WSRC-MS--92-386-Del.Ver.

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SRS K-REACTOR PRA LOCA ANALYSES USING BEST-ESTIMATE METHODS (U)

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A paper proposed for
at/in the Probabilistic Safety Assessment International Topical Meeting (PSA '93)
Clearwater Beach, FL
01/26-29/93

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ABSTRACT

The thermal-hydraulic system computer code RELAP5/MOD2.5 was used to investigate the response of the primary cooling system during loss-of-coolant accidents (LOCAs) at the Savannah River Site (SRS) K-Reactor. In contrast to the conservative safety analyses performed to support the restart of K-Reactor, the assumptions and boundary conditions used in the analyses described in this paper were carefully selected to reflect best-estimate values wherever possible. The results of the calculations indicate that, for a small break LOCA, one functional emergency cooling system pumping source combined with one operational injection path will maintain core cooling. For a large break LOCA, one additional injection path is needed. The incorporation of these results into the latest SRS K-Reactor Probabilistic Risk Assessment (PRA) contributed significantly to the reduction in severe core melt frequency over the previous version.

I. INTRODUCTION

The Savannah River Site (SRS), located in South Carolina approximately 25 miles southeast of Augusta, Georgia, is operated by Westinghouse Savannah River Company (WSRC) for the U. S. Department of Energy (DOE) and is responsible for the production of nuclear materials. Five nuclear production reactors are located at SRS, and of these, only one–the K-Reactor–is currently scheduled for future operation. In order to ensure the safe operation of K-Reactor, WSRC has completed a full-scope Probabilistic Risk Assessment (PRA).[1,2] This "Rev. 0" PRA considered the 1987 configuration of the K-Reactor operating at full historical power–2500 MW (thermal). Since 1987, a number of safety upgrades have been performed, and the operating power limit has been reduced to 720 MW. Therefore, a revision of the PRA that includes these changes is currently under way (Rev. 1).

The SRS reactors are significantly different from commercial power reactors, and their response to loss-of-coolant-accidents (LOCAs) is different, as well. The reactors operate at relatively low temperatures and pressures and are used strictly for the production of nuclear materials; no electrical power is generated. (A schematic diagram of an SRS reactor is shown in Figure 1.) Heavy water is utilized as both the moderator and primary coolant, and the fuel assemblies are concentric annuli through which coolant passes in downflow. Circulation of the primary coolant is provided by six Bingham pumps (one per cooling loop), each of which is powered by both an AC and a DC motor. The DC motors alone are capable of maintaining about 30% of full flow. (Full flow is 25,000 gpm per loop.) Heat is transferred from the primary coolant to a secondary coolant (water taken from the Savannah River) via twelve large shell-and-tube heat exchangers (two per cooling loop).

In the event of a LOCA, core cooling can be provided by an emergency cooling system (ECS). This system contains five independent pumping sources and four separate injection paths into the primary cooling system (see Figure 2). Generally, adequate cooling can be maintained with less than the full complement of sources/injection paths operational, and for the

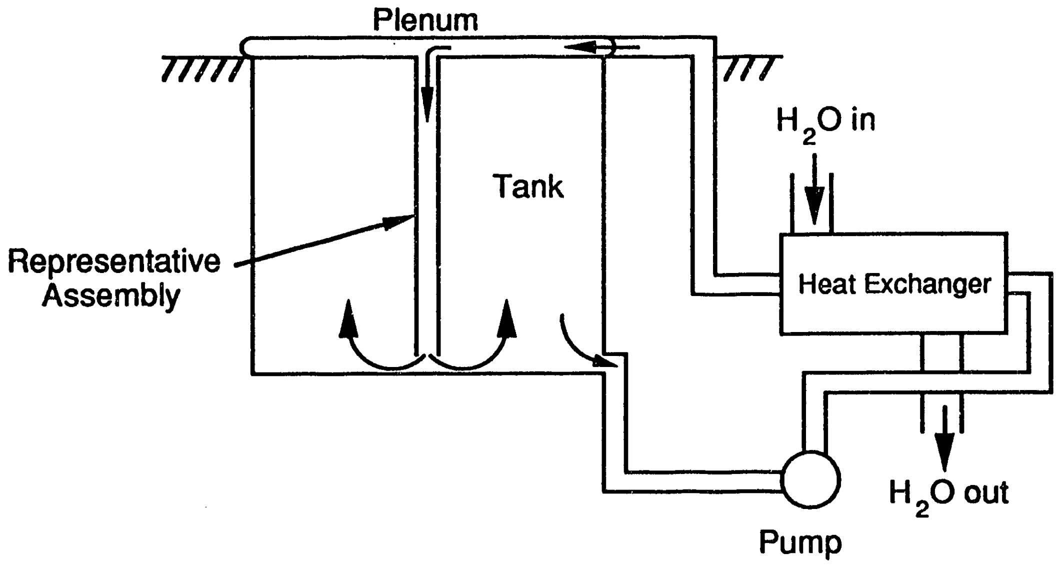

Figure 1. Schematic of an SRS Reactor

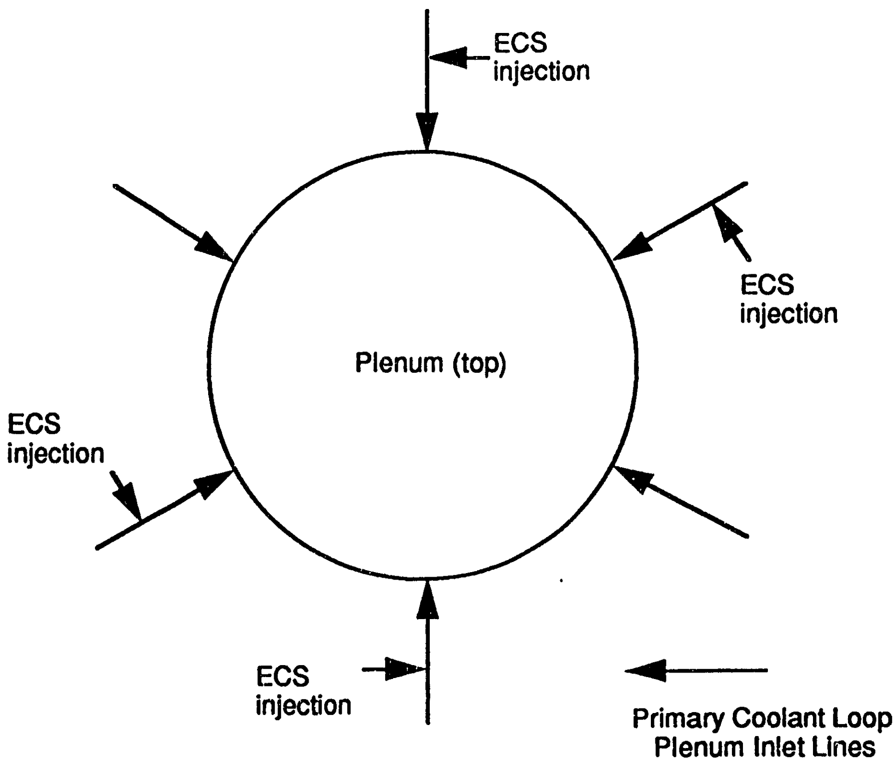

Figure 2. ECS Injection Paths

PRA, a set of "ECS success criteria" is used to specify the operational configuration of the ECS necessary to maintain adequate core cooling.

The LOCA ECS success criteria utilized in the Rev. 0 SRS PRA were based in part on the required minimum assembly flows calculated prior to 1987. (Here, the term "minimum assembly flow" refers to the lowest liquid coolant flow allowed in any assembly at any time during the LOCA.) Thus, it was desired to investigate and update these criteria for Rev. 1, taking into account the safety upgrades and new operating power. The thermal-hydraulic (t-h) computer code selected to help facilitate this update was RELAP5.[3]

It is generally recommended that analyses performed in support of a PRA should represent a "best-estimate" of the expected system performance. This is in direct contrast to the types of conservatisms built into analyses associated with design basis accidents. Thus, results from best-estimate t-h methods are usually more useful to PRAs than those obtained from conservative methods. For this reason, the assumptions and boundary conditions used in these analyses were carefully selected. The power decay data, pump coastdown model, and ECS supply data were different than those used in conservative safety analyses for K-Reactor. In addition, reactor trip setpoints, instrumentation delay times, cooling water temperature, and other parameters were changed to represent their best-estimate values.[4]

The scenarios analyzed were divided into small break LOCAs (SBLOCAs) and large break LOCAs (LBLOCAs), based on break size. Basically, a LBLOCA consisted of a double-ended-guillotine-break (DEGB) in a single primary coolant system pipe, while a SBLOCA considered a partial break in a single thermal expansion joint. Various break locations were considered, and in each case, the minimum configuration of the ECS required to successfully cool the core during the accident was determined.

II. CODE AND INPUT MODELS

The RELAP5 computer code was developed at the Idaho National Engineering Laboratory and provides advanced thermal-hydraulic system analysis capability.[3] The code is based on a nonhomogeneous, nonequilibrium, two-phase fluid model that utilizes a six equation formulation for the conservation of mass, conservation of energy, and momentum equations. Empirical correlations are used to model such phenomena as wall shear, interphase drag, and wall heat transfer. Although RELAP5 is primarily a one-dimensional code, multidimensional effects can be simulated to a limited extent using the so-called "crossflow" model. This model provides reasonable results in regions where fluid momentum in all but the primary flow direction is insignificant. Additionally, since RELAP5 has been applied primarily to the analysis of light water reactors (LWRs), a special version – MOD2.5 – was developed to accommodate the unique characteristics of the SRS reactors.[5]

Three-dimensional flow patterns in the inlet plenum and moderator tank can have important effects on the behavior of K-Reactor during a LOCA. Therefore, a six-loop, multidimensional RELAP5 model containing over 350 control volumes was developed at the INEL. This model was used in the design basis LOCA analyses documented in Reference 6, and the same model with minor modifications was used to perform the calculations described here.

III. RESULTS

The aforementioned K-Reactor model was applied to a series of SBLOCA and LBLOCA calculations. All total, 22 calculations were performed, varying the following parameters:

- <u>Break Location</u> - For the SBLOCAs, the break locations were in the pump suction and heat exchange discharge piping expansion joints. For the LBLOCAs, the break locations were in the pump discharge and plenum inlet piping.

- <u>Motor Status</u> - Procedures call for the operators to trip the AC motors during a LOCA to reduce the leak rate; it is possible that they could fail to do so. Additionally, four of the DC motors will run out of fuel in a relatively short period of time if electrical power is lost. Thus, calculations considered no AC trip, AC trip, and AC/4-DC trip.

- ECS Source - There are five possible ECS sources which can be utilized in any combination. (All calculations here used the weakest source.)

- Number of Injection Paths - There are four possible injection paths. (For this study, it was not necessary to have more than two operational.)

A representative plot of the flow through the minimum flow assembly (i.e., the assembly which has the lowest amount of coolant passing through it) during a SBLOCA is shown in Figure 3. This case involved a partial break in a single pump suction pipe expansion joint bellows at 10 s. The AC motors were tripped 80 s after the break, while the DC motors continued to operate throughout the transient. The leak rate from the small break was between 2,500 and 5,000 gpm, and the ECS easily provided more than 5,000 gpm of make-up flow, even with only one pumping source and one injection path (in the leaking loop) operational. The corresponding maximum fuel surface temperature is shown in Figure 4. It can be seen that the temperature dropped rapidly following scram, increased slightly as ECS coolant at 308 K (35°C) was injected, and then fell once again as cooler ECS coolant became available. (The first 20,000 gallons of ECS coolant is contained in a reservoir near the heat exchangers. ECS coolant added after this reservoir is exhausted comes from the Savannah River and is at a much lower temperature.) At no time did the surface temperature of the fuel assembly approach 373 K, so no boiling occurred.

As an example of the large-break events considered, a plot of flow through the minimum flow assembly during a representative LBLOCA is shown in Figure 5. In this case, the DEGB occurred in a single plenum inlet pipe at 10 s, and the AC motors were not tripped. The leak rate from the break was initially over 50,000 gpm but fell rapidly to around 10,000 gpm. The ECS was able to provide a sufficient level of make-up flow to prevent core melt with one pumping source and two injection paths operational (> 10,000 gpm). The corresponding maximum fuel surface temperature is shown in Figure 6. The temperature at first increased about 10 K as the break at 10 s caused a significant decrease in coolant flow prior to the reduction in core power due to scram. The temperature then dropped rapidly following scram, increased slightly as ECS coolant at 308 K was injected, and then fell once again as cooler ECS coolant became available. At no time did the surface temperature of the fuel assembly exceed 373 K, so boiling was again precluded.

Based on results including those detailed above, the LOCA ECS success criteria shown in Tables 1 and 2 were specified for the Rev. 1 PRA.

Table 1. Rev. 1 SBLOCA ECS Success Criteria

Number of Bingham Pumps Operating[a]	Number of ECS Pumping Sources Operating	Number of ECS Injection Paths Available	Number of Backflow Loops Allowed
2	1 (any)	1(any)	4

Table 2. Rev. 1 LBLOCA ECS Success Criteria

Number of Bingham Pumps Operating[a]	Number of ECS Pumping Sources Operating	Number of ECS Injection Paths Available	Number of Backflow Loops Allowed
2	1 (any)	2	4

a - only DC motors required

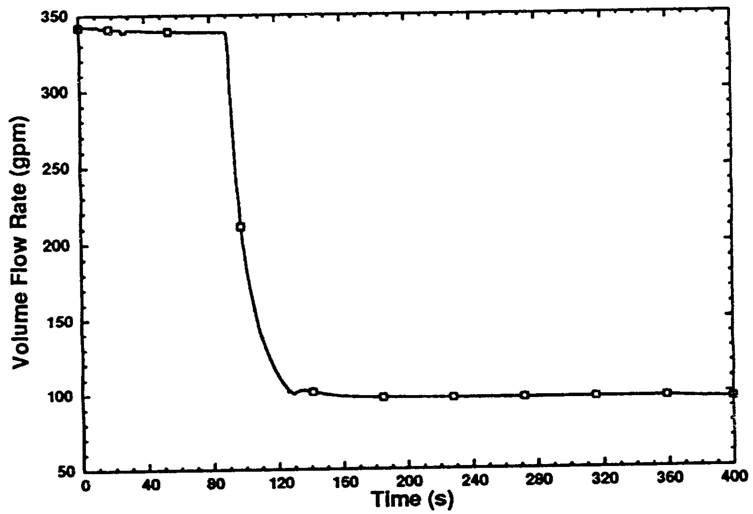

Figure 3.
SBLOCA - Minimum Assembly Coolant Flow Rate

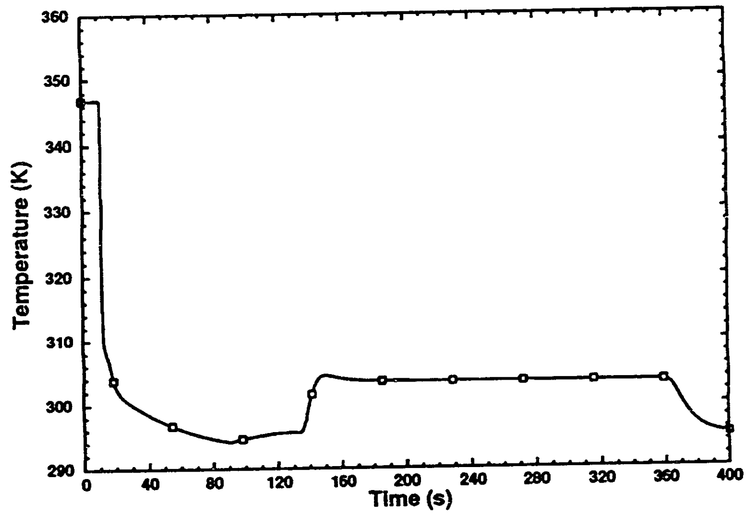

Figure 4.
SBLOCA - Maximum Fuel Surface Temperature

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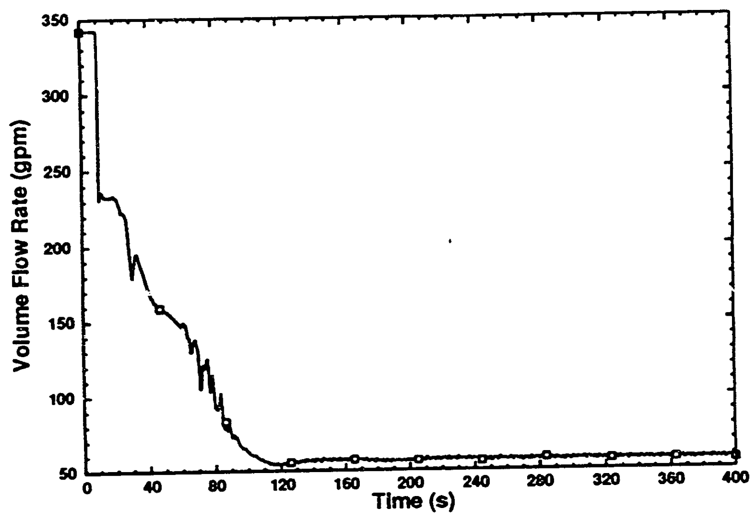

Figure 5.
LBLOCA - Minimum Assembly Coolant Flow Rate

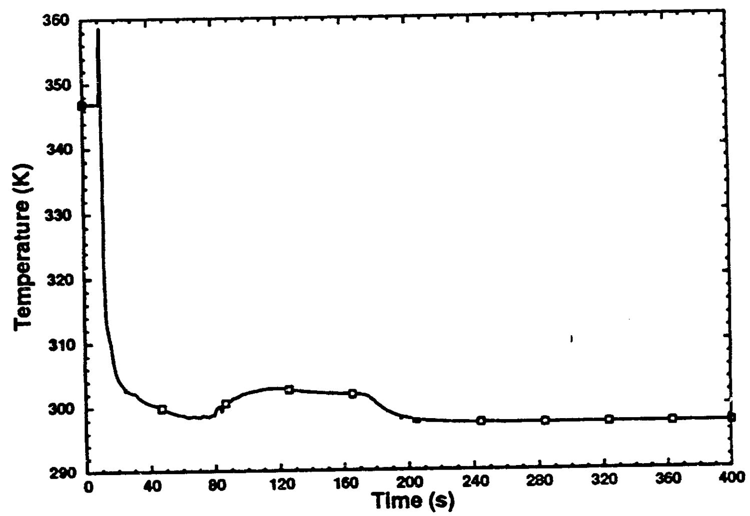

Figure 6.
LBLOCA - Maximum Fuel Surface Temperature

The column "Number of Backflow Loops Allowed" represents the maximum number of non-pumping loops in which the flow isolation valves do not have to be closed in order to adequately cool the core for the specified combination of Bingham pumps operating, ECS sources functioning, and injection paths available. These "backflow loops" generally provide a pathway for some ECS flow to circumvent the core and thus reduce ECS effectiveness. Note that, for the SBLOCA, the minimum number of ECS sources and injection paths was sufficient even with all of the non-pumping loops in backflow. For the LBLOCA, an additional injection path was required. The potential exists that a single path would be sufficient if multiple sources and/or some closure of flow isolation valves were considered. However, the number of calculations associated with these additional considerations was beyond the scope and timeframe of this work.

IV. IMPACT ON THE PRA

For comparison purposes, the LOCA ECS success criteria used in Rev. 0 are shown in Table 3. Only one set of criteria is listed since SBLOCAs and LBLOCAs were not treated separately. Looking at Tables 1, 2, and 3, it can be seen that the new criteria used in Rev. 1 are much less restrictive than those of Rev. 0. For example, a LBLOCA with two ECS injection paths is allowed four backflow loops without leading to core melt. Previously, only two backflow loops were allowed. Also, for all SBLOCAs, one injection path is now sufficient, while for Rev. 0, one injection path was never sufficient.

The preliminary results of the Rev. 1 Level 1 SRS PRA indicate a significant reduction in the severe core melt frequency (SCMF) due to LOCAs from the Rev. 0 value. Table 4 presents a comparison of the Rev. 0 and Rev. 1 results.

The large reduction in SCMF can be attributed to a number of factors: 1) installation of new safety systems designed to cope with LOCAs, 2) improved emergency operating procedures, 3) improved reactor operating training, 4) best-estimate ECS and shutdown system success criteria, and 5) reduction in operating power to 720 MW (30% historical).

Currently, the model uncertainty analyses intended to assess the specific impact of each of the above factors on SCMF are under way. Unfortunately, the results of these analyses were not available at the time of this writing. However, it can be stated that the consensus of the SRS PRA staff is that the use of LOCA ECS success criteria derived using best-estimate methods had a significant impact on reducing the SCMF in the Rev. 1 Level 1 PRA and that the new criteria represent a substantially more accurate prediction of the requirements for core cooling under severe accident conditions.

Table 3. Rev. 0 LOCA ECS Success Criteria (SBLOCA and LBLOCA)

Number of Bingham Pumps Operating[a]	Number of ECS Pumping Sources	Number of ECS Injection Paths	Number of Backflow Loops Allowed
2	1 (any)	4	3
		3/3[b]	3
		3/4[c]	2
		2	2

a - only DC motors required
b - three injection paths; none in the leaking loop
c - four injection paths; one in the leaking loop

Table 4. Rev. 0 and Rev. 1 SRS PRA SCMF for LOCAs.

PRA Version	LOCA Initiator Frequency Per Reactor Year	SCMF Per Reactor Year
Rev. 0	5.6E-3	1.2E-4
Rev. 1	5.6E-3	5.4E-6[a]

a- preliminary result

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