Robert Braun
Site Vice President-Salem

PSEG Nuclear LLC
Salem Nuclear Generating Station
P.O. Box 236, M/C S-05, Hancocks Bridge, NJ 08038
tel: 856.339.1998 fax: 856.339.2956
email: Robert.Braun@pseg.com

PSEG Nuclear L.L.C.

JUL 23 2008

10 CFR 50.90

LR-N08-0149

United States Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

SALEM GENERATING STATION – UNIT 1 and UNIT 2
FACILITY OPERATING LICENSE NOS. DPR 70 and DPR-75
NRC DOCKET NOS. 50-272 and 50-311

Subject: **RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION - REQUEST FOR CHANGES TO TECHNICAL SPECIFICATIONS REFUELING OPERATIONS – DECAY TIME LICENSE AMENDMENT REQUEST (LAR) S08-01**

References: (1) Letter from PSEG to NRC: "Request for Changes to Technical Specifications, Refueling Operations - Decay Time, LAR S08-01, Salem Nuclear Generating Station, Unit 2, Facility Operating License DPR-75, Docket No. 50-311", dated March 11, 2008

(2) Letter from PSEG to NRC: "Supplement (Reduced Scope) - Request for Changes to Technical Specifications, Refueling Operations - Decay Time, LAR S08-01, Salem Nuclear Generating Station, Unit 2, Facility Operating License DPR-75, Docket No. 50-311", dated June 17, 2008

In Reference 1, PSEG Nuclear LLC (PSEG) submitted License Amendment Request (LAR) S08-01, proposing revisions to the requirements for fuel decay time prior to commencing movement of irradiated fuel. TS 3/4.9.3 "Decay Time" would be (1) revised to allow fuel movement to commence at 80 hours after the reactor is subcritical between October 15th and May 15th, and (2) relocated to the Salem UFSAR, or Technical Requirements Manual (TRM). Currently, TS 3/4.9.3 requires a fuel decay time of 100 hours prior to fuel movement between October 15th and May 15th.

In Reference 2, PSEG submitted a supplement that reduced the scope of LAR S08-01 by withdrawing the request to relocate the TS to the UFSAR or TRM (Item 2 above).

A001
NRR

JUL 23 2008

The NRC provided PSEG a Request for Additional Information (RAI) on LAR S08-01. On July 3rd, 2008, PSEG and the NRC discussed the RAI to provide additional clarification. The response to the RAI is provided as an attachment to this submittal.

PSEG had requested approval of the proposed License Amendment by September 30, 2008 to be implemented within 30 days, to support Salem Unit 1 refueling outage 1R19. Since the proposed change would not be applicable until October 15th, approval by October 14th, 2008 would still support outage 1R19.

If you have any questions or require additional information, please do not hesitate to contact Mr. Jeff Keenan at (856) 339-5429.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on 7/23/08
(Date)

Sincerely,

Robert C. Braun
Site Vice President
Salem Generating Station

Attachments: 3

C Mr. S. Collins, Administrator – Region I
U. S. Nuclear Regulatory Commission
475 Allendale Road
King of Prussia, PA 19406

Mr. R. Ennis, Project Manager - Salem Unit 1 and Unit 2
U. S. Nuclear Regulatory Commission
Mail Stop 08B1
Washington, DC 20555-0001

USNRC Senior Resident Inspector – Salem Unit 1 and Unit 2

Mr. P. Mulligan
Bureau of Nuclear Engineering
PO Box 415
Trenton, New Jersey 08625

REQUEST FOR ADDITIONAL INFORMATION

REGARDING PROPOSED LICENSE AMENDMENT

DECAY TIME TECHNICAL SPECIFICATION REQUIREMENTS

SALEM NUCLEAR GENERATING STATION, UNIT NOS. 1 AND 2

DOCKET NOS. 50-272 AND 50-311

By letter dated March 11, 2008 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML080930080), as supplemented by letter dated June 17, 2008, PSEG Nuclear LLC (PSEG or the licensee) submitted an amendment request for Salem Nuclear Generating Station (Salem), Unit Nos. 1 and 2. The proposed amendment would revise the requirements for fuel decay time prior to commencing movement of irradiated fuel in the reactor pressure vessel (RPV). Currently, Technical Specification (TS) 3/4.9.3, "Decay Time," requires that: (a) the reactor has been subcritical for at least 100 hours[1] prior to movement of irradiated fuel in the RPV between October 15th through May 15th; and (b) the reactor has been subcritical for at least 168 hours prior to movement of irradiated fuel in the RPV between May 16th and October 14th. The calendar approach is based on average river water temperature which is cooler in the fall through spring months. The proposed amendment would allow fuel movement to commence at 80 hours after the reactor is subcritical between October 15th through May 15th.

The Nuclear Regulatory Commission (NRC or the Commission) staff has reviewed the information the licensee provided that supports the proposed amendment and would like to discuss the following issues to clarify the submittal.

1. The NRC staff estimates that the proposed reduction in decay time increases the spent fuel pool (SFP) decay heat level by 10 percent. Past communication on related amendment requests has indicated the NRC staff's concern with the quality of the modeling used to predict SFP temperature response, the reliability of the fuel building ventilation system at high SFP temperatures, and the reliability of the operators completing repeated transfers of a single cooling train between SFPs following the design-basis loss of a single heat exchanger. The staff has accepted some of the related amendment requests based, in part, on the margin provided by lower decay heat or increased cooling capability

[1] The current TS decay time requirement of 100 hours is applicable through the year 2010. After 2010, the 168 hour decay time requirement would be applicable for refueling outages occurring between October 15th and May15th. On March 5, 2008, the NRC approved a one-time change for Salem Unit No.2 (Amendment No. 271) which revised TS 3/4.9.3 to allow fuel movement to commence at 86 hours after the reactor is subcritical for refueling outage 2R16 (spring 2008 outage).

overcoming the uncertainties associated with these issues. The staff concludes that the proposed amendment would eliminate much of the margin and increase the probability of the SFP water temperature approaching the design basis limit of 180 °F. Accordingly, please provide the following information:

a) Data validating the CROSSTIE model for evaporative cooling during SFP temperature excursions exceeding 150 °F and approaching 180 °F, such as by benchmarking model predictions to test pools at similar temperatures.

b) Data demonstrating by test or detailed analysis that the ventilation system will maintain performance consistent with that assumed in the CROSSTIE model at SFP temperatures approaching 180 °F.

Alternatively, propose a modification to the SFP cooling system to enhance the reliability of the system in providing forced cooling to two SFPs simultaneously.

<u>Response</u>

Sufficient margin in SFP cooling will remain with the proposed changes as discussed below:

There is inherent margin in the CROSSTIE model due to the following conservatisms:

1. Decay heat load is based on Branch Technical Position ASB 9-2, which is a conservative methodology for determining decay heat.
2. Fuel Handling Building (FHB) temperature and humidity assumed to be at design conditions (105°F; 100%). Actual temperature and humidity during refueling months will be lower.
3. Technical Specification minimum water level for the SFP is assumed. Normal water level is maintained between 9.75 and 27.75 inches above the minimum requirement.

There is also inherent margin in the calculation methodology due to the following conservatisms:

1. The assumed difference between Component Cooling (CC) and Service Water (SW) temperature of 9°F is based on a bounding Spent Fuel (SF) decay heat load and design thermal fouling of the Component Cooling Heat Exchangers (CCHXs). The bounding SF decay heat load is based on the core split into three batches with effective full power operation for one, two and three operating cycles, respectively. For the Integrated Decay Heat Management (IDHM) calculation, actual fuel burnups are assumed. The bounding SF decay heat load is also based on a higher assumed reactor power than the IDHM calculation (< 1%). Actual heat load is estimated to be 5% - 10% less. Actual thermal fouling of the

CCHXs is much less than design based on GL 89-13 thermal performance testing. Thus the actual temperature difference will be less.

2. Cross-connect operation is assumed to start immediately after core offload is complete, when the SF decay heat load is at its maximum.
3. SFP temperature at which swapover between SFPs starts during cross-connect manipulations is based on the SFP heatup to 180°F in a one-hour period. Actual time to complete swapover is less than one hour. This was demonstrated by a planned operational evolution in January 2008. During this evolution, the cross-connect was utilized to support planned maintenance on the SFP heat exchangers. The swapover was completed in less than one hour; this was accomplished without the additional support, pre-staging, and urgency that would be present during refueling conditions. The use of cross-connect is for planned operation evolutions, and is considered non credible in outage situations as discussed later in this response.

Section 4.1.3 of the LAR discusses the original benchmarking of the CROSSTIE model performed by Holtec, as well as subsequent validation based on field data from recent outages. The following results are noted:

1. Chart 1 shows that during and after core offload, the SFP temperature predicted by CROSSTIE is conservative compared to measured data by about 3°F on average.
2. From Attachment 4 of LAR S07-06, which provides the basis for the charts in Section 4.1.3, the difference between the measured SW and CC temperatures that correspond to the Chart 1 SFP temperature profile was about 6-7°F. Thus the assumed 9°F temperature difference in the calculation is conservative by 2-3°F. Since SFP temperature is approximately linear with respect to CC temperature, this yields an additional 2-3°F margin in SFP temperature.

For normal cooling with both SFHXs available, Attachment 4 of the LAR shows that the maximum CC temperature during 1R19 corresponding to a peak SFP temperature of 149°F is 86°F. This corresponds to a maximum SW temperature of 77°F based on the conservative 9°F temperature difference stated above. The historical maximum SW temperature for mid-October is 70°F. This corresponds to a CC temperature of 79°F, and a corresponding peak SFP temperature of 142°F, or a 7°F margin. From Appendix A of Attachment 4, the peak SFP temperature for the worst case SFP heat load (SFP at full capacity) is less than 1°F higher than for 1R19, resulting in a margin of greater than 6°F below the temperature limit of 149°F. Combining this with the above validation data from Section 4.1.3 and Attachment 4 of LAR S07-06, there is at least 10°F margin available in SFP temperature compared to the temperature limit of 149°F.

For cross-connect operation with only one SFHX available, the above effects result in margin in terms of the time between swapovers between the two SFPs.

Namely, the above effects will result in the SFP that is being cooled to cool down to a lower temperature prior to swapping cooling back to the other SFP. This results in an increased time for the SFP to reach the swapover temperature limit once cooling is removed, and thus an increased time between swapovers. From Attachment 4 of the LAR, the difference in time for swapover from the non-outage pool (Unit 2) to the outage pool (Unit 1) for a difference of 10°F CC temperature, which represents the effect of a 10°F margin in CC temperature, is 1.2 hours for a swapover temperature limit of 170°F. In other words, the time for the Unit 1 SFP to heat up to 170°F once cooling is removed will be 1.2 hours longer for a CC temperature 10°F less.

1(a) - Data validating the CROSSTIE model for evaporative cooling during SFP temperature excursions exceeding 150°F and approaching 180°F:

Attachment 2 [MPR Report 0108-0810-0362-1] documents a literature search for correlations and data on evaporative cooling. The report references EPRI Report CS-511, which provides test data on evaporative cooling that covers temperatures up to 180°F. The Ryan-Harleman correlation referenced in the MPR report closely fits this test data. The CROSSTIE model over predicts evaporative cooling at temperatures 150°F and above compared to the EPRI data. Based on this, CROSSTIE under predicts the SFP heatup rate at these temperatures. The impact on cross-connect operation predicted by CROSSTIE is that the uncooled SFP will reach the swapover temperature limit sooner than predicted, and the time between swapovers will be less. However, this impact is not significant as discussed below.

A sensitivity study was performed to assess the impact of CROSSTIE over predicting evaporative cooling at high SFP temperatures. The 1R19 cross-connect case with 80°F CC temperature was selected (see Attachment 4 of LAR S08-01). The 80°F CC corresponds to a SW temperature of 71°F - as stated previously, the historical maximum value for mid-October is 70°F. For conservatism, evaporative cooling was effectively removed from the CROSSTIE model by setting the ambient temperature to 180°F. The resultant heatup rate increased from 9.1°F/hr to 9.8°F/hr, which supports the conservative assumption in the calculation of a one-hour swapover time, and a swapover temperature limit of 170°F. After the initial swapover from the Unit 1 SFP to the Unit 2 SFP, the time between swapover from the Unit 2 SFP to the Unit 1 SFP decreased from 3.8 hours to 3.3 hours, which is still satisfactory. These are conservative bounding values since no credit is taken for evaporative cooling. Therefore, although CROSSTIE over predicts evaporative cooling, there is no impact on the ability to maintain the SFPs $\leq$ 180°F during cross-connect manipulations.

Calculation S-C-SF-MDC-1810 will be revised to reduce the evaporative cooling loss during cross-connect manipulations. Since evaporative cooling predicted by CROSSTIE at SFP temperatures ≤ 150°F agrees with the test data, normal cooling with both SFHX's available is not impacted. This issue has been entered in the PSEG corrective action program.

1(b) - Data demonstrating by test or detailed analysis that the ventilation system will maintain performance:

Attachment 8 of Calculations S-1-FHV-MDC-0705 and S-2-FHV-MDC-0706 (Attachment 3 - only Unit 1 calculation attached; Unit 2 calculation is typical) demonstrates that the Fuel Handling Building (FHB) Ventilation System is capable of maintaining the FHB ambient temperature within design limits, and within the assumptions of Calculation S-C-SF-MDC-1810, with a SFP temperature of 180°F. This is based on outside air conditions that bound the peak values between October and May, when outages are typically performed. This calculation is conservative as it is based on the maximum historical hourly average outside air temperature from October through May.

Concerning the statement about modification to the SFP cooling system to enhance the reliability of the system in providing forced cooling to two SFPs simultaneously; PSEG does not currently plan any modifications. Under all normal operating scenarios forced cooling is provided to the two SFPs simultaneously. UFSAR Section 9.1.3.2, states that the cross connect "allows one heat exchanger to be used to alternatively cool the spent fuel pools in both units during times when one heat exchanger is out for maintenance". Removal of a SFP heat exchanger from service would be a planned maintenance evolution that would never be scheduled during an outage. There has never been an operational occurrence at Salem that resulted in a SFP heat exchanger being unavailable following a core off-load. The SFP heat exchanger is a passive component; there is no single active failure that would result in the loss of a heat exchanger. Operating history and experience have demonstrated that the current design is sufficiently reliable that the abnormal operating scenario of a SFP heat exchanger becoming unavailable during refueling operations is considered non-credible. However, as a conservative, abnormal operation planning scenario, the IDHM Program does evaluate the time available to swap cooling between the SFPs prior to the un-cooled SFP reaching the design limit of 180°F with only one heat exchanger available.

2. The license amendment request states that the integrated decay heat management (IDHM) program would be used to calculate a maximum allowable component cooling water (CCW) temperature for each outage, which is required to be procedurally verified prior to the start of core offload. The amendment request includes the statement that analysis and controls in place will ensure the capability of the SFP cooling system to (1) maintain both Salem pools below 149 °F with two SFP heat exchangers available and (2) maintain both pools below 180 °F with only one heat exchanger available. However, Calculation S-C-SF-

MDC-1810, Revision 8, "Decay Heat-up Rates and Curves," provides information related to the required time to switch cooling between SFPs that is not bounding. This calculation considers conditions based on expected SFP inventories for future spring and fall outages beginning on April 15 and October 15, respectively. Actual refueling outages could allow much less than six months decay for the most recent refueling batch, which would increase the heat load in the non-outage SFP relative to the heat load used in the calculation.

Explain the criteria that apply to the IDHM program evaluation when determining that both SFPs could be maintained below 180 °F with only one heat exchanger available and the basis for the criteria.

Response

Sections 4.1.1.and 4.1.4 of Attachment 1 of LAR S08-01[2], along with Attachment 4, provide a discussion of the criteria and criteria basis that apply to the IDHM Program evaluation with only one heat exchanger available (i.e., cross-connect operation). A further expansion of the criteria discussion is provided below.

Cross-connect Operation is a postulated scenario where the SFPs for each unit are swapped between a single spent fuel pool heat exchanger (SFHX), with the other Unit's SFHX unavailable. Both SFHX's are required to be available and aligned to their associated SFP prior to the start of core offload. Subsequent post-core off-load loss (unavailability) of a heat exchanger is not considered credible. The heat exchanger is a passive piece of equipment; there is no single active failure that would result in the loss of a heat exchanger. But, as a conservative, abnormal operation planning scenario, the IDHM Program does evaluate the time available to swap cooling between the SFPs prior to the un-cooled SFP reaching the design limit of 180°F, assuming that a SFHX becomes unavailable post core off-load. For this case it is conservatively assumed that cross-connect operation begins right after core offload is complete, with maximum decay heat load in the SFP.

The following is an outline of the cross-connect process:

a. The outage (e.g., Unit 1) SFP is initially aligned to the available SFHX. If the Unit 1 SFHX is unavailable, the Unit 1 SFP would be cross-connected to the Unit 2 SFHX.
b. When the non-outage (e.g., Unit 2) SFP reaches the swapover temperature limit, cooling is swapped to the Unit 2 SFP (initial swapover) via cross-connect valve manipulations.

2 Letter from PSEG to NRC: "Request for Changes to Technical Specifications, Refueling Operations – Decay Time, LAR S08-01, Salem Nuclear Generating Station, Unit 2, Facility Operating License DPR-75, Docket No. 50-311", dated March 11, 2008

c. Swapping of cooling between the two SFPs via cross-connect valve manipulations continues as needed until the unavailable SFHX is returned to service.

The IDHM Program calculation provides not only the normal cooling temperature profile for the SFP; it also provides the heat-up rates of the SFP if cooling becomes temporarily unavailable (and thus requiring the need for cross-connecting). The projected maximum heat-up rate is used to establish the time available prior to the SFP exceeding 180°F in the pool with the recently offloaded core, and consequently the swap-over temperature limit of the pool. The heat-up rate for the non-off-load SFP is also provided by the IDHM Program, providing the time available before the heat exchanger must be re-connected to the other pool. Consequently, Operations has the expected pool heat-up rates prior to fuel off-load, to support potential abnormal operations (See Abnormal Operation discussion below). The cross-connect re-alignment of the SFP cooling system requires less than one hour to complete; this has been validated by system walkdown, and planned operation evolution. Based on this conservative one-hour cross-connect re-alignment time, the SFP heat-up rates also determine the swap-over temperature limit the pool can attain before cross-connect must commence; i.e., the swap-over temperature limit accounts for the maximum one hour realignment time. (see Cross-Connect Evaluation Example for Outage 1R19 below).

Example of Cross-Connect Evaluation Scenario for Outage 1R19

An initial run was performed for cross-connect operation at 180°F. With the Unit 1 SFP aligned to the Unit 2 SFHX, the isolated Unit 2 peak SFP temperature is shown to reach the licensing basis limit of 180°F with one SFHX isolated, and thus swapping of SFPs between the available SFHX is required. A second run was performed for cross-connect operation at 170°F. This swapover temperature limit is based on a Unit 1 SFP heatup rate of 9.1°F/hour without cooling and a one-hour duration to complete cross-connect manipulations to ensure the uncooled SFP does not reach 180°F prior to cooling being restored[3]. The 170°F temperature provides the extra margin allowing for cross-connect operations.

The worst-case scenario would be the unavailability of one SFHX just upon completing a full core offload. (If the SFHX becomes unavailable on the outage unit then the SFP on the outage unit would be immediately (within one hour) cross-connected with the SFHX on the non-outage unit). After the initial swap of cooling back to the non-outage (Unit 2) SFP (47 hours), operators would have a minimum of 3.1 hours at the maximum allowable component cooling (CC) supply temperature of 86°F (service water temperature of 77°F) before cross-connect

[3] As a further example, if the heat-up rate was determined to be 11.5°F/hour in a future outage, then the swap-over temperature limit would be reduced to 168°F to ensure the uncooled SFP does not reach 180°F prior to cooling being restored.

valve manipulations would be required to swap cooling back to the recently offloaded SFP, and 32.2 hours at a CC supply temperature of 86°F to swap cooling back again to the non-outage SFP. Additional cross-connect manipulations (if required) are bounded by these initial times. Due to the low heatup rate for the non-outage Unit 2 SFP, the number of cross-connect operations required is anticipated to be low. Cross-connect manipulations at the expected lower (historical) CC temperatures are also bounded by these times.

The results demonstrate a decay time of 80 hours is acceptable. A maximum CC temperature of 86°F is required to be procedurally verified prior to the start of core offload. The corresponding SW temperature is 77°F. Note that the historical maximum SW temperature for mid-October is 70°F, corresponding to a CC temperature of 79°F. This provides additional margin. This conclusion is based on the capability of the SFP cooling system to (1) maintain both Salem pools below 149°F with two SFHX available and (2) maintain both pools below 180°F with only one heat exchanger available. This capability meets the requirements of UFSAR Chapter 9.1.3.1. Analysis provided in LAR S08-01 Section 4.1.1 demonstrates that the 80 hour decay time is also acceptable for future outages with the SFP at full capacity.

Abnormal Operation – One Available Heat Exchange Scenario

PSEG abnormal operating procedure for loss of spent fuel cooling, S1(2).OP-AB.SF-0001, has also been enhanced to provide more rigor and to provide a streamlined process for cross-connect operations, in the unlikely event a SFP heat exchanger becomes unavailable post core off-load. The procedure provides for promptly initiating cross-connect operations with the other unit's SFHX, if required, and ensure the temperature of both SFPs is monitored, and the available SFHX is alternated between both units as required to maintain both SFPs below 180°F.

- If unavailability of the outage unit's SFHX occurs post core off load, S1(2).OP-AB.SF-0001 will promptly initiate SFP cooling cross-connect operations and temperature trending for both SFPs. If required, the procedure will then direct the system alignments needed to alternately cool both SFPs.

- Appropriate cautions and notes have been incorporated to account for the time required to perform cross-connect and/or restoration operations in conjunction with the monitored heat-up rates. This will ensure actions will be initiated early enough that neither SFP will exceed 180°F.

- Various enhancements have been incorporated throughout to expedite the overall response strategy during a loss of Spent Fuel Pool Cooling. Due to time constraints associated with cross-connecting cooling, the steps to perform the necessary system alignment are included in the abnormal operating procedure rather than reference a separate procedure.

- In the event the available SFHX must be alternated between SFPs the abnormal operating procedure also contains the necessary steps to align the system to alternately cool one SFP and then the other. The time between the alternating cycles and the swapover temperature limit is based on actual SFP heat up rates that are monitored during the evolution.

- The procedure directs the operators to reference the calculations performed as part of the IDHM program, which are provided to the operators prior to the outage. These calculations will provide the operators with expected heat up rates and swapover temperature limit for both the outage and non-outage SFPs.

3. Define the key methods and assumptions of the IDHM program in making the determination that the SFP cooling system would have the capability to (1) maintain both Salem pools below 149 °F with two SFP heat exchangers available and (2) maintain both pools below 180 °F with only one heat exchanger available. At a minimum, the method of determining decay heat for a given fuel inventory, the method of calculating SFP heat exchanger performance, and the method of calculating heat losses to the environment (i.e., pool structure and fuel building atmosphere) should be defined.

Response

The key methods and assumptions of the IDHM Program were previously docketed by PSEG letter dated October 2, 2002 (ADAMS ML022880098), as part of the Holtec Verification and Validation (V&V) documentation (Appendix 2 of Critical Software Document for the CROSSTIE Program; S-C-SF-MCS-0113).

The CROSSTIE Program consists of the following key methods and assumptions:

(1) The method of determining decay heat for a given fuel inventory is provided in the Holtec V&V Report Section 2.2. The decay heat load is based on the methodology provided in Branch Technical Position ASB 9-2. The decay heat is a function of the power level, time at power and the time after shutdown. It is calculated separately for the existing (pre-offload) SFP inventory and the offloaded core. For both groups, the actual burnup values for the fuel assemblies (MWD/MTU – MW-days / metric ton uranium), assembly mass and the power level are inputted. The time at power is determined based on these inputs. For the existing SFP inventory, the decay heat load for an individual assembly is a fixed value based on a fixed time after shutdown (difference between the shutdown date for the outage being evaluated and the shutdown date for the outage in which that assembly was permanently removed from the core).

For the offloaded core, the decay heat load added to the SFP is a function of time. It is calculated for each incremental time step based on the time after shutdown and the number of assemblies offloaded to the SFP. The number of assemblies offloaded at a given point in time is based on time after shutdown to start core offload (80 hours) and the time to complete core offload. The time to complete core offload comes from the projected outage schedule. The core is split into batches in the model with different burnups. The batches are offloaded in sequence from the highest burnup to the lowest, maximizing the decay heat load in the SFP at a given point in time.

(2) The method of calculating SFP heat exchanger performance is provided in the Holtec V&V Report Section 2.1. The heat exchanger is modeled as a tube and shell heat exchanger. The model calculates the effectiveness for a given case based on the input flow rates and heat exchanger geometry. The effectiveness is assumed constant for the entire transient. The heat exchanger heat load is then calculated based on the effectiveness, coolant flow rate and specific heat, and the difference between the SF and CC inlet temperatures.

(3) The method of calculating heat losses to the environment is provided in the Holtec V&V Report Section 2.3, and discussed in Section 4.1.5 of the LAR. The program calculates evaporation, convection and radiation losses. Evaporation is the primary heat loss mechanism. Evaporative losses are based on mass transfer principles as discussed in Section 4.1.5. The mass transfer coefficient ($h_D(\Delta T)$) discussed in Section 4.1.5 is a function of the temperature difference between the pool and ambient air, and is based on the methodology provided in: Threlkeld, J. L., "Thermal Environmental Engineering", Prentice Hall, 1970. The convective heat transfer coefficient discussed in Section 4.1.5 is a function of the temperature difference between the pool and ambient air, and is based on the methodology provided in: Jakob, M. and Hawkins, G. A., "Elements of Heat Transfer", John Wiley and Sons, 1957. These components are added, and then multiplied by a correction factor determined during the initial benchmarking of the model. The correction factor accounts for conduction through the pool walls, which is not explicitly modeled, and other uncertainties, such that the modeled results matched the test data. Section 4.1.3 of the LAR discusses this initial benchmarking, as well as validation from recent outages. This methodology was additionally reviewed as discussed in the response to question 1(a) above.

(4) The SFP temperature as a function of time is assumed to be a homogeneous mixture, based on the thermal capacity of the pool (BTU/°F), decay heat in, SFHX heat removal and heat loss to the environment.

MPR Report 0108-0810-0362-1

MPR ASSOCIATES INC.
ENGINEERS

July 21, 2008
0108-0810-0362-1, Revision 0

Kevin King
PSEG Nuclear, LLC
P.O. Box 236
Hancocks Bridge, NJ 08038

Subject: Salem Spent Fuel Pool Cooling RAI Responses

Dear Mr. King:

The enclosure to this letter is our report on the NRC request for additional information (RAI) regarding the license amendment request for reducing the minimum decay time before fuel from a Salem unit is moved into its spent fuel pool (SFP) during a refueling outage. The enclosure focuses exclusively on Questions 1.a and 1.b, which relate to evaporative cooling when the pool is at elevated temperatures.

If you have any questions on the enclosed report, please do not hesitate to contact us.

Sincerely,

J. L. Hibbard

J. L. Hibbard

Enclosure

cc: A. Johnson, PSEG Nuclear

320 KING STREET ALEXANDRIA, VA 22314-3230 703-519-0200 FAX: 703-519-0224 http://www.mpr.com

MPR ASSOCIATES INC. ENGINEERS

Enclosure to
MPR Letter Dated July 24, 2008
0108-0810-0362-1, Revision 0

Salem Decay Time Technical Specification Requirement License Amendment: Assessment of RAI Questions 1.a and 1.b

QUALITY ASSURANCE DOCUMENT
This document has been prepared, reviewed and approved in accordance with the Quality Assurance requirements of 10CFR50, Appendix B, as specified in the MPR Quality Assurance Manual.

Prepared by: James L. Hibbard

Reviewed by: H. William McCurdy, PhD

Approved by: FOR John W. Simons

Prepared for

PSEG Nuclear LLC
P.O. Box 236
Hancocks Bridge, NJ 08038

1. Purpose

This report evaluates the evaporative heat transfer issues raised by the NRC regarding a request to reduce the minimum decay time in the vessel before fuel can be moved to the Salem Spent Fuel Pool (SFP) during a refueling outage.

2. Background

2.1. License Amendment and RAI

PSEG Nuclear submitted a license amendment request for Salem Generating Station to reduce the technical specification requirement for minimum decay time in the vessel before fuel can be moved to the SFP during a refueling outage. The proposed change will allow core offload earlier in the outage, thereby reducing refueling outage duration.

The amendment was submitted to the NRC in March 2008, with a supplemental submittal in June 2008. The NRC has issued a draft Request for Additional Information (RAI). PSEG Nuclear has requested support from MPR for responding to the RAI on evaporative cooling in the SFP at the elevated temperatures possible during cross-tie operation of SFP cooling. The RAI in question has two parts as identified below.

- Provide data validating the CROSSTIE model for evaporative cooling during SFP temperature excursions exceeding 150°F and approaching 180°F, such as by benchmarking model predictions to test pools at similar temperatures. ***(RAI Question 1.a)***

- Provide data demonstrating by test or detailed analysis that the ventilation system will maintain performance consistent with that assumed in the CROSSTIE model at SFP temperatures approaching 180°F. ***(RAI Question 1.b)***

Both parts of RAI 1 relate to the cross-connect mode of SFP cooling. Each Salem unit has its own SFP with a single-train cooling system. If a SFP heat exchanger is out of service, the heat exchanger for the other unit is used to cool both pools. In cross-connect mode, the in-service heat exchanger is aligned to a single pool at any given time. Cooling is alternately aligned to each pool to keep both pools within the maximum allowed pool temperature (180°F). Pool temperatures cycle as cooling is alternated, approaching 180°F when uncooled. The NRC is questioning the accuracy of the predicted pool temperatures during cross-connect operation, particularly the evaporative heat loss component.

2.2. Analytical Basis for SFP Cooling in Cross-Connect Configuration

In support of the license amendment request, PSEG Nuclear evaluated SFP temperatures assuming full core offload earlier in the refueling outage. Although station practice is to ensure the SFP coolers at both units are in-service prior to the refueling outage, the evaluations considered cross-connect operation as this is limiting with respect to pool temperature. The evaluations used the CROSSTIE, a computer code developed for Salem by Holtec in the 1990's as part of re-rack project (Reference 9). The code was benchmarked against Salem data for SFP temperatures in the range of 80 to 140°F (Reference 8, Appendix A, Pages 3 and 4, and Reference 11, Figures 5.3 and 5.4). The calculations showed that both pools could be maintained below 180°F by alternately aligning each pool for cooling.

CROSSTIE combines the effects of forced cooling in the SFP heat exchanger and evaporative and radiative losses from the pool to the surroundings. It does not include the Fuel Handling Building ventilation system; instead, it considers the air temperature/humidity above the pool as a constant boundary condition specified by the user.

Performance of the Fuel Handling Building ventilation system is evaluated in S-1-FHV-MDC-0705. The calculation uses a hand calculation analysis approach to model the system. The calculation considers evaporation from the pool separate from the CROSSTIE model. Since the system is once-through system, evaporation humidifies the outside air that is subsequently exhausted, but does not change the calculated temperature and humidity above the pool.

3. Summary

3.1. RAI Question 1.a

Comparison of CROSSTIE results to a hand calculation model that used the Ryan-Harleman correlation shows that CROSSTIE results are not conservative or reasonable for temperatures in the range 150 to 180°F. The Ryan-Harleman correlation was selected for the hand calculation model on the basis that: (1) review of the literature indicated that it provides a reasonably accurate prediction of evaporation heat loss in the temperature range 150 to 180°F; (2) comparison of it to published data showed favorable results.

Scoping calculations with CROSSTIE which suppressed heat loss from the pool surface showed that cross-connect operation remains a viable approach if a SFP heat exchanger is out-of-service. With no credit for heat loss from the pool surface, the switchover times are reduced somewhat, but not enough to challenge operators' ability to implement the switchover in sufficient time. It is recommended that PSEG Nuclear consider using CROSSTIE with no heat transfer from the pool surface to address the NRC concern and assure a conservative approach.

3.2. RAI Question 1.b

PSEG Nuclear Calculation S-1-FHV-MDC-0705 evaluates performance of the Fuel Handling Building ventilation system. Review of the calculation concludes that the calculation is a detailed analysis that addresses the important parameters. The NRC concern with evaporation from the spent fuel pool has no impact on the important results of this calculation with respect to room temperatures. It is recommended that PSEG Nuclear submit Reference 10 to the NRC in order to respond to RAI Question 1.b.

4. RAI Question 1.a

RAI Question 1.a requests test data to validate the evaporative cooling calculations in the CROSSTIE model for pool temperatures above 150°F and approaching 180°F. The CROSSTIE model was benchmarked to in-plant data for the Salem SFPs in the temperature range of 80-140°F (Reference 8, Appendix A, Pages 3 and 4, and Reference 11, Figures 5.3 and 5.4). However, in-plant data for higher pool temperatures are not available. Therefore, the validity of the CROSSTIE model is assessed by comparison to published correlations and test data.

The approach used to address RAI 1.a is outlined below and presented in detail in the following sections.

- A literature review was used to identify a correlation suitable for calculating the evaporative heat loss from the SFP. This selected correlation was compared to high temperature evaporation data (in the range 150 - 180°F).

- A hand calculation model was prepared to determine the total heat loss from the spent fuel pool accounting for evaporative heat loss, radiation heat loss, and natural convection heat loss. The natural convection and radiation models are based on classic heat transfer texts.

- CROSSTIE was used to calculate heat loss from the spent fuel pool at elevated temperatures (again, in the range 150°F to 180°F). These results were compared to results obtained with the hand calculation model.

  Note: CROSSTIE is a computer code that was written for PSEG Nuclear by Holtec (Reference 9). MPR was not involved in the development of the CROSSTIE code. MPR used CROSSTIE to perform scoping calculations for this report. MPR used CROSSTIE as a black box by checking inputs and reviewing CROSSTIE output results for reasonableness.

- CROSSTIE results were obtained using inputs from the 1R19 outage. The CROSSTIE air temperature in the input file was increased from 110°F to 180°F to eliminate heat transfer from the spent fuel pool surface 0 BTU/hr. Results of the two cases were compared to show the effect of having no heat transfer from the spent fuel pool surface.

4.1. Literature Review to Identify an Evaporation Correlation

A literature review was used to identify correlations to calculate evaporative heat loss from a hot pool. Reference 1 provides a comparison of six correlations for evaporative heat loss. Figure 1 shows the comparison of the six correlations. The comparison shows that the Ryan-Harleman correlation gives the highest prediction of evaporative heat loss and the Brady correlation provides the lowest prediction of evaporative heat loss.

Reference 3 provides a detailed evaluation of the Ryan-Harleman correlation. The Ryan-Harleman correlation is as follows (Reference 2, Equation 2.35 is the original publication by Ryan and Harleman and Reference 3, Equation 4.44 provides the correlation in SI units).

$$\phi_e = \left(2.7 * \Delta\theta_v^{\frac{1}{3}} + 3.1 * W_2\right) * (e_s - e_2)$$

where

ϕ_e	=	evaporation heat loss (W/m^2)
$\Delta\theta_v$	=	water surface temperature minus free stream air temperature (°C)
W_2	=	wind speed (m/s)
e_s	=	vapor pressure of water at surface (mbar)
e_2	=	vapor pressure of water in the free air stream (mbar)

This correlation accounts for evaporation due to natural convection and forced convection.

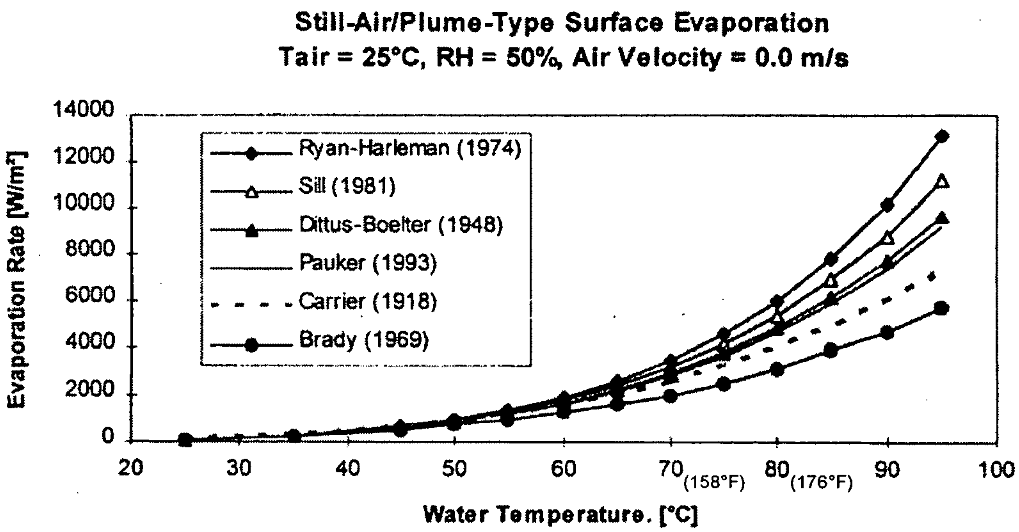

Figure 1. Comparison of Evaporation Correlations (Reference 1)

Table 1 is a modification of Table 4-1 in Reference 3. With the exception of East Mesa and Savannah River, the water temperatures for the investigations listed in Table 1 are in the range 68°F to 86°F (Reference 3, p. 4-8). The water temperature for the East Mesa investigation varied between 95°F and 104°F. The water temperature for the Savannah River Pond 1 investigation varied between 145°F and 154°F.

Table 1 shows that the Ryan-Harleman correlation provides reasonable accuracy in the prediction of evaporation heat loss. It is noted that Reference 3 evaluated the Ryan-Harleman correlation for use at high temperature using the Savannah River data and concluded that Ryan-Harleman correlation may over predict evaporation heat loss at high temperature for a large body of water by as much as 18%.

Reference 4 provides data on evaporation heat loss at water temperatures between 63°F and 200°F. The data are based on laboratory measurements for a one-foot diameter pool of water. Figure 2 compares the data to the evaporation heat loss prediction from Ryan-Harleman. The air temperature for the Reference 4 experiments ranged from 65 to 80°F and the relative humidity ranged from 54 to 98%. To simplify the comparison in Figure 2, the Ryan-Harleman heat loss was calculated with the mean air temperature (71°F) and the mean relative humidity (84%).

Table 1. Comparison of Evaporation Heat Loss Data to Ryan-Harleman Correlation (Adapted from Reference 3)

Site	Surface Area (hectare)	Water/Air Temp. Diff. (°F)	Approx. Wind Speed (fps)	Ratio Free Conv. to Forced Conv.	R-H Heat Loss Correlation (BTU/hr-ft^2)	Ratio of Actual Heat Loss to R-H Correlation
Lake Hefner	1000	4	16	0.19	6.0	--
Brady et al. (3 ponds)	250-100	14	8	0.63	4.0	~1.0[1]
Hazelwood (Main)	500	14	9	0.52	4.5	~1.0[1]
Hazelwood (Hot)	28	32	9	0.61	4.9	~1.0[1]
Dresden	510	29	10	0.59	5.2	0.79
Powerton	575	32	10	0.62	5.3	0.81
Lake Anna (WHTF)	1360	22	8	0.70	4.4	0.75
East Mesa	0.3	32	7	0.60	4.4	1.07
Savannah River (Pond 1)	4	121	6	1.1	4.6	0.82
Laboratory	10^{-4}-8×10^{-3}	5-72	0	∞	1.2-2.9	~1.0[1]

[1]Based on visual agreement between measured and computed wind speed functions.

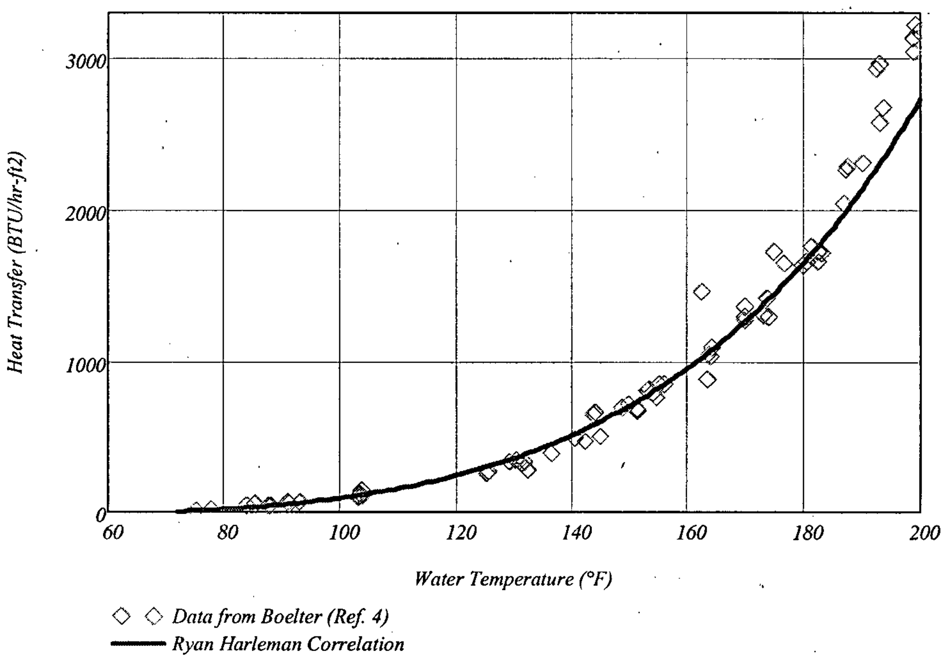

Figure 2. Comparison of Reference 4 Evaporation Data to the Ryan-Harleman Correlation

Based on the review, it was concluded that the Ryan-Harleman correlation provides an accurate prediction of evaporation heat loss at high temperatures (in the range 150°F to 180°F). The Ryan-Harleman correlation was used for the hand calculations that are discussed in the following sections.

4.2. Hand Calculation Model

A simple hand calculation model was developed to estimate the total heat loss from the SFP surface. It combines the various heat transfer modes and uses published correlations to estimate the individual heat transfer terms.

$$q_{tot} = q_{evap} + q_{rad} + q_{nc}$$

where
- q_{tot} = total heat loss
- q_{evap} = evaporation heat loss
- q_{rad} = radiation heat loss
- q_{nc} = natural convection heat loss

Natural convection heat transfer from the spent fuel pool is typically included in the evaporation term. However, for consistency with the CROSSTIE computer program and consistency with the ventilation system calculation, natural convection is calculated as a separate term. The discussion provided below for Table 3 shows that the natural convection term is small (less than 4% of the total) and so including a natural convection term in the above equations has a small impact on calculation results.

4.2.1. Evaporation Heat Loss Correlation

The Ryan-Harleman correlation (see Section 4.1) is used to determine evaporation heat loss.

4.2.2. Natural Convection Heat Transfer Correlation

The correlation for natural convection heat transfer from the spent fuel pool is Equation 10-32 in Reference 5.

$$Nu = a * (Gr * \Pr)^m$$

where
- Nu = Nusselt Number
- Gr = Grashof Number
- $\Pr$ = Prandtl Number
- a,m = parameters that depend on the flow regime

Y = Ngr*Npr	A	m
$10^5 < Y < 2*10^7$	0.54	¼
$2*10^7 < Y < 3*10^{10}$	0.14	1/3

4.2.3. Radiation Heat Transfer Correlation

The correlation for radiation heat loss from the pool surface to the surroundings is:

$$q = \sigma * \varepsilon_w * (T_w^4 - T_a^4)$$

where
- q = heat flux
- σ = Stefan-Boltzmann constant
- e_w = water emissivity
- T_w = water surface temperature
- T_a = ambient surface temperature

4.3. Comparison of CROSSTIE and Hand Calculation Model

The CROSSTIE computer program developed by Holtec calculates the heat loss from the surface of the SFP and the heat transfer to the SFP heat exchanger to determine the transient temperature of the spent fuel pool. The program was developed for the case where the SFP heat exchanger is unavailable at one unit and the both pools are cooled alternately by heat exchanger at the other unit (i.e., cross-connect mode). The program user specifies the crossover temperature at which the switch is made from one pool to the other pool.

CROSSTIE output provides the total heat loss from the SFP surface. This is the heat loss due to evaporation, natural convection, and radiation.

Figure 3 plots the total heat loss from the SFP surface (combination of evaporation, natural convection and radiation) as a function of SFP temperature based on CROSSTIE results. The CROSSTIE calculations are based on the conditions shown in Table 2. The calculation results are from the Reference 7 calculation and from a scoping calculation performed by MPR with CROSSTIE to obtain additional data in the temperature range of interest.

Table 2. Conditions for CROSSTIE and Hand Calculations

Parameter	Value
Air Temperature	110°F
Air Humidity	100%
Air Velocity	20 fpm
Area of Spent Fuel Pool and Transfer Pool	1568 ft^2

Figure 3 also shows the heat loss calculation result for the hand calculation model. The comparison shows that CROSSTIE calculates more heat loss from the spent fuel pool surface than the hand calculation model.

CROSSTIE was calibrated against plant data in References 8 and 11. This calibration was for a SFP temperature in the range of 80 to 140°F (Reference 8, Appendix A, Pages 3 and 4, and Reference 11, Figures 5.3 and 5.4). The calculation with the Ryan-Harleman correlation assumes perfect mixing of the SFP, i.e., the surface temperature and the bulk temperature are the same. Figure 3 shows agreement of CROSSTIE and the hand calculation model in the 120 to 140°F temperature range. Based on Figure 3, CROSSTIE over predicts heat transfer from the pool surface at temperatures above approximately 140°F.

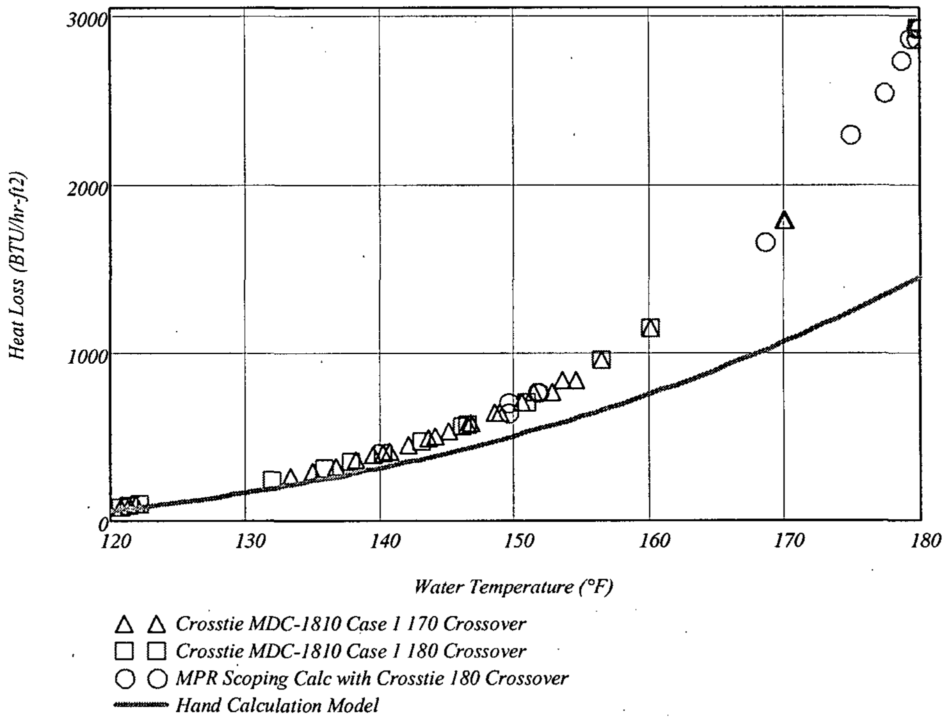

Figure 3. Comparison of CROSSTIE Results to Hand Calculation Results

Table 3 breaks down the total heat transfer from the pool surface into the loss due to evaporation, radiation, and natural convection. These results are at a pool water temperature of 180°F. As expected, Table 3 shows that the primary mechanism for heat transfer from the pool surface is evaporation.

Table 3. Detailed Hand Calculation Results

Heat Transfer Result	Value (BTU/hr-ft^2)	Percent of Total
Total	1449	—
Evaporation	1285	89
Radiation	100	7
Natural Convection	64	4

4.4. Assessment of CROSSTIE with No Heat Transfer from Pool Surface

Table 4 provides results from CROSSTIE for the total heat transfer and the heat transfer from the pool surface. The total heat transfer is the sum of the heat transfer to the SFP heat exchanger and the heat transfer from the SFP surface. These results are from the 170°F and the 180°F switchover cases in Reference 7. The results are provided for several SFP temperatures from 141°F to 180°F. As shown, heat transfer from the surface of the spent fuel pool is a small percent of the total heat transfer: about 3% of the total at a low pool temperature to about 17% of the total at a high pool temperature.

Table 4. CROSSTIE Heat Transfer Results

Spent Fuel Pool Temperature (°F)	Total Heat Transfer (BTU/hr)	Pool Surface Heat Transfer (BTU/hr)	Percent of Total (%)
141	$2.43*10^7$	$6.50*10^5$	2.7
151	$3.01*10^7$	$1.10*10^6$	3.7
160	$3.67*10^7$	$1.60*10^6$	4.9
170	$2.78*10^7$	$2.80*10^6$	10.1
180	$2.76*10^7$	$4.60*10^6$	16.6

Figure 4 shows results from Reference 7 calculated with CROSSTIE for the 1R19 outage. The figure shows the transient temperature of the Unit 1 and Unit 2 SFPs when operated in cross-connect mode, i.e., one operational SFP heat exchanger. The switchover for this case from Reference 7 is a spent fuel pool temperature of 170°F. These results were based on the following: Component Cooling water temperature of 80°F, air temperature of 110°F, and air relative humidity of 100%.

Figure 4 shows that when the cooling flow is aligned to the Unit 2 SFP, the temperature in the Unit 1 spent fuel pool rises quickly. The time to rise from a temperature of about 137 to 170°F is on the order of 4 hours. When the cooling flow is aligned to the Unit 1 SFP, the time for the Unit 2 pool to heat up from about 130°F to 170°F is about 40 hours. The difference in heat up time is due to the difference in decay heat from the spent fuel in the two pools.[1]

---

[1] The calculation was for the 1R19 refueling outage. In this case, Unit 1 has the higher decay heat as it considers the time after full core offload.

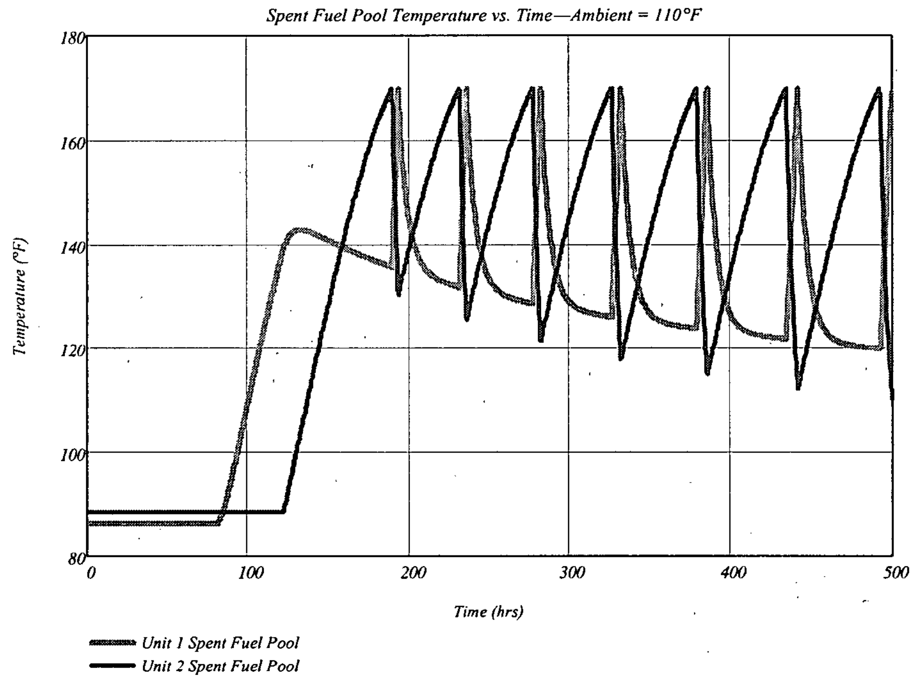

Figure 4. Unit 1 and Unit 2 Spent Fuel Pool Temperature vs. Time (adapted from Reference 7)

A scoping calculation was made with CROSSTIE to assess the effect of having no heat transfer from pool surface. The calculation presented in Reference 7 was duplicated with one change: the air temperature was increased from 100°F to 180°F to eliminate heat loss from the pool surface. Figure 5 provides the transient temperature results for the Unit 1 and Unit 2 spent fuel pools.

> *Note: MPR used CROSSTIE to perform scoping calculations for this report. MPR used CROSSTIE as a black box by checking inputs and reviewing CROSSTIE output results for reasonableness.*

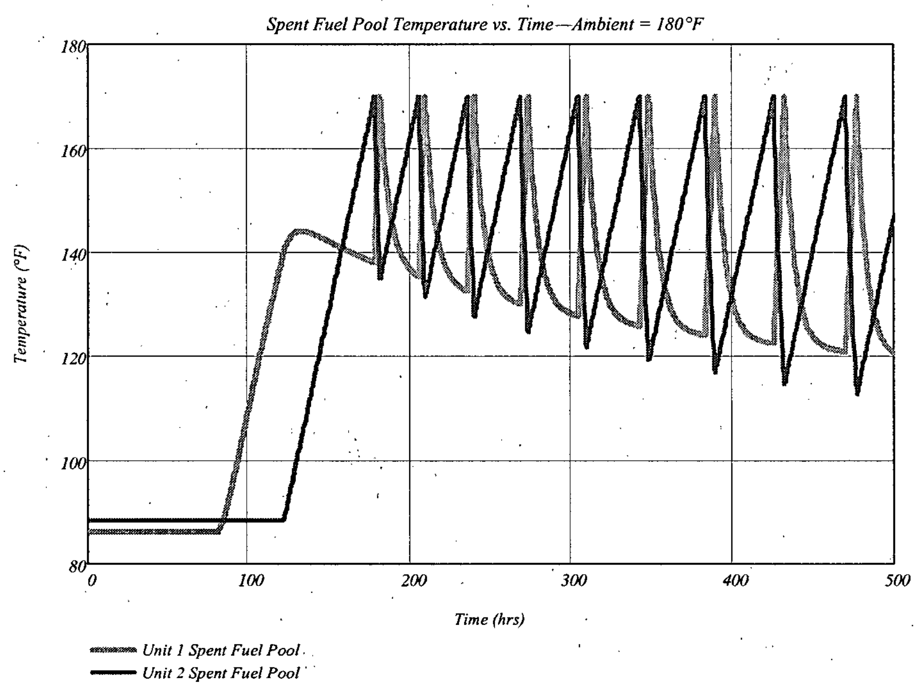

Figure 5. Unit 1 and Unit 2 Spent Fuel Pool Temperature vs. Time with Ambient Air Temperature of 180°F

Table 5 provides the time that the SFP heat exchanger is aligned to provide cooling to the Unit 1 and the Unit 2 SFPs for two cases: an ambient temperature of 110°F, and an ambient temperature of 180°F (no heat loss from the surface). For each case, Table 5 provides results for the first four changes in alignment (switchovers) for each pool.

Comparing the two cases in Table 5 shows that the operating times with no cooling from the spent fuel pool surface (ambient air temperature equal to 180°F) are shorter. For example, the operating time for the first period for the Unit 2 pool drops from 3.8 to 3.3 hours. The operating time for the first period for the Unit 1 pool drops from 38 hours to 24 hours. In general, the elimination of heat transfer from the pool surface had a reasonably small impact on these calculation results. The reason is that the heat transfer from the pool surface is a small percent of the total heat transfer (see Table 4).

Based on these results, an option that PSEG Nuclear can pursue is to revise the calculations that support the licensing amendment to use an air temperature of 180°F. This will eliminate heat transfer from the pool surface and thereby eliminate NRC concern with the evaporation correlation used by CROSSTIE. The scoping calculation results provided in Table 5 show that the switchover times with this calculation approach are likely within the capability of the Salem operators.

Table 5. Switchover Times

Switchover No.	Ambient Temp 110°F		Ambient Temp 180°F	
	Time Cooling U2 Pool (hr)	Time Cooling U1 Pool (hr)	Time Cooling U2 Pool (hr)	Time Cooling U1 Pool (hr)
1	3.8	38	3.3	24
2	4.5	42	3.8	26
3	5.2	45	4.3	29
4	5.9	47	4.8	31

5. RAI Question 1.b

RAI Question 1.b requests test data or detailed analysis to show that the ventilation system will maintain performance consistent with that assumed in the CROSSTIE model calculations.

The Fuel Handling Building is cooled by a ventilation system. This is a once through system, in which outside air is supplied to the Fuel Handling Building by a supply fan, the air from the Fuel Handling Building is pulled from the air space by exhaust fans, and the air is exhausted to the outside. There is no air conditioning unit in the air flow path. A heater is used in the winter time to heat the air before it is supplied to the Fuel Handling Building.

Performance of the ventilation system is evaluated in Calculation S-1-FHV-MDC-0705 (Reference 10), which was not provided to the NRC. The calculation is a hand analysis that models the building air spaces served by the ventilation system and accounts for the important effects. Rather than perform separate calculations to assess ventilation system performance, MPR reviewed the existing calculation to assess the reasonableness of the methodology. Key observations from this review are summarized below.

- Evaporation from the SFP is calculated with a correlation from the ASHRAE handbook (Reference 6). In addition, the calculations determine the heat transfer from the pool surface due to natural convection and radiation. The ASHRAE correlation is compared to evaporation data in a section below.
- Evaporation from the SFP increases the humidity of the outside air supplied by the ventilation system. The humidified air is exhausted to the outside. There is no effect of evaporation from the SFP on the building calculated room temperatures.
- The natural convection coefficient correlation was compared to the correlation described in Section 4.2.2 above. The result of this comparison is provided in Section 5.2 below.

It is concluded that Salem has a detailed calculation for the Fuel Handling Building ventilation system. A review of the calculation shows that the important parameters are included. Further, the NRC concern with evaporation from the SFP has no impact on the important results of this calculation with respect to room temperatures. It is recommended that PSEG Nuclear submit Reference 10 to the NRC in order to respond to RAI Question 1.b.

Two minor issues related to our review of Reference 10 are discussed in the following two sections.

5.1. ASHRAE Evaporation Correlation

ASHRAE provides the following evaporation correlation in Reference 6.

$$W_p = \frac{A}{Y} * (95 + 0.425 * v) * (p_w - p_a)$$

where

W_p	=	water evaporation rate (lb/hr)
A	=	water surface area (ft^2)
Y	=	latent heat of vaporization at surface water temperature (BTU/lb)
v	=	air velocity over water surface (fpm)
p_w	=	saturation vapor pressure at surface water temperature (in. Hg)
p_a	=	saturation vapor pressure at room air dewpoint (in. Hg)

Figure 6 compares the ASHRAE correlation to the evaporation data in Reference 4. As shown, the ASHRAE equation under predicts evaporation at pool temperatures above 160°F.

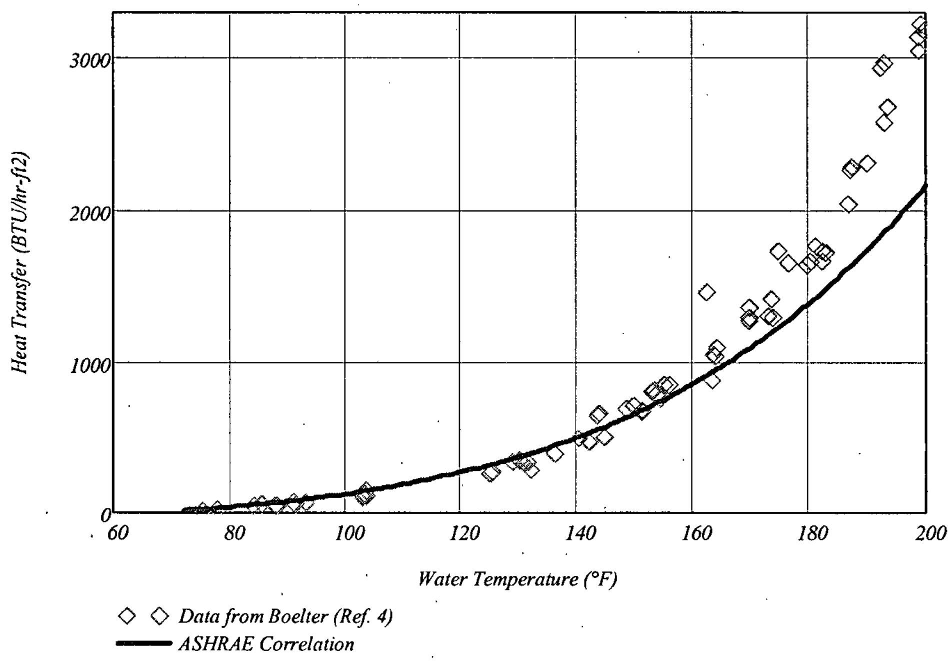

Figure 6. Comparison of Reference 4 Evaporation Data to the ASHRAE Correlation

5.2. Natural Convection Coefficient

The natural convection coefficient correlation used in Reference 10 is:

$$U_N = 0.5 * \frac{(t_w - t_R)^{0.25}}{L}$$

where	U_N	=	natural convection heat transfer coefficient (BTU/hr-ft^2-^{0}F)
	t_w	=	water temperature (^{0}F)
	t_R	=	room temperature (^{0}F)
	L	=	length of pool (ft)

The natural convection coefficient used in MDC-0705 is 0.637 BTU/hr-ft^2-°F based on the following: room temperature of 105°F, water temperature of 180°F, and a pool length of 28.5 ft. Using the same parameters in the natural convection correlation in Section 4.2.2 gives a heat transfer coefficient of 0.86 BTU/hr-ft^2-°F. The natural convection coefficient from Section 4.2.2 is 28% larger than that used in Reference 10. Although this difference is not large considering the large scatter in data for natural convection, it is recommended that the PSEG Nuclear review the natural convection coefficient if the Reference 10 calculation is revised in the future.

6. References

1. T. P. Yilmaz and J. C. Lai, "Spent Fuel Pool Thermal Hydraulics," ANS Transactions, v. 75, 1996, pp. 279-281.

2. P. J. Ryan and D. R. F. Harleman, "An Analytical and Experimental Study of Transient Cooling Pond Behavior," Report No. 161, Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics, January 1973.

3. EPRI CS-5171, *Analysis of Evaporation Data from Heated Ponds*, April 1987.

4. L. M. K. Boelter, H. S. Gordon, and J. R. Griffin, "Free Evaporation into Air of Water from a Free Horizontal Quiet Surface," Industrial and Engineering Chemistry, v. 38, no. 6, June 1946, pp. 596-600.

5. Perry & Chilton, *Chemical Engineers' Handbook*, McGraw-Hill, 5th Edition.

6. 1991 ASHRAE Handbook, *Heating, Ventilating, and Air Conditioning Applications*.

7. PSEG Nuclear Calculation S-C-SF-MDC-1810, *Decay Heat-up Rates and Curves*, Revision 8.

8. PSEG Nuclear Calculation S-C-SF-MDC-1800, *Decay Heat-up Rates and Curves*, Revision 6.

9. PSEG Nuclear Calculation S-C-SF-MDC-1240, *SFP Thermal Hydraulic Calc*, Revision 1.

10. PSEG Nuclear Calculation S-1-FHV-MDC-0705, *FHV Sys Htg/Clg Load and Air Flow Performance Calcs*, Revision 5.

11. PSEG Nuclear Calculation S-C-SF-MCS-0113, Appendix 2, Attachment 1, *Verification and Validation Documentation for Computer Program CROSSTIE*, Revision Original.