-A-11
Washington, DC 20555-0001

Subject: Final comments on "DRAFT Technical Study of Spent Fuel Pool Accident for Decommissioning Plants," Contract No. NRC-03-95-026, Task Order No. 246.

Dear Ms. Eaton:

Attached are the final set of draft comments summarizing the evaluation of the report entitled "DRAFT Technical Study of Spent Fuel Pool Accidents for Decommissioning Plants," dated June 1999. The attached comments are from Dr. Fred Mowrer in regard to the fire protection portion of the draft report.

Should you need any additional information, please do not hesitate to contact me at (301) 255-2279.

Sincerely,

Dr. Leonard W. Ward
Project Manager

Enclosure: As Stated

cc: D. Jackson, NRC, DSSA/SPLB
J. Meyer, SCIENTECH
M. Straka, SCIENTECH

QA File 1022

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Final Comments on the Fire Protection Portions of the Draft Study

1. Page 3 – What properties were used to perform the adiabatic heating calculations? What are the respective volumetric heat capacities of the spent fuel and protective cladding? What is the decay heat generation rate per unit volume used for the calculations? Is this heat generation rate temperature dependent or is it assumed to be constant? It is recommended that these calculations be shown along with associated parameters and assumptions in an appendix to permit the calculations and their bases to be verified and clearly understood.

2. Page 8 – The report indicates that "the existing combustion literature indicates that ignition of zirconium cladding is considered probable when some combination of the following conditions are available: (1) an oxide-free surface exposed to a high oxygen concentration in a high pressure environment, (2) the presence of fine particles of zirconium, and (3) fuel assembly loading configuration and decay heat load." It would seem that the first two conditions identified here would not be likely in a spent fuel pool. If this is true, then the overall risk of a zirconium fire might be significantly overestimated. If this is not true, then the report should be reworded to properly reflect the conditions needed for a zirconium fire to occur in a spent fuel pool.

3. Page 8 – The second paragraph of Sec. 2.1.2 suggests that zirconium is a metal that forms a protective oxide layer. Is this initial oxide layer accounted for in the analysis?

4. Page 8 – What is the relevance of the reported heat of formation and adiabatic combustion temperature? Are these data used anywhere else in the report?

5. Page 9 – Combustion zone propagation rate data are cited in a pure oxygen environment at 0.1 atmosphere? What is the relevance of this to the SFP building, which is at normal atmospheric conditions of approximately 21% oxygen by volume at 1 atmosphere of pressure. Combustion zone propagation rate data are also cited at 1 atmosphere, but it is not clear if this data is in a pure oxygen environment or under normal atmospheric conditions. The report suggests this data is relevant to the SFP building, but even if this was true its relevance to the report is not clear. Furthermore, the propagation rate will depend on a number of other variables, including fuel orientation and thickness, which are not discussed.

6. Page 10 – The last paragraph in Sec. 2.1.3 indicates that the working group considered the use of high expansion foam as a potential mitigating action. What evidence is there that this is a viable alternative for extinguishing zirconium fires? In other applications where high expansion foam has been used, the basic premise is that submergence in high expansion foam will significantly reduce air movement into the combustion zone, thereby smothering the fire. This may not be effective in the case of a zirconium fire. As noted in the report, "the effectiveness of high expansion foam on bulk zirconium fires is not known at this time." There are plenty of other potential

fire mitigation schemes with unknown effectiveness on bulk zirconium fires that are not mentioned. Is there any evidence at all about the use of high expansion foam on metal fires? If so, the relevant literature should be summarized and cited. If not, it is recommended that the discussion on expansion foam be eliminated at this time.

7. Page 19 – As mentioned, it is recommended that the bases and calculations associated with the adiabatic heating model should be described in detail to permit review and verification.

8. In general, one has the impression that much of the scientific literature on zirconium fires relates to the combustion of forms of zirconium with large surface area to volume ratios, such as dust particles or machine turnings. Based on the review of the draft report, it is not entirely clear how much data exists on bulk zirconium fires, particularly in an air environment. It may be instructive to include a discussion of limitations and potential impacts associated with the lack of supporting data on bulk fire behavior.

Thermal Hydraulic Issues

The additional comments summarized below followed from the review of the report. While the focus of the report was to address criticality and fire protection, questions regarding the thermal hydraulics also arose, since the thermal hydraulics are closely coupled to criticality and fire issues. For completeness these questions are summarized for further information to the Staff.

1) The scenario where a complete loss of inventory occurs implies a large rate of loss of pool liquid inventory. If such an event occurs, it is not clear how one recovers the fuel with coolant since a very large injection rate is needed which may be beyond the capacity of the sites. As such, reliance on a spray system that is uniformly sprayed on the top of the fuel appears to be a necessity. The consequences of spraying and whether it will be effective in meeting the 565 °C or 800 °C temperature limits are not discussed. That is, recovery actions could result in more severe conditions than the initiating event postulated to cause the pool to totally uncover and heat-up. See item 3) below for a discussion of potential concerns regarding recovery and the ensuing thermal hydraulic phenomena.

2) It is agreed that the scenario where the pool inventory boils down and achieves a low level of two feet or less, thus producing a situation which is more severe than that for the totally uncovered pool due to the limited steam cooling provided by the low level, is not considered credible. Since this boil-down will take many hours, it is agreed that there is clearly sufficient time to preclude a slow boil-down. However, when recovering from the proposed complete loss of inventory event, the recovery actions could produce a scenario where a low level may be recovered in the pool causing a more undesirable cooling situation to develop. This suggests that the consequences of recovery need to be addressed in more detail, as well. See item 3) below.

3) The report emphasizes the complete loss of inventory as the initiating event and the focus of the assessment is in regard to the consequences. There is very little discussion of the consequences of recovery, which could exacerbate the consequences of an event that meets the criterion that the fuel rods not exceed the 565 °C temperature threshold for rod swelling. That is, an evaluation of the recovery from an event, which leads to a complete uncovery of the fuel that is cooled by air circulating from below, was omitted. More specifically, if the water is sprayed on top of the fuel, the water could pool above the hot bundles forming hot spots in the interior of the bundles. **Since the partial down-flow of coolant and the partial quenching of the rods will deposit potentially large amounts of heat into the coolant, the steam velocities in the interior will increase and exceed that from static decay heat boil-off.** These increased steam velocities at atmospheric pressure could produce conditions that could momentarily preclude a down-flow of liquid since the counter-current flow limit (CCFL) conditions could be exceeded for some periods of time. During this time, the water level could also recover to a few feet in the bottom of the bundle. Unless the water level is recovered quickly, **there could be localized pockets of hot**

fuel with water pooled on top that is unable to penetrate the lower bundle portions due to the high steaming velocities. Since the water level partially recovers the pool bottom, terminating the air circulation and cooling, the fuel central or upper regions could experience further or excessive heating. There is the potential for these interior regions to heat-up above the zirconium-water reaction threshold and possibly fail fuel or produce cladding melt. The process could be sustained for some periods of time or oscillate in a quenching heat-up type behavior, thermally cycling the fuel. The consequences of the heat up and partial quenching are also not discussed. It is recommended that a discussion of this potential scenario be included or the reasons for its omission explained.

4) Specific guidance is recommended to deal with the methodologies that are employed to analyze the pool heat-up. The objective of the thermal hydraulic analysis is to identify the limiting or hottest fuel bundle regions and ultimately show that the fuel does not heat-up beyond the zirconium-water reaction temperature threshold or other suitable limits. To accomplish this a system code is needed to model the circulation of air in the building while a computational fluid dynamics (CFD) code is needed to model the multi-dimensional mixed convection behavior to identify the hottest fuel regions in a totally uncovered pool. The CFD code could provide the boundary conditions to locate the bundle with the lowest inlet velocity so the hot rod response can then be analyzed. Justification that the codes employed can credibly simulate the conditions characterizing an uncovery event in a spent fuel pool is also needed and should be recommended. Suitable benchmarks could be recommended and a list of the key phenomena associated with the major or key parameters could also be mentioned. For example, there are many CFD codes available to perform the analyses, however, proper benchmarking is still required to demonstrate that the code is appropriately applied and can capture the key phenomena characterizing the scenario. For example, have the potential flow stagnation areas been identified in the pool? And, more specifically for heat-up calculations, the radial and velocity profiles in an asymmetrically heated channel can result in fuel rod cladding temperatures that may be under-predicted by lumped parameter codes, simply because the codes cannot accommodate laminar flow or omit viscous shear altogether and the multi-dimensional effects, for example. The mixing of the hot and cold fluid streams in the building simulation could be incorrect because of an improper modeling technique or a lack of physics in the code. Benchmarking would help isolate these limitations. It may be prudent to develop some separate guidance that addresses the thermal hydraulic approaches and important concerns and issues. This may be beyond the scope and intent of the draft report, although some CFD codes are mentioned as well as some of the key phenomena. Because the report does address some of the thermal hydraulic phenomena, it may be helpful to expand the report or consider a separate report that addresses all key phenomena and issues for completeness.

5) Since temperatures can remain at elevated values following a complete loss of inventory, a time-at-temperature limit may be appropriate since fuel temperatures can remain below the acceptance limit for many hours or days. If fuel cladding temperatures remain in the 900 – 1200 °F range for many hours, although analyses

demonstrate that the metal-water reaction threshold is not exceeded, sustaining these temperatures for long periods of time could cause a large fraction of the cladding to oxidize and fail when the water level is recovered. In these low temperature ranges, low rate heat oxidation processes can still oxidize the fuel and cause a loss of structural integrity. As a consequence, a time-at-temperature, or a time frame within which the fuel temperature must be cooled is recommended. The other consequences of remaining at elevated temperatures should also be addressed such as release of fission gas if the fuel remains at elevated temperatures for extended periods of time.

6) When borated water is added to the pool to recover from a complete loss-of-coolant inventory event, boiling could persist for extended periods of time. Assurance that boric acid precipitation does not occur is recommended. While precipitation limits are not expected to be achieved in a timely manner, high concentrations of boric acid may still develop. If during the recovery, a colder source of water is located and injected, boric acid that would remain in solution may now precipitate simply from the recovery actions of adding colder water, since there was no warning or discussion of the potential for inadvertently causing a precipitation. A discussion of precipitation is recommended for completeness.

7) Other issues/subjects:

   Can the CFD codes predict the multi-dimensional (radial) velocity and temperature profiles in asymmetrically heated channels? Lumped parameter codes cannot model these effects and may therefore over-estimate convective heat transfer coeffficients, especially when the Reynolds numbers are below turbulent conditions. Are the CFD codes applied to the limiting hot channel in the hottest/limiting bundle? How is the CFD qualified/benchmarked to perform the analyses? Are there stagnant regions in the pool (flow separation) that could cause localized heat-ups or instabilities. For example, the counter-rotating vortices that develop in closed cavities, can they occur in the pool and are the CFD codes using sufficient detail to resolve these flow behaviors. How is the diffusive behavior of these codes dealt with. If first order approximation are used for the convection terms, has it been shown that sufficient spatial detail is used to render the first order approximations legitimate? Should higher order methods with flux limiters/etc. be employed, for example. Benchmarking is important for the CFD methodologies.

   Can boric acid plate-out on lower support plate and partially block coolant inlet channels after a sustained boiling scenario?

   What are the long-term effects/consequences of heated fuel bundles on fission gas release if the bundles remain 900- 1200 °F for many hours? Pin pressures can be as high as 2000 psia in the pool. What temperature or time at temperature conditions, just below the swelling temperatures are needed ,if any to release the fission gas. What effect does the fission gas have on the heat transfer in the hot bundles?

What assurances are there that water is sprayed uniformly over an uncovered pool?
Could there be localized regions that are not cooled that could heat-up undetected?