UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D. C. 20555

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MEMORANDUM TO: ACRS Members and Staff

MEMORANDUM #: [redacted]

FROM: A. W. Cronenberg

SUBJECT: Observations from Review of Report "Draft Final Technical Study of Spent Fuel Pool Accident Risk at Decommissioned Nuclear Power Plants" "

Summary: Subject report documents staff efforts regarding an assessment of the *technical basis* for estimating risk for decommissioned plants. This effort is to support agency reviews of exemption requests from regulations in the areas of emergency preparedness/insurance for shutdown plants. Risk is taken to be the estimated dose to the public resulting from the release of radionuclides from severely damaged fuel stored in a spent fuel pool (SFP) facility, where damage is due to loss-of-spent fuel-cooling and resultant decay-heat induced heatup to temperatures for auto-catalytic Zircaloy-air oxidation and cladding breach.

Subject report concentrates on an assessment of a variety of initiating SFP events (loss of spent pool pumping power, seismic events, cask drop accidents, etc) that could lead to coolant loss and spent fuel uncovery, and presents estimates of the fuel uncovery frequency (FUF, analogous to CDF). Consequence analysis of radionuclide release and public exposure are also given in Appendix-A4. The consequence analysis is largely based on prior studies (ORIGEN2/CORSOR release estimates) extended to a 1-year decay time, and is less detailed in scope than the frequency analysis. Estimates of several risk measures are presented in Appendix-A4 [Risk (fatalities/yr) = Frequency (event/yr) X Consequences (fatalities/event)], specifically point estimates for early fatalities and latent cancers.

Although subject report can be viewed as analogous to WASH-1400 or NUREG-1150, where both early fatality and latent cancer risks are estimated for SFP accidents, the SFP study is much more limited in scope and the quantitative estimates for risk are suspect. Most of my concerns center on inadequacies in the consequence analysis, credit for off-site emergency equipment, and arguments for "non-physical" defense-in-depth measures. Nevertheless, the report does present a reasonable case that "*risk-insights*" can be argued for SFP accidents. The following are my primary observations.

a) The nine **initiating events** considered in the report appear reasonable (loss of off-site power from plant centered and grid related events, loss of off-site power from weather, internal fires, loss of coolant circulation by pump failure, loss of coolant inventory/drainage, seismic events, cask drop accidents, aircraft impact and tornado missile impact). The calculated fuel uncovery frequency (FUF) for these initiating events is estimated to be low, largely based on Industry Decommissioning Commitments (IDC, see pgs 14 & 15 of report). The estimated FUF is likewise sensitive to spent fuel pool (SFP) staff performance that remains at the facility after plant decommissioning. Life can be rather mundane at such facilities, which may tend to diminish staff attentiveness, thus begging questions of human performance. Any agency rule-making would have to assure that IDC are being adhered to. It seems that the initiating events assumed are reasonable, however the FUF estimates are open to considerable uncertainties related to human performance and adherence to industry commitments.

b) The FUF is estimated to be low (1.3E-7) for **loss-of-offsite power (LOOP)/weather related events**, based on the assumption of the **availability of backup (off-site) emergency equipment** (portable pumps and emergency power). The assurance of backup emergency equipment is largely based on Industry Decommissioning Commitments (IDC, see pg 14), specifically the following:

> IDC #2: Procedures and training of personnel will be in place to ensure that on-site and off-site resources can be brought to bear during and event.
>
> IDC #3: Procedures will be in place to establish communication between on-site and off-site organizations during severe weather and seismic events.
>
> IDC #4: An off-site resource plan will be developed which will include access to portable pumps and emergency power to supplement on-site resources. Th plan would principally identify organizations or suppliers where off-site resources could be obtained in a timely manner.

It should be noted that Westinghouse wanted to credit availability of off-site emergency equipment for severe accident recovery actions for the AP-600, a position that was not accepted by the staff or ACRS in the AP-600 design review. Although the timing for accident recovery actions is much longer for SFP events than for at-power core uncovery accidents, still I have concerns related to credit for SFP off-site emergency equipment. The Florida Power & Light experience at Turkey Point, related to difficulties in replenishing the diesel fuel supply for emergency/diesel-powered decay-heat removal during hurricane Andrew (5 days before the on-site 7-day supply was replenished, if I remember correctly), heightens concerns related to credit for off-site emergency equipment for weather related events. I question the low FUF estimate for weather related LOOP events, based on credit for off-site emergency equipment.

c) Loss-of-offsite-power (LOOP) events remain a primary initiator for reactor LERs (Licensee Event Report) and high-risk events per insights from the Accident Sequence Precursor (ASP) program. Subject risk study indicates that this is also true for SFP events. Recovery form LOOP related reactor events largely stems from reactors having on-site emergency diesel power to assure decay-heat removal capability. This however, is not the case for typical spent fuel pool facilities for decommissioned plants. Decay-heat removal at SFP facilities would typically rely on coolant circulation by motor-driven (electric) pumps (see report Fig. 3.1), without benefit of backup/on-site diesel-powered circulation pumps (only the SFP makeup system calls for a diesel powered pump). Although the timing for recovery actions is considerably longer for SFP LOOP events than for a reactor LOOP, still I question the wisdom of SFP designs that incorporate only electric-motor driven circulation pumps that rely on off-site grid power, without benefit of on-site/backup diesel power for SFP coolant circulation. Concerns related to credit for off-site emergency equipment for LOOP events would be alleviated, if on-site backup (diesel) power were available to assure SFP coolant circulation.

d) Source term (radionuclide release fractions) and **consequence analysis** (prompt fatalities, cancer fatalities, societal dose) was provided in Appendix- A4 of said report, based on release methods (ORIGEN2-inventory estimates and CORSOR-release fractions) used in prior studies (NUREG/CR-4982: Severe Accidents in Spent Fuel Pools in Support of Generic Issue-82, 1987 —see pg 64; and NUREG/CR-6451: Safety and Regulatory Assessment of Generic BWR and PWR Permanently Shutdown Nuclear Power Plants, 1997). A better description of the release/consequence analysis I believe is *"guesstimate"*, owing to the fact that the ORIGEN2/CORSOR predictions were not benchmarked to data for the accident conditions at hand, i.e. spent fuel rods with a considerable degree of burnup subjected to cladding destruction by runaway Zircaloy-air oxidation.

The CORSOR release model is basically a "fuel-temperature/release-fraction correlation" that are empirically based. The data base for the CORSOR models is taken from a limited range of fuel burnup conditions and some of the data are for UO_2 pellet samples that were "pre-conditioned/doped" with simulated fission products. The CORSOR model is also largely correlated to release data obtained from sectioned fuel rod samples that were heated in out-of-pile induction or furnace heating experiments, generally in a steam or inert environment. I do not believe any of the CORSOR data base is for decay-heatup or Zircaloy-air oxidation conditions. The CORSOR release models are likewise notoriously inadequate in modeling the impact of fuel burnup and associated fuel morphology effects on release, and I do not believe correlated to burnups greater than 30 GWD/t-U (Note: spent fuel can be expected to be >40 GWD/t-U). At the rather **slow heatup** conditions (hours) associated with SFP accidents, considerable fuel grain-growth/micro-structural changes can be expected, with a considerable impact on fission product morphology. Such changes in fuel micro-structure and fission product morphology are know to exert a significant impact on release behavior and timing (note data from INEEL-PBF, Oak Ridge-HI & VI tests). The report does not draw attention to any of these shortcomings. In view of these and other limitations, it is difficult to assess the accuracy of CORSOR predictions for high-burnup/decay-heat/Zircaloy-air oxidation/spent fuel destruction conditions. In the absence of release-data to benchmark the CORSOR results, I view the release/consequence analysis for SFP accidents with a **large degree of scepticism.** Indeed, here is an example of ACRS concerns expressed in its Research Report, that policy decisions are being made without a sufficient technical basis. The CORSOR based SFP release/consequence analysis I believe are simply a calculational exercise, and to be viewed as such. The CORSOR predictions would need to be validated against release data for prototypic SFP accident/fuel-destruction conditions, before they can be accepted as reasonable estimates of fission product release for SFP accidents.

In spite of the above arguments, *insights* can be drawn from the release/consequence study that have merit. The NUREG/CR-4982 and NUREG/CR-6451 studies yielded more conservative consequence predictions, since releases were based on a *generic* spent fuel inventory with a limited decay period of 30 to 90 days after fuel discharge. The present study extended this generic inventory to a decay of 1 year, which obviously resulted in a significant reduction in prompt fatality consequence, largely due to decay-out of volatile iodine and xenon species (note ½-lives: I-133=0.87 dy; I-134=0.04 dy; I-135=0.27 dy; Xe-135=0.38 dy). The evaluation indicated a factor of 2 reduction in prompt fatalities if the accident occurs after 1 year after fuel discharge, instead of a shorter 30 day decay period. Logic would support these observations. The analysis also showed that cesium species, with their long half-lives (Cs-137= 30 yr; Cs-134=2.1 yr), are the dominant contributor to consequences for accidents with 1-year decay. Estimates indicate that 97-% of the societal dose is due to release of cesium. It was concluded that early evacuation could reduce prompt fatality consequences by more than an order of magnitude. These **qualitative consequence <u>insights</u> appear reasonable**, albeit the **quantitative values of release are highly suspect**.

e) Industry Decommissioning Commitments (IDC): IDC-5 states that industry will assure that instrumentation for all spent fuel pools will include readouts and alarms in the control room for the following: 1) spent fuel temperature, 2) spent fuel pool water level, and 3) area radiation levels. I would add to this list of commitments, indicators for degradation of spent fuel pool pumping capacity—such as motor-driven pump voltage drop and/or pump flow meter readout. Early indicators of degradation of spent fuel cooling/pumping capacity would appear appropriate.

f) Defense-in-Depth (Section 4.2.2): The following statement is abstracted from Section 4.2.2 of said report and summarizes, what is termed the SFP *Defense-in-Depth Philosophy.*

> The staff 's risk assessment demonstrates that the risk f rom a decommissioning plant SFP accident is very small if industry commitments and additional staff assumptions are implemented as assumed in the risk study. Due to the very different nature of a SFP accident versus an accident in an operating reactor, with respect to system design capability needs and event timing; the defense-in-depth function of reactor containment is not necessary. However, the staff has identified that defense-in-depth in the form of accident prevention and some form of emergency planning can be useful for as long as a zirconium fire is possible, as a means of achieving consequence mitigation. The degree to which it may be required as an additional barrier is a function of the uncertainty associated with the prediction of the frequency of the more catastrophic events, such as beyond design basis earthquakes. There can be a trade off between the formality with which the elements of emergency planning (procedures, training, performance of exercises) are treated and the increasing safety margin as the fuel ages and the time for response gets longer.

The above offers another example of how *Defense-in-Depth* has become a *'catch-all'* for any interpretation one wishes. The above adds fuel to the fire. In the traditional sense, Defense in Depth has largely been associated with physical barriers and systems to minimize public exposure to radionuclide release....e.g. the multiple-barrier/backup-system concept .....fuel cladding, reactor vessel, reactor containment, ECC, containment spray, etc. Defense-in-depth systems/components generally form an integral part of the design, and are largely independent of human intervention. Equating industry commitments/emergency procedures, which largely rely on human performance, seems a bit of a stretch to be cast under the "Defense In Depth" umbrella. In the reactor domain we have industry commitments, in the form of *Technical Specifications* and *Operational Limits*, as well as emergency planning procedures, but these are not generally cast as *Defense-in-Depth* measures. I see little utility and much confusion, in equating SFP commitments and procedures to *Defense-in-Depth.* Why not just call them for what they are----commitments and procedures.....Period. I would hope that industry commitments would be embodied in the Technical Specifications (operation procedures) for site-specific spent fuel pool facilities, or something analogous to Tech. Specs. for decommissioned plant. Again, I would not cast such commitments as *Defense-in-Depth* measures.