AREVA

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Title: FCS RSG – AFAS Verification - RAI Responses

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Technical Manager Statement: Initials TRH for Giardini

Reviewer is Independent.

Remarks:

This document provides responses to NRC RAIs on the AFAS setpoint verification analysis (attachment 4 of the following reference).

Reference:

1. Letter, OPPD to NRC, "Fort Calhoun Unit No. 1 License Amendment Request, *Updated Safety Analysis Report Clarification of Operator Action During Loss of Main Feedwater Event*," LIC-05-0001, July 1, 2005.

Revision 1 includes editorial changes in the responses to Questions 3 and 4 and removal of all proprietary brackets except for Figure 1.

Name	Signature	P/R	Date	Pages/Sections Prepared or Reviewed
K. E. Carlson	[signature]	P	12/5/05	Question 2
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Question (2): Heat Transfer Model

Discuss the SG heat transfer model in S-RELAP5 for events that experience SG dryout. Provide the values of SG dryout heat transfer coefficients used in the analysis of non-LOCA transients, in particular, the loss of main feedwater (LMFW) and feedwater line break (FLB) events.

The Semiscale test data for FLB (as discussed in Section 4.3.3.2 of NUREG/CR-4945, dated July 1987) show that SG heat transfer capacity remains unchanged until the SG liquid inventory is nearly deleted. This is followed by a rapid reduction to zero percent heat transfer with little further reduction in the SG water inventory. In light of these test data, you are requested to verify that the heat transfer model used in the LMFW and FLB events (that experience SG dryout) is conservative as compared to the Semiscale test data.

Response:

The dominant characteristic of both scenarios is the reduction in steam generator mass, either through boil-off or blowdown and boil-off. The S-RELAP5 convective heat transfer package computes the total heat flux q", expressed in the general form:

$$q'' = h_{cf}(T_w - T_f) + h_{csat}(T_w - T_{sat}) + h_{cg}(T_w - T_g) \quad (1)$$

where T_w, T_f, T_g and T_{sat} are temperatures of wall (heat structure surface), liquid phase, vapor phase and saturation, respectively. The saturation temperature corresponds to the total pressure for a boiling process and to the partial steam pressure for a condensing process. The heat transfer coefficients, h_{cf} (liquid convective heat transfer coefficient), h_{csat} (two-phase convective heat transfer coefficient), and h_{cg} (vapor convective heat transfer coefficient) are obtained from correlations which represent various heat transfer processes or phenomena in different heat transfer regimes. However, not all of the heat transfer coefficients in Equation (1) may be present in a particular regime. For example, in single-phase vapor flow, only h_{cg} is present. It should also be pointed out that, for computational purposes, a total heat transfer coefficient is defined in S-RELAP5 as

$$h_{c,total} = h_{cf} + h_{csat} + h_{cg} \quad (2)$$

The quantity $h_{c,total}$ appears as the 'heat transfer coefficient' in the set of major and minor edit variables. As each of the heat transfer coefficients in Equation (2) is not defined with respect to the same temperature difference, the variable $h_{c,total}$ has, in a strict sense, no physical meaning under general circumstances. Consequently, the heat transfer coefficients presented herein are computed from the S-RELAP5 calculated heat fluxes divided by the difference between the wall temperature and saturation temperature where the saturation temperature is a function of total pressure. This method best approximates the experimental procedure for computation of 'measured' heat transfer coefficients.

The FLB scenario is presented first. The boiler section consists of four vertically stacked control volumes with two sets of heat structures representing the 'up' and 'down' portions of the steam generator tubes. Figure 1 shows a nodalization diagram for the affected steam generator. In that figure, component 524 represents the boiler section with node 524-1 representing the bottom node, 524-2 representing the lower middle node, 524-3 representing the upper middle node, and 524-4 representing the top node of the boiler section. The initial void fraction profile in the affected steam generator boiler section varies from 0.37 at the bottom to 0.81 at the top. In the first 10 seconds after the blowdown is initiated, the void fraction in the top boiler section transitions to above 0.97, and the heat transfer coefficient transitions from approximately 10,000 BTU/hr·ft^2·°F to approximately 1,500 BTU/hr·ft^2·°F. The void fraction transitions to all vapor by 40 seconds and the ultimate total heat transfer coefficient becomes approximately zero. The lower sections show similar characteristics at later times. Figure 2 shows the total heat transfer coefficients for the hot side, bottom through top, nodes from time 0.0 to 50 seconds. For comparison purposes, Figure 3 shows heat transfer coefficients from the unaffected steam generator. The quantities shown are from the structures representing the hot side. The nodal heat transfer coefficients remain relatively constant until their respective control volumes dry-out. Note that the heat transfer coefficient from the bottom node retains a finite value greater than zero throughout the transient. This is the effect of auxiliary feedwater on the nodal heat transfer coefficient.

The S-RELAP5 code was satisfactorily benchmarked to the LOFT L6-5 Loss of Feedwater experiment for the approved Non-LOCA Methodology EMF-2310. For the loss of feedwater analysis presented here, the transient was initiated from the same conditions as the feedwater line break. In this scenario, the heat transfer coefficients remain relatively constant until the mass in a control volume is boiled off. The nodal heat transfer coefficients after boil-off are approximately zero for the upper steam generator nodes and approximately 350 BTU/hr·ft^2·°F, for the bottom node. The bottom node shows the affects of auxiliary feedwater on the heat transfer coefficient. Figure 4 shows the S-RELAP5 hot side steam generator heat transfer coefficients as a function of time.

The next figure, Figure 5, is presented to demonstrate that the S-RELAP5 calculations of feedwater line break are conservative with respect to Semiscale feedwater line break Tests S-FS-6, S-FS-11, and S-FS-7 (NUREG-4945). Figure 5 shows the normalized total primary to secondary heat transfer versus the normalized total steam generator mass for the affected steam generator from the previously mentioned tests and from selected S-RELAP5 calculations. Note that the data in this figure was digitized from the plot on page 70 of NUREG-4945, thus there is some uncertainty concerning the absolute values of the data, but the trends are approximated adequately. Figure 6 shows a reproduction of the NUREG-4945 figure for verification that the digitized data is acceptable.

In Figure 5, the data shows more than 90% heat transfer until the inventory is reduced to below 20%, after which the heat transfer is reduced ultimately to zero. The smallest break, 14.3%, decreases to zero from 20% to 5% inventory while the larger breaks show the heat transfer decreasing to zero over the span of 10% to 0% inventory. In contrast, the calculated heat transfer starts decreasing between 40% and 50% inventory. The early decrease is due to the top boiler node drying out for the break sizes shown. As the inventory further decreases, the next two boiler section nodes dry-out and the heat transfer again decreases. Finally, at approximately 10% inventory the bottom node becomes virtually empty and the heat transfer is approximately zero. The results shown are conservative with respect to the Semiscale data.

Although a 14.3% break calculation was not performed, it would be expected to show similar behavior as the other calculations. That is, dry-out in the top boiler node will immediately decrease the heat transfer. As the lower sections experience dry-out, abrupt drops in heat transfer will occur with decreasing inventory. The Semiscale data and the calculations show the same trend relative to break size. Thus, all break size calculations are expected to show less heat transfer than the Semiscale data. Therefore, S-RELAP5 calculates conservative heat transfer with respect to Semiscale.

Figure 1 Nodalization Diagram of Affected Steam Generator Showing Boiler Section Noding

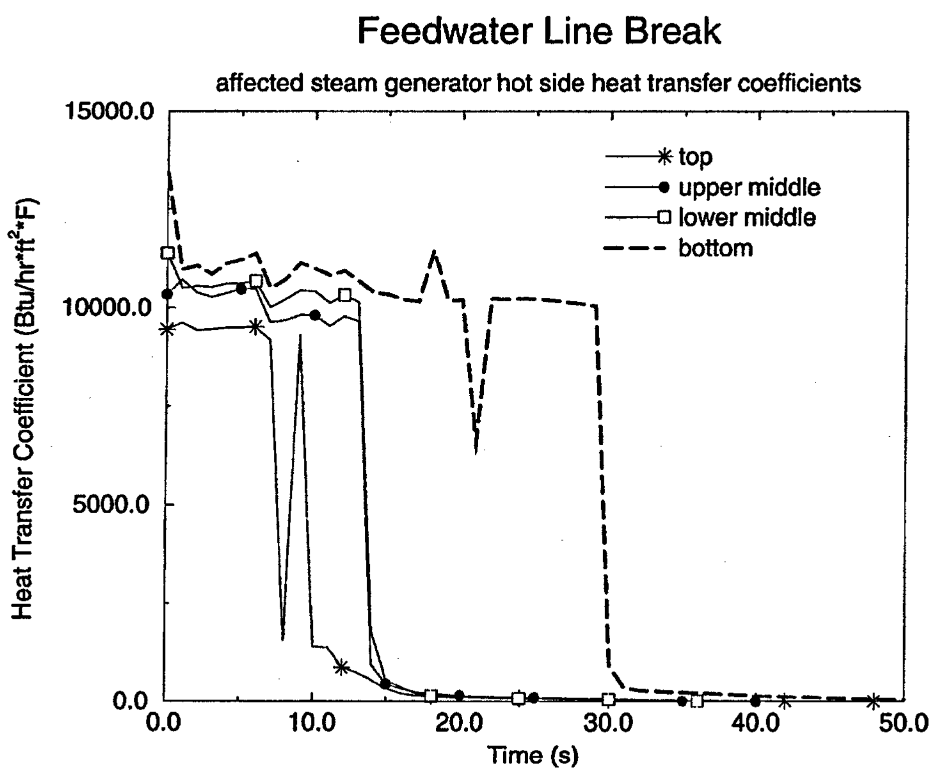

Figure 2 Feedwater Line Break Hot Side of Affected Steam Generator Heat Transfer Coefficients

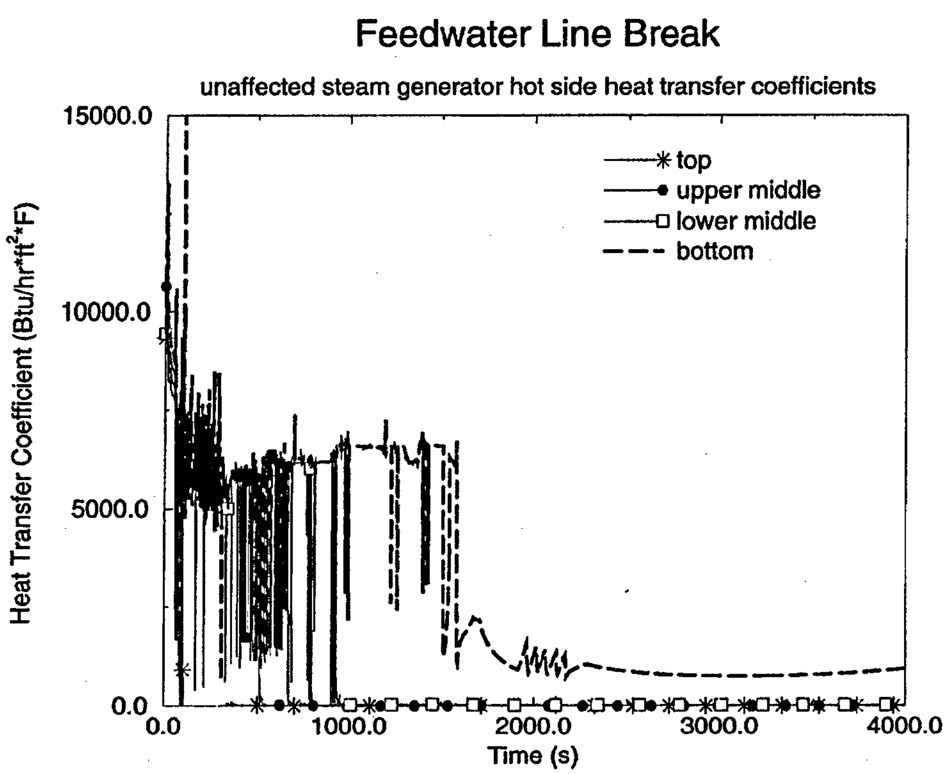

Figure 3 Feedwater Line Break Hot Side of Unaffected Steam Generator Heat Transfer Coefficients

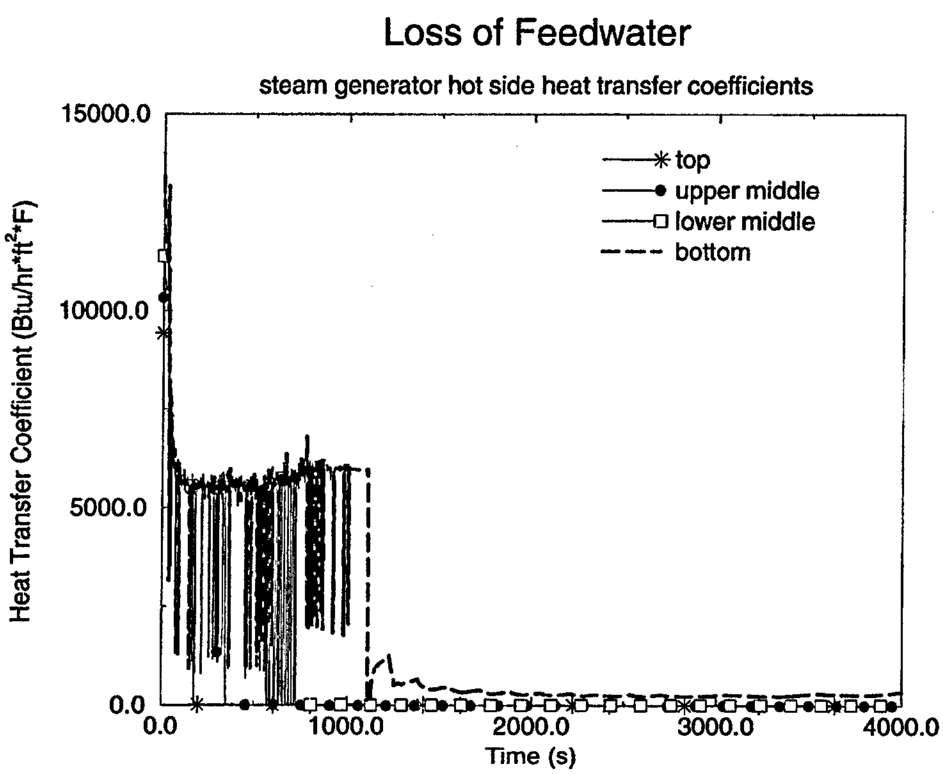

Figure 4 Loss of Feedwater Hot Side Steam Generator Heat Transfer Coefficients

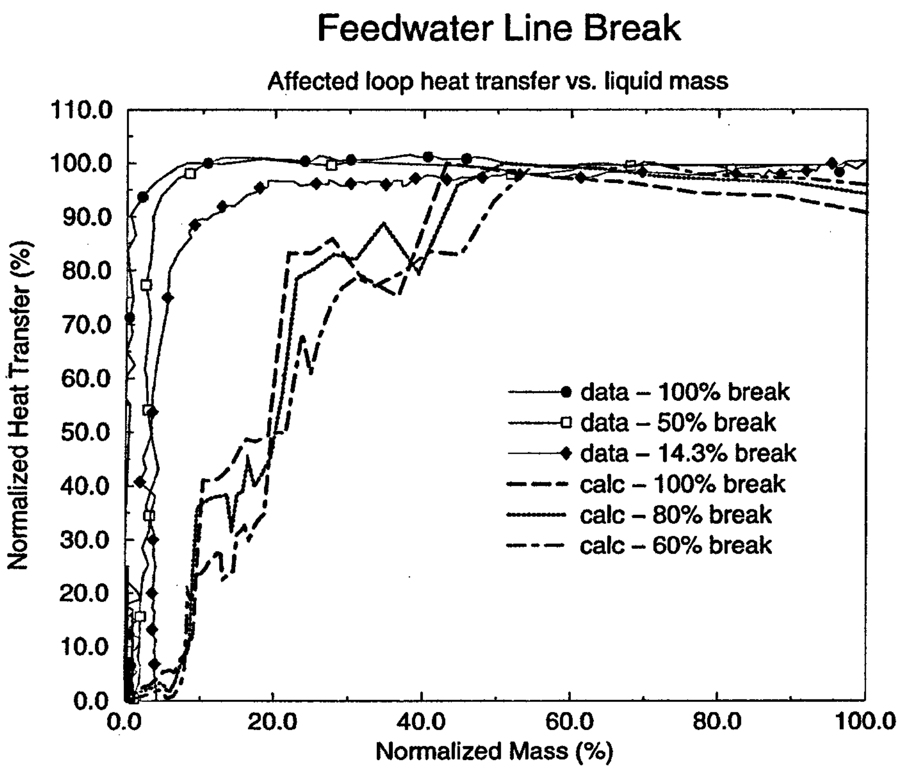

Figure 5 Normalized Total Heat Transfer Versus Normalized Total Steam Generator Mass in Affected Steam Generator

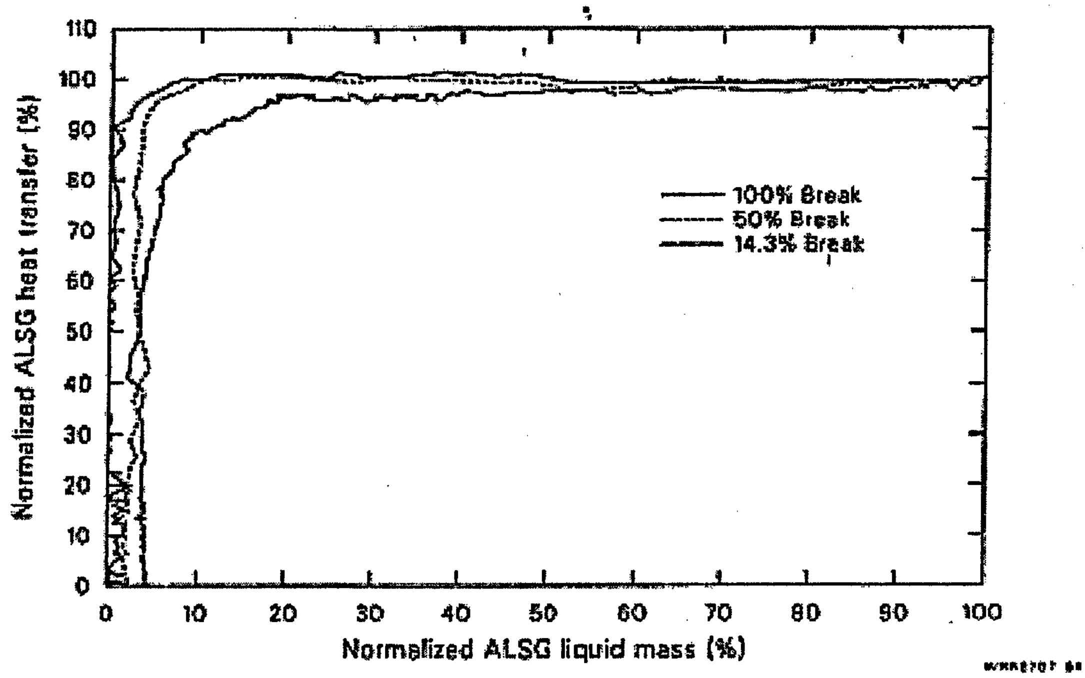

Figure 64. Affected loop steam generator normalized heat transfer versus normalized liquid mass for Tests S-FS-6, S-FS-11, and S-FS-7.

Figure 6 Normalized Total Heat Transfer Versus Normalized Total Mass in Affected Steam Generator From Page 70, In NUREG/CR-4945.

Question (3): Initial Conditions

Discuss the effects of each parameter of the plant initial conditions listed in Table 1 and 3 of Attachment 4 to July 1, 2005 letter on the LMFW and FLB analyses, respectively. Justify that the values of the parameters used in the analysis are conservative in determination of the shortest required operator action time for SG blowdown isolation.

Response:

Following is a discussion of the effect of each parameter listed in Table 1 relative to determining the shortest required operator action time for SG blowdown isolation for the LMFW event.

- The initial core power determines the amount of decay heat that the secondary system must remove following reactor trip. An initial core power of rated power plus measurement uncertainty is conservative because it maximizes the primary side heat generation rate and energy that must be removed by the secondary system.
- The initial RCS flow rate does not have a significant effect on SG inventory or the timing of SG blowdown isolation. A minimum initial RCS flow rate does result in a minor increase in the initial hot leg temperature and initial RCS stored energy, but also results in a minor decrease in the amount of primary side energy to be removed by the secondary system due to a minor increase in the primary-to-secondary temperature difference resulting from a slightly lower primary side SG heat transfer coefficient.
- The initial core inlet temperature is set at the maximum Technical specification value or target value. This is conservative relative to initial RCS stored energy that must be removed by the secondary system.
- The initial pressurizer pressure has no significant effect on SG inventory or the timing of SG blowdown isolation.
- The initial pressurizer level has no significant effect on SG inventory or the timing of SG blowdown isolation.
- The magnitude of SG tube plugging and the initial SG pressure have no significant effect on SG inventory or timing of SG blowdown isolation.
- The RPS trip, modeled to occur on a low NR SG level signal, determines the SG level and inventory at the time of reactor trip. The trip setpoint is biased low by the measurement uncertainty to minimize the SG inventory at reactor trip and maximize the challenge of the secondary system to remove primary side energy.
- The AFAS setpoint, based on WR SG level, determines when AFW is available to the SGs. This setpoint is biased low by the measurement uncertainty to minimize the SG

inventory at AFW actuation and maximize the challenge of the secondary system to remove primary side energy.

- AFW flow rate is minimized to challenge the long term heat removal capacity of the AFW system. The flow rate modeled in the analysis represents the minimum flow rate from one pump accounting for a single failure of the other pump.

- AFW actuation delay time also determines when AFW is available to the SGs. This delay time is biased high to minimize the SG inventory at AFW actuation and maximize the challenge of the secondary system to remove primary side energy.

- The SG blowdown flow rate is modeled at a value representing the design sustained flow rate per SG. The SG blowdown flow diminishes the SG inventory and challenges the heat removal capability of the secondary system. Blowdown flow is assumed to be occurring simultaneously in each SG until isolation.

- The SG blowdown flow isolation time is a key parameter for this event. Continued SG blowdown flow until isolation significantly depletes SG inventory both prior to and after AFW initiation that would otherwise be available for removal of decay heat via the MSSVs, thus delaying the time that AFW flow can recover SG inventory and adequately remove decay heat.

- The uncertainty on the MSSV setpoints has no significant effect on SG inventory and the timing of SG blowdown isolation.

The effect of the above parameters is similar for the FLB event, however, the FLB event does not rely on operator action for SG blowdown isolation.

Question (4): Non-Safety Grade Components and/or Systems

Identify any non-safety grade systems and/or components that were credited for consequence mitigation in the LMFW and FLB analysis, and justify that the use of identified non-safety systems and/or components for event mitigation is acceptable.

Response:

Only safety-grade equipment is credited to mitigate the consequences of the LMFW and FLB events.

Additional Clarification

Criterion 2 page 8 of the AFAS Setpoint Verification report: Justify that the conditions with T_h < 600°F and RCS subcooling > 20°F will assure fuel cladding integrity in meeting the plant specific DNBR safety limit and fuel centerline melting limit.

Response:

The DNB and fuel centerline melt SAFDLs are not challenged in the short term prior to reactor trip because the reactor coolant conditions at reactor trip are close to the initial steady-state values. In the longer term following reactor trip, the DNB and fuel centerline melt SAFDLs are shown to be satisfied by demonstrating that the steam generators provide a sufficient heat sink for decay heat and RCP heat by maintaining the hot leg temperature below 600°F with at least 20°F subcooling margin. Since the RCPs continue to operate in the LMFW event, the flow to power ratio at decay heat power levels after reactor trip is extremely high compared to normal operation. Therefore, boiling and DNB will not occur as long as sufficient subcooling margin is maintained. The maximum post trip hot leg temperature was determined to be 567°F, which is significantly less than 600°F. Also, it can be seen in Figure 1 that the subcooling margin is approximately 80°F. Therefore, boiling and DNB will not occur. Thus, the DNB and fuel centerline melt SAFDLs are satisfied.