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

June 20, 2000

MEMORANDUM TO: ACRS Members and Staff

MEMORANDUM #: AWC-105.2000

FROM: A. W. Cronenberg

SUBJECT: Travel Report: Power Uprate Paper at American Nuclear Society San Diego Meeting of June 4-8, 2000

Summary: This memo constitutes a travel report related to participation at the San Diego-ANS summer meeting, where I presented a summary paper related to my review of operational events noted for power uprates and potential synergistic safety issues. The meeting also included two embedded topical meetings, one DOE Spent Fuel & Fissile Material Management, the other on Nuclear Installation Safety. Here I briefly comment on my presentation, as well as impressions of several sessions I attended.

PRESENTATION: The paper I gave was based on work completed last fall and entitled: *Potential Synergistic Safety Issues Related to Reactor Power Uprates* (summary attached). The paper was included in a session devoted to Performance Monitoring/Trending in Support of the Maintenance Rule, with approximately 20-25 in attendance. The session was held on Thursday morning, the last day of the meeting, at a time when more than half the attendees had departed; thus a good turnout, all things considered. I used the same overheads as previously presented to the ACRS in February, which need not be repeated here. The presentation generated significant questions/discussions, which are paraphrased, as best I can recall:

a) Why has not the agency developed a formal mechanism for review of power uprates in view of the Maine Yankee experience and expected requests for power increases?

b) Can you comment more on the extent of NRC's audit of the safety analysis for design basis accidents, particularly LOCAs, which are submitted by a utility when requesting a power uprate?

c) Does the ACRS review applications for increases on the order of 1-2%, related to better system measurements, which the Commission has stated will be left for staff approval only?

d) How do you anticipate that your recommendation for inclusion of risk indicators for uprate applications be accomplished and incorporated into a utility submittal?

e) You included QHOs as one of the risk indicators that might be included in an uprate request. How do you envision this?

My response to these comments/questions are as follows:

Comment-a: Why has not the agency developed a formal mechanism for Review of Power Uprates in view of the Maine Yankee experience and expected applications for power increases?

Reply: The Commission has put License Renewal on the fast track, so the staff has not been able to devote the time needed for development of a more formal approach for power uprate reviews. I noted that with the expected 15-17% power uprate requests for Duane Arnold and the Commonwealth Edison Dresden and Quad Cities plants, this may change.

Comment-b): Can you comment more on the extent of NRC's audit of the safety analysis for Design Basis Accidents, particularly LOCAs, which are submitted by a utility when requesting a power uprate?

Reply: I reiterated my presentation comment, that I have not seen any documentation in the uprate-SERs (Safety Evaluation Report) issued by the staff, of thermal-hydraulic or neutronic audit calculations to benchmark licensee predictions. I stated that the only audit calculations I've seen are those done after the Maine Yankee uprate approval, which were done not as part of the uprate review process but rather in response to, and after the fact, related to *Whistle Blower* allegations of faulty submittal analysis. I mentioned that the allegations were submitted to the Maine State authority, where the alligator indicated nil confidence or willingness by NRC to challenge or uncover faulty analysis. I stated that it was my personal opinion that some sort of audit of a utility's thermal-hydraulic and neutronic predictions should be required of the NRC staff, as an integral part of its review of each power uprate. I stated that maybe the Maine Yankee story might be different if this had been done. I closed with the comment that the Maine Yankee uprate story was a failure not only for the licensee, but more importantly the NRC uprate review process.

c) Does the ACRS review applications for increases on the order of 1-2%, related to better system measurements, which the Commission has stated will be left for staff review only?

Reply: I first asked for clarification of the comment; then responded that ACRS has a memo of understanding with the EDO that it will only review requests for 5-% or more.

Comment-d): How do you anticipate that your recommendation for inclusion of risk indicators for uprate applications be accomplished and incorporated into a utility submittal?

Reply: I replied that I was really thinking of a "change in risk" or "delta-risk". I stated that one might estimate the change in failure probability (and impact on overall risk) for a piece of equipment, say for a feedwater pump or piping, operated at the higher flow rates/temperatures for uprated conditions, versus the failure probability of the same pump or pipe if it remained at the prior/lower power level conditions. Another example cited was from the Susquehanna-BWR experience, where one might estimate the risk related to failure of the recirculation pump which was thought to be due to the increased vibrational fatigue at the higher flow rates for the uprated plant, versus the risk associated with the pump failure probability at the lower/slower pumping conditions at the prior power level; again where on the delta risk would be of interest.

Comment-e: You included QHOs as one of the risk indicators that might be included in an uprate request. How do you envision this?

Reply: I said that I did not have in mind any particular Quantitative Health Objective (QHO), but rather some risk indicator; where CDF seemed those most amenable for power uprates. I said I just mentioned QHOs, because some in industry believe that QHOs should be the primary measure for assessing the real risk to the public. I also mentioned Rick Sherry's thoughts that LERF (Large Early Release Fractions) might be a better measure for public risk than CDF.

There were no more comments. I closed with the remark that I believed ACRS would, in the near future, be reviewing with the staff the adequacy of agency uprate review procedures in light of expected uprate requests in the range of 15-% or more.

Other paper at the session were entitled:

1) *Performance Monitoring/trending in Support of the Maintenance Rule at the San Onofre Plant: R. Allen of San Onofre.* I asked a question on the proposed "On-line risk monitor" for shutdown operations.....i.e. was it solely an in-house effort, did they feel they had enough risk information for shutdown conditions, and the time frame for the on-line shutdown monitor? The author replied that they were just starting to think out the basics of the shutdown monitor, but replied that he thought it would be as robust as the risk monitor for at-power conditions.

2)*Auxiliary Condenser Circulating Water Flow Optimization Using an Integrated Optimization Procedure: Z. Huang of Penn State.* I made the comment that this optimization tool might be of particular use in power uprate applications, where condenser thermal-hydraulic conditions would be expected to change to accommodate the higher power conditions, and that the condenser conditions at the uprated power might be best optimized with this tool. The author commented that he had not thought of his analysis in terms of uprate conditions, but that yes.....it would seem appropriate.

3) My paper followed.

4) *Curricular Developments in Maintenance and Reliability Engineering at the University of Tennessee: Prof. Kerlin* I had no questions/comments on this paper. Others were seeking more information on the details for certification versus an actual university degree in maintenance engineering. The session closed with this paper.

OTHER PAPERS/SESSIONS:

Tues-June 6/Morning: I attended the session entitled *Overview of Space Nuclear Power*, due to personal interest in the subject and prior consulting involvement with Los Alamos Labs during the early 1980s. I came away with the general feeling that the program has been significantly scaled back from what is was in the 1980's, although their seems to be the accepted belief that nuclear power is still a viable option for space station support power. Likewise, nuclear propulsion seems to be the only viable option for deep-probe missions. Nevertheless, I got the distinct feeling that this session was more of a pep talk to the choir, with very little in the way of new technical information.

Tues-June 6/Afternoon: My afternoon was divided between two sessions, one on *Economics of Nuclear Power in a Deregulated Environment (panel discussion)*; the other on *DOE Melter Technology for Nuclear Waste Treatment.* The first session was primarily a panel discussion of how nuclear power fits into a deregulated electric utility environment, although there were several formal presentations. One was given by NEI (I forget the name of the presenter) , indicating the general view that NEI expected that about 70 of the approximate 100 N-plants currently operating will survive into the next decade. Most of the surviving plant, if not all, will be owned by several (5-10) large N-plant operators, rather than current situation of numerous utility operators. He presented slides on fuel duty/cycle trends, operation/downtime trends, and indicated that both higher burn-ups and higher-power levels will be important factors in the viability of a plant in a deregulated environment. I asked the question: "We have an idea that BWRs may requests power uprates on the order of 10-20% over the next few years, noting Duane Arnold, and the Dresden and Quad Cities BWR plant; my question is do you have an idea of what can be expected for PWRs". He did not answer my question directly, saying that he did not have any specific numbers on what could be power uprates for PWRs, but that he would expect some increase over current power levels. No one on the panel offered any additional information per my question fro PWRs.

During the latter part of the afternoon, I attended a session devoted to melter technology for nuclear waste remediation, primarily due to my prior work and interest in this area. A significant portion of the session dealt with explosive hazards and off-gassing during the vitrification process, largely centering on the use of vitrification at the Hanford and Savannah River DOE sites. The session moderator also asked a BFNL manager at the session to fill in the audience on details of the recent DOE decision to terminate the BFNL-Hanford contract.

Wed.-June 7/Morning: I attended the session on *Cost Performance for Decommissioned Plants*, which largely centered on presentations by both utilities and DOE contractors on the costs related to plant decommissioning. Each individual presenter gave slides which basically outlined the costs for various elements for plant decommissioning. One of the presentations was by engineers from the Portland General Electric Company for the decommissioned Trojan plant.. The most surprising part of the presentation to me was that most of the major cost

over-runs were for non-nuclear related items, such as the costs of housing personal at the site. Indeed, the cost of actual removal and shipping of the reactor vessel and embedded piping was at or under the original budget estimate. This was also in line with Duke Engineering Company's experience, the contract managers for decommissioning of the Yankee-Rowe plant. Most major over-runs for that plant were likewise non-nuclear costs. The total decommissioning costs for these plants were also quite similar, at about 400-500 million each.

Wed.-June 7/Afternoon: Attended part of the session on *Public Confidence in Nuclear Energy (Panel discussion).* General consensus is that nuclear power is gaining in acceptance by general public.

Thurs-June 8/Morning: Session where my paper was given (discussed above).

End of conference.

3. Potential Synergistic Safety Issues Related to Reactor Power Uprates, *August W. Cronenberg (NRC)*

During the past several decades, the U.S. Nuclear Regulatory Commission (NRC) has reviewed and approved more than 30 licensee requests for power uprates. Each request has been evaluated to ensure that plant safety and regulatory requirements are satisfied. Recent events, however, point to potential synergistic concerns that may not have been adequately covered in the uprate application-and-review process. Specifically, higher power levels when combined with system/component degradation via plant aging, as well as high power in combination with fuel-life extensions to elevated burnup levels, may affect safety margins. Evidence of these effects stem from recent operational events, including failure to fully insert control rods in high-power high-burnup fuel assemblies and piping failures. This paper examines the potential for synergistic effects (*synergistic*—the cooperative action of discrete agencies such that the total effect is greater than the sum of the individual effects) and the adequacy of the NRC uprate review process.

A utility seeking a power uprate will submit a licensing amendment request (LAR), which contains information similar to that found in the original Final Safety Analysis Report but at the uprated power level. The LAR centers on a reevaluation of design-basis accidents and off-normal transients at the higher power level, the adequacy of safety systems to perform their intended function, and a no-significant-hazard assessment. Changes to plant equipment, operating conditions, and technical specifications to achieve the intended power increase must also be specified. Information presented in the LAR is reviewed by the NRC staff, and its findings are reported in an uprate Safety Evaluation Report (SER). The NRC review is conducted in accordance with 10 CFR-Part 50.59 and encompasses consideration of any new or unreviewed safety concerns. The uprate application is approved if the case has been made that there is no significant degradation in plant safety margins and that all applicable regulations are satisfied.

The uprate applications reviewed in this study include that for the Brunswick, Callaway, Maine Yankee, North Anna, Surry, Susquehanna, and Wolf Creek plants. A review of the LARs and SERs for these plants revealed little documentation with regard to consideration of potential synergistic effects of high-core-power densities when combined with component aging or high-burnup effects. A review of operational events for uprated plants, however, points to potential compounding effects. Examples include the control rod insertion problems noted at the Wolf Creek and North Anna plants, both having received power uprate approvals in the range of 4 to 5%. At the Wolf Creek plant, five control rods failed to fully insert during scram from full power. The affected control rods involved Westinghouse Vantage-5H fuel assemblies in the area of 47 600 MWd/t U. Root-cause analyses indicate distortion of the Zircaloy control rod guide tubes (thimbles) due to irradiation-induced growth. Because Zircaloy irradiation growth is influenced by neutron energy spectrum and flux (power-level effects), as well as total exposure (burnup effect), potential synergisms may exist. Control rod sticking problems have also been noted at North Anna-1. An examination of the Wolf Creek and North Anna uprate documentation (LARs and SERs) for control rod behavior did not reveal consideration of the effects of higher power level when combined with elevated burnup conditions. Other incidents include power offset anomalies for long-cycle/high-power cores tied to crud buildup on high-burnup fuel rods. The crud appears to gather boron, causing a distortion of the axial power profile, particularly in high-power assemblies, indicative of potential elevated power/burnup synergisms.

Aged reactor components and systems, combined with the higher flow rates that often accompany uprates [primary and secondary flow increases for boiling water reactor (BWR) uprates; secondary-side flow increases for pressurized water reactor (PWR) uprates], may likewise produce degradation that is greater than the sum of the individual effects. Research has shown that pipe corrosion can be exacerbated at increased fluid velocities, indicative of a synergistic corrosion (aging)/erosion (flow) process. Root-cause analysis has also pointed to corrosion (aging)/vibration-fatigue (flow)-induced pipe failures. Uprated plants that have experienced recent pipe failures attributed to corrosion/erosion and corrosion/vibrational effects include the Callaway (PWR) break of an 8-in. steam line leading to a feedwater heater and a weld leak in a 1-in. line in the recirculation system at the Susquehanna (BWR) plant.

Inadequacies were also noted in the Maine Yankee and Brunswick uprate reviews, where deficient licensee submittal information was not uncovered during the initial review by the NRC staff. These incidents point to a need for independent agency thermal-hydraulic and neutronic audit analysis to verify licensee submittal information. NRC in-house computational efforts would go a long way in providing an independent check and verification of what is now essentially a licensee effort. In view of these observations, the following recommendations are made:

1. NRC should issue a Standard Review Plan (SRP) for power uprate applications, which should include acceptance criteria that consider the influence of potential synergistic effects, specifically high-fuel-burnup levels and component/system aging effects combined with uprated power conditions. The NRC is in the process of developing a power uprate SRP.

2. NRC uprate review procedures should include requirements for independent NRC staff analysis (i.e., thermal-hydraulic and neutronic code predictions) to verify uprate predictions submitted by the licensee. The results of NRC audit calculations should be part of the SER for each uprate review and include comparisons with licensee submittal analysis.

3. A comparison of probabilistic safety measures (e.g., core damage frequency, QHO, and LERF) at the uprated and prior power levels is recommended for future uprate applications.

4. Reliability Analysis of Aging Effects Considering Imperfect Testing and Maintenance, *Kang M. Park, Young W. You, Chang H. Chung (Seoul Natl Univ–Korea)*

Aging effects are dealt with in the evaluation of periodic test and maintenance, replacement, and life extension. Because the interval-averaged unavailability for a component and a system is used in the existing reliability analyses, continuous time trend of each component's unavailability cannot be analyzed. The use of both extremes, as-good-as-new and as-bad-as-old, in the quantitative evaluation of test and maintenance has difficulty in reflecting the actual maintenance activities. In this paper, time-dependent unavailability is derived under periodic test and maintenance with the discrete renewal process, and accumulated aging effects are evaluated with the introduction of a new factor based on imperfect test and maintenance and its sensitivity analysis.

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The unavailability can be derived with the discrete renewal process.[1–3] The result is as follows:

$$Q(t) = R(nT)CF_0(t)$$

$$= \sum_{k=1}^{n} Q(kT)(Q(kT)(1-p_k) + R((n-k)T)CF_k(t))$$

$$nT < t < (n+1)T\ , \qquad (1)$$