UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

ACRSR-2277

December 20, 2007

The Honorable Dale E. Klein
Chairman
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: SUSQUEHANNA STEAM ELECTRIC STATION UNITS 1 AND 2 EXTENDED POWER UPRATE APPLICATION

Dear Chairman Klein:

During the 548th meeting of the Advisory Committee on Reactor Safeguards, December 6–8, 2007, we completed our review of the NRC staff's Safety Evaluation (SE) associated with the Susquehanna Steam Electric Station (SSES) extended power uprate (EPU) application. Our Subcommittee on Power Uprates also reviewed this matter on October 9–10, 2007, and November 14, 2007. During these reviews, we had the benefit of discussions with the staff, Susquehanna PPL, (PPL, the licensee) and its consultant, AREVA. We also had the benefit of the documents referenced.

CONCLUSIONS AND RECOMMENDATIONS

1. The PPL application for the SSES EPU should be approved subject to the conditions imposed in the SE and the modification in recommendation 2.

2. An appropriate margin should be added to the operating limit minimum critical power ratio (OLMCPR) as an interim measure to account for uncertainties in the void fraction correlation and the lack of data for its validation at void fraction above 90 percent. This interim measure should be reviewed when PPL submits more detailed analyses that account for the effect of uncertainties in the void fraction on the OLMCPR.

3. We concur with the staff that the load rejection and main steam isolation valve closure transient tests should not be required. The plant transient testing program adequately addresses the performance of the modified systems.

4. We concur with the staff that the monitoring that will be performed during power ascension to the uprate conditions provides adequate assurance that if vibration modes are induced in the steam dryer, they will be identified.

5. The proposed methodology for reducing the Oscillation Power Range Monitor (OPRM) scram setpoint values to account for errors caused by bypass voiding is acceptable.

6. The staff should develop the capability and perform a thorough review and assessment of the risk of pellet-cladding interaction (PCI) fuel failures with conventional fuel cladding, during anticipated operational occurrences (AOOs).

7. Review Standard (RS)-001, “Review Standard for Extended Power Uprates,” provides a structured process for the review of EPU applications. The guidance document should be improved to include cross-referencing of related sections between the power uprate safety analysis report (PUSAR) and the staff’s SEs.

DISCUSSION

SSES Units 1 and 2 are boiling-water reactor (BWR)/4 design, with Mark II containment. PPL has applied for an EPU of approximately 20 percent above the original licensed thermal power (OLTP) level of 3293 MWt to 3952 MWt. The current licensed thermal power (CLTP) level of 3489 MWt is approximately 6 percent higher than the originally licensed thermal power. While the SSES application is similar to other uprates that have been approved, such as Quad Cities Units 1 and 2, Brunswick Units 1 and 2, and Vermont Yankee, the uprate is the first to use AREVA ATRIUM-10 non-barrier fuel and for which AREVA methods are used for analyses of fuel and system behavior.

BWR fuel designs have evolved to 10x10 rod arrays, which provide larger heat transfer areas that can result in acceptable minimum critical power ratios (MCPRs) for both normal operating conditions and anticipated transients at EPU conditions. Such fuel designs also help lead to acceptable calculated peak clad temperatures during loss-of-coolant accidents. To minimize increases in the peak heat fluxes relative to current design levels, the fuel loading for EPUs is adjusted to radially flatten the core power distribution. All this leads to peak heat fluxes for EPUs that are within the range of experience, although the average void fractions at the core exit are higher than those covered by current operating experience. Because the increased uncertainties associated with these higher void fractions result in increased uncertainties in the associated reactor physics calculations, as well as in the pressure drop and void fraction predictions, the staff has required increases in the power distribution uncertainties that are to be applied to the safety limit minimum critical power ratio (SLMCPR) to provide additional margin in the MCPR safety limit. The added margin that is required may be changed as more gamma scan data on ATRIUM-10 fuel under appropriate operating conditions are obtained and compared with the predictive capabilities of the reactor physics codes. We concur with the staff’s assessment that the increase in the power distribution uncertainties applied to the cycle-specific SLMCPR is an appropriate interim measure.

The EPU will also lead to higher core average void fractions than at OLTP conditions. The uncertainties in the prediction of the higher void fractions appear to be ±0.05, and there are no void fraction data above 90 percent. To account for these uncertainties, the licensee performed calculations in which the proposed void fraction correlation was replaced with another correlation, which had a bias of 0.02 in void fraction in the range of interest. The calculations were intended to investigate the effect of changes in the void fraction correlation on the reactor power and on the thermal limits. The results of the analysis showed that the SLMCPR and the OLMCPR impact balance each other such that the net effect on the OLMCPR is small. However, further calculations are needed to validate these preliminary findings. The effect of the ±0.05 uncertainty should be addressed by performing calculations with the same void fraction correlation in which the key correlation parameters are varied to span the void fraction uncertainty ranges and the effects on the OLMCPR and then assessed.

An appropriate margin should be added to the OLMCPR as an interim measure to account for uncertainties in the void fraction correlation and the lack of data for its validation at void fraction above 90 percent. When the licensee submits more detailed analyses that account for the effect of uncertainties in the void fraction on the OLMCPR, the interim measure should be reviewed.

At the high-power/low-flow conditions that are susceptible to instabilities, the presence of bypass voiding in the upper regions of the core leads to errors in the local power range monitor (LPRM) signals. SSES is an Option III plant, which relies on OPRMs to initiate scram. The LPRM signals feed into the OPRMs, and therefore the errors in the LPRM signals will also affect the OPRMs. We concur with the staff that errors in the LPRM signals caused by bypass voiding must be accounted for in the determination of the OPRM setpoint. The methodology proposed for determining OPRM setpoint values is acceptable.

PPL does not plan to undertake large transient tests, such as main steam isolation valve (MSIV) closure and generator load reject with bypass that would result in a reactor trip. Such tests would not directly address confirmation of the performance of systems claimed to support the proposed EPU. We concur with the staff's assessment that these large transient tests should not be required.

A potential EPU impact is a reduction in available operator action response times. Minor changes have been made in the emergency operating procedures to accommodate EPU modifications. We concur with the staff that the time available for critical operator actions is adequate.

EPU conditions require higher steam and feedwater flow rates that may lead to increases in flow-accelerated corrosion. Experience indicates that flow-accelerated corrosion rates at SSES are acceptably low. PPL has recently adopted the EPRI CHECWORKS program and plans to perform periodic inspections that should provide reasonable assurance that unacceptably high corrosion rates would be detected before the corroded components reach unsafe conditions.

The proposed EPU will also increase flow rates in certain components that could vibrate and lead to failure. Prior experience suggests that the steam dryer is the most likely component to be affected by such phenomena. Cracks have been detected in SSES steam dryers, and the licensee has elected to replace them with sturdier dryers. The Unit 1 and Unit 2 steam lines have been instrumented with external strain gauges to measure the pressure fluctuations in the steam lines. In addition, the new dryer for Unit 1 will be instrumented with strain gauges to determine stress levels in critical areas for comparison with calculated results. The strain gages on the dryer will be damaged during the refueling outage before the second EPU phase is implemented and thus will not be functional during actual full power operation and will permit monitoring only up to 107 percent uprate operation.

The applicant has developed a program for power ascension involving holds at a number of power levels and monitoring of steam line strain gauges, as well as steam dryer strain gauges, where possible. Direct measurements will be made of dryer stress/strain levels in Unit 1 at flow rates characteristic of 107 percent of CLTP with all four MSIVs open and up to 114 percent of CLTP (the EPU level) with three MSIVs open. Unexpected behavior would lead to power limitations until resolution. PPL has also committed to inspections of the steam dryers in the next two outages following the uprates for each of the units. We concur with the staff that the proposed program of monitoring power ascension and the proposed inspections provide reasonable assurance that unacceptable stresses induced in the steam dryer will be identified during the power ascension before component failure.

We concur with the staff that the acceptance criteria for the design-basis loss-of-coolant accidents will be met after the proposed EPU. However, operation in the EPU domain will lead to conditions where core average exit void fractions are larger than those under CLTP conditions. These conditions may impact events such as an anticipated transient without scram (ATWS) and an ATWS with instability. We concur with the staff that the effects of the EPU would be bounded by the current uncertainty bounds associated with such events. These uncertainties, associated with difficulties in modeling such events and the paucity of data available to validate calculational methods, are tempered by the low frequency and the resulting low risk significance of these events. Should the EPU operation at SSES be extended to include the maximum extended load line limit analysis plus (MELLLA+) domain, conditions may arise during ATWSs that are more difficult to manage. We would like the opportunity to review methods and analyses for ATWS instability under such circumstances.

AREVA presented the results of thermal mechanical analyses addressing the performance of ATRIUM-10 fuel during operation at current and EPU conditions. The analyses addressed the standard regulatory limits, which are intended to ensure fuel integrity during steady-state operation and during AOOs. The PPL application is unique because the SSES units will be the first plants to operate full cores of fuel with non-barrier cladding at EPU conditions. During normal operation, the non-barrier fuel cladding is protected from PCI failure by the use of the power and power-ramp-rate operating restrictions developed by AREVA. Although non-barrier cladding has less built-in PCI resistance, these operating restrictions appear to be effective in preventing PCI fuel failures in the SSES units as evidenced by a good fuel performance history. In addition to the challenges of normal operation, there are upset sequences that can lead to fuel failure by the PCI mechanism. The applicant presented analyses to demonstrate that the peak clad stresses at EPU conditions under such conditions will be comparable to those calculated for the current operating conditions, although more of the cladding will be subjected to higher stresses.

The staff has applied RS-001 in the review of the SSES EPU. RS-001 provides a structured approach to the review. The RS-001 guidelines should continue to be improved, with cross-referencing between sections of the PUSAR and the staff’s SEs.

We would like to have the opportunity to review the applicability of the AREVA methodology to MELLLA+ conditions before it is applied to any MELLLA+ application based on the AREVA fuel and core design.

Additional Comments by ACRS members Dr. Sam Armijo, Dr. Sanjoy Banerjee, and Dr. Dana Powers are provided.

Sincerely,

/RA/

William J. Shack
Chairman

Additional comments by ACRS Members Dr. Sam Armijo, Dr. Sanjoy Banerjee, and Dr. Dana Powers

We agree with our colleagues that the PPL application for extended power uprate (EPU) of the Susquehanna units should be approved. However, we are concerned that the licensee's plan to operate the units with conventional (non-PCI-resistant) fuel has increased the risk of pellet-cladding-interaction (PCI) fuel failures during Anticipated Operational Occurrences (AOOs) at EPU conditions. This risk has not been assessed quantitatively by the licensee and the staff and is unnecessary since proven PCI-resistant fuel designs are available. Since conventional fuel has no built-in PCI resistance, prompt operator actions or automatic scrams will be the only defense against fuel failures during AOOs. The staff should develop qualified analytical tools to demonstrate that operator actions will assure an acceptably low number of failures. If this can be demonstrated by analysis, then the required operator actions should be incorporated into the regulatory process through commitments or inclusion in the updated FSAR.

The PPL application is unique because the Susquehanna units will be the first BWRs to operate at 20 percent above their originally licensed power levels with full cores of conventional fuel. Due to its susceptibility to PCI failure, conventional fuel must be protected during normal operation by the use of detailed power and power-ramp-rate operating restrictions. These operating restrictions, however, cannot protect the fuel during AOOs. During a Loss of Feed Water Heater (LOFWH) event, the Susquehanna core power can increase to 118 percent of the EPU power within 10 minutes. The core power can be reduced by operator action early in the transient or by an automatic scram when the core power exceeds the Average Power Range Monitor (APRM) flux scram setpoint. The Protection-Against-Power-Transients (PAPT) linear-heat-generation-rate (LHGR) limit is intended to protect fuel from failure during AOOs by limiting cladding strains to less than 1 percent. However, PCI is an aggressive stress corrosion mechanism that is capable of failing conventional BWR fuel cladding at strains far lower than 1 percent. For the Susquehanna Units, the maximum PAPT LHGR limit [ ][1] will be well above the PCI failure threshold [ ][2] reported by AREVA for ATRIUM-10 fuel.

During the December 7, 2007 Committee meeting, the licensee reported that Susquehanna plant procedures require immediate operator action in the event of a LOFWH transient, and that their operators are trained to recognize and respond to this event. They cited a LFWH event that occurred in Susquehanna Unit 2 in 2007. During the event operators reduced power in less than three minutes. These actions were effective since no fuel failures occurred. This plant experience is not conclusive for EPU conditions because the core power density will be 20% higher and fuel rod power transients will be more severe. The effectiveness of operator actions

1 Deleted AREVA proprietary information
2 Deleted AREVA proprietary information

in preventing PCI fuel failures during AOOs at EPU conditions will be dependant on fuel design, burnup, and the magnitude, rate and duration of power increases. This effectiveness cannot be assessed qualitatively. PCI is a stress corrosion phenomenon and time is required to nucleate and grow through-wall cracks. This time window is not well known but is in the range of minutes to hours depending on the severity of the transient.

During our reviews, AREVA reported that they are developing the XEDOR model to assess the risk of PCI failures during AOOs. Although the model has not been completed, AREVA concluded that cladding stresses and PCI risk at EPU conditions would be comparable to current cycles. These analyses are not adequate, because the XEDOR model is in development and has not been documented and submitted to the staff for review and approval. The staff reported that they were unable to address PCI risk without a robust methodology capable of differentiating PCI resistance for various fuel rod designs. Further, the staff indicated that PCI risk during AOOs was not a matter of regulatory concern. We believe this is an extraordinarily narrow interpretation of current regulations.

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