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SAVANNAH RIVER SITE REACTOR HARDWARE DESIGN MODIFICATION STUDY

J. E. Fisher
Idaho National Engineering Laboratory
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, Idaho 83415

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ABSTRACT

A study was undertaken to assess the merits of proposed design modifications to the Savannah River Site (SRS) reactors. The evaluation was based on the responses calculated by the RELAP5 systems code to double-ended guillotine break loss-of-coolant-accidents (DEGB LOCAs). The three concepts evaluated were (a) elevated plenum inlet piping with a guard vessel and clamshell enclosures, (b) closure of both rotovalves in the affected loop, and (c) closure of the pump suction valve in the affected loop. Each concept included a fast reactor shutdown (to 65% power in 100 ms) and a 2-s ac pump trip. System recovery potential was evaluated for break locations at the pump suction, the pump discharge, and the plenum inlet. The code version used was RELAP5/MOD2.5 version 3d3, a preliminary version of RELAP5/MOD3. The model was a three-dimensional representation of the K-Reactor water plenum and moderator tank. It included explicit representations of all six loops, which were based on the configuration of L-Reactor.

A combination of features is recommended to ensure liquid inventory recovery for all break locations. Valve closure design performance for a break location in the short section of piping between the reactor concrete shield and the pump suction valve would benefit from the clamshell enclosing that section of piping.

INTRODUCTION

The Savannah River Site (SRS) contains three production reactors operated for the U.S. Department of Energy (DOE). These reactors are cooled and moderated with heavy water and operate at low pressure and temperature. Figure 1 shows the configuration of an SRS reactor. It consists of a water plenum, a moderator tank containing approximately 600 fuel assemblies, and six external loops. Each loop contains a Bingham pump, powered by both ac and dc motors, two horizontal shell-and-tube heat exchangers connected in parallel, and associated piping. There is an isolation valve in each pump suction line, and a rotovalve in each heat exchanger outlet line. Hot reactor effluent is pumped from the bottom of the moderator tank and out through each loop where it is cooled by the heat exchangers. It then flows into the water plenum and is distributed to the fuel assemblies. Each assembly is a separate flow path; water enters at the top and exits at the bottom. The

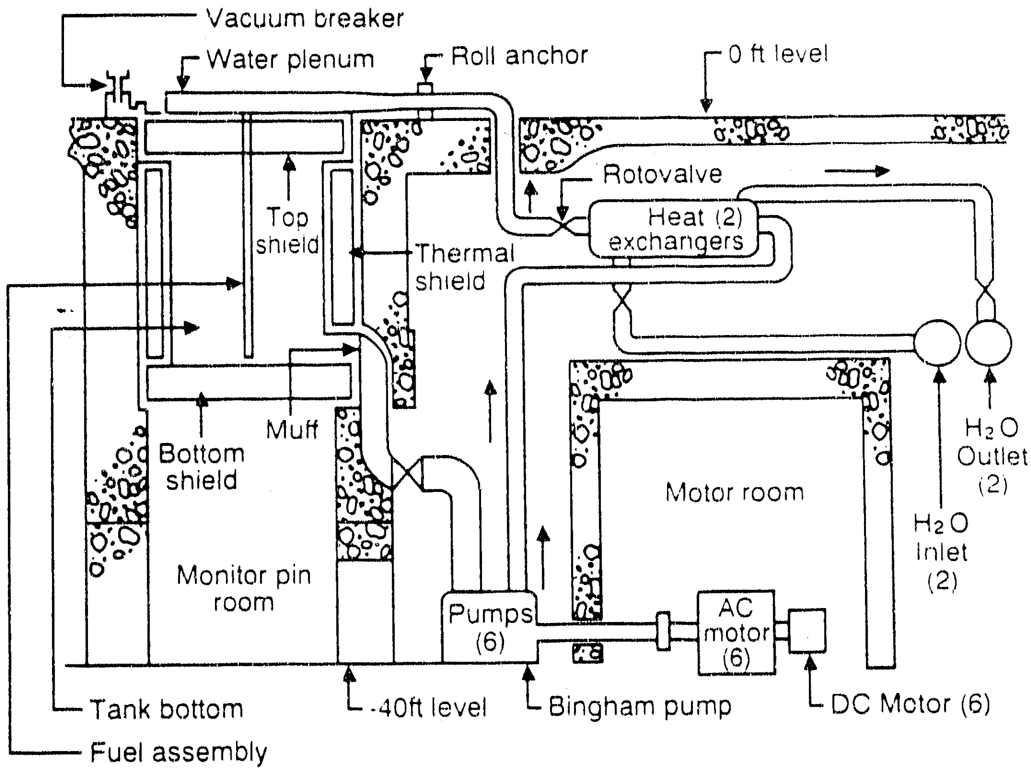

Figure 1. Schematic of an SRS reactor.

assemblies discharge into the bottom of the moderator tank, thus completing the flow circuit.

In December 1988 a team was chartered by DOE to evaluate potential design modifications intended to improve the core cooling performance of these reactors during a during a severe loss-of-coolant accident (LOCA).[1] The result was an integrated design concept which included: (a) elevated plenum inlet piping, (b) guarded piping between the tank outlet and the pump discharge and around the water plenum to a height of 6 ft, (c) an additional means for ECS injection, (d) an ac pump trip at 2 s, (e) reduced dc pump speed, and (f) a fast shutdown system. All the features were considered in concert; thus the merits of implementing individual modifications could not easily be determined, although the ac pump trip and the fast shutdown were recommended as stand alone options. Therefore, this study was undertaken to evaluate individual hardware modifications separately. Concepts evaluated were (a) the elevated piping (including the guard piping), (b) rotovalve closure in the affected loop, and (c) pump suction valve closure in the affected loop. All three design evaluations included the fast shutdown system and an ac pump trip. The study consisted of double-ended guillotine break (DEGB) LOCA calculations for plenum inlet, pump suction, and pump discharge break locations for the three concepts.

The RELAP5/MOD2.5 computer code was used for the evaluation. The following sections contain (a) descriptions of the RELAP5/MOD2.5 code, the model of the SRS K-Reactor, and the implementation of the design modifications, (b) the results of the calculations and a discussion of the relative merits and drawbacks of each design, and (c) the conclusions of the study.

CODE AND MODEL DESCRIPTION

The code version used in this analysis was RELAP5/MOD2.5[2] version 3d3. It contained heavy water property tables and updates which incorporate additional time step control for large changes in pressure and void fraction, limiting and smoothing condensation rate at low void fraction, and an improved water packing model. The updates are necessary for calculational success in the low pressure, low temperature operating region of the SRS reactors, and have been incorporated in RELAP5/MOD3.

Model Description

The model is a six-loop, three-dimensional representation of K-Reactor; the nodalization is shown in Figure 2. It was previously used for the comparison between RELAP5 and TRAC,[3] and was developed from a six-loop, three-dimensional RELAP5 model of L-Reactor.[4] A schematic of the three-dimensional plenum, moderator tank, and fuel assemblies is shown in Figure 3. A complete model description is contained in References 3 and 4. Modifications were made to model the hardware design changes for this study and to install the piping breaks in the required locations. These changes are described in the following section. Initial conditions used were the same as used in the RELAP5/TRAC comparison study and reported in Table 1 of Reference 3; power was 1326 MW, average pump suction temperature was 58.4°C, total pump flowrate was 157,989 gpm.

Description of Design Modifications

AC pump trip

The purpose of the pump trip is to reduce pumped break flow following a DEGB LOCA. The trip activates on the reactor scram signal with a 2 s delay time; it was included in the pump control variable logic so the effects of pump cavitation (prior to trip) would be included. The pump coastdown is controlled by a speed versus time table based on the L-area ac motor coastdown test,[5] and is shown in Figure 4. Pump speed goes from 1000 rpm (ac speed) to 291.7 rpm in the 100 s following the ac trip. The ac pump trip was included in the DEGB LOCA calculations for all the proposed design modifications.

DC pump operation at low moderator tank levels requires the lowest tank junctions have a height of 2 ft to properly include

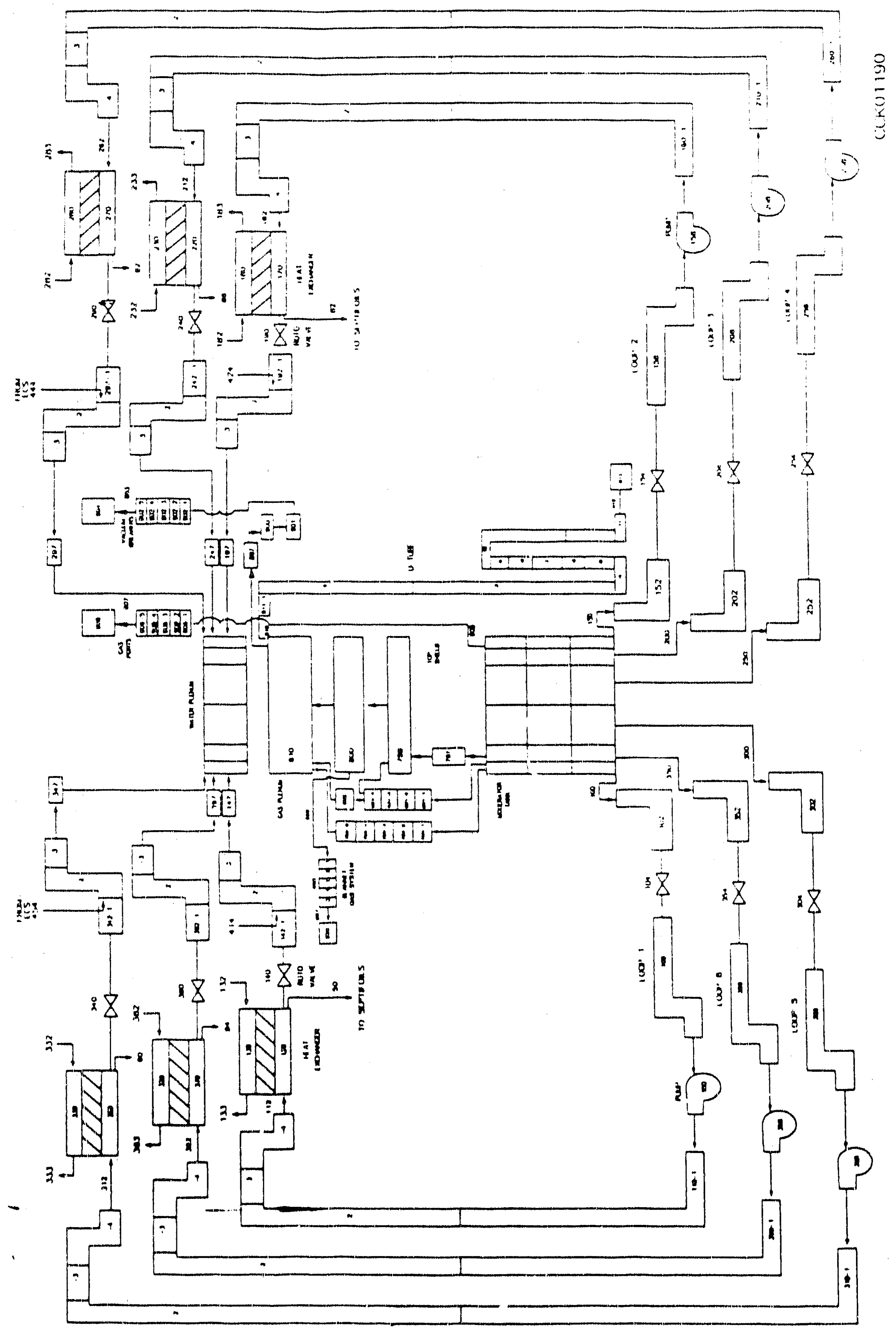

Figure 2. Nodalization of the six-loop model of K-Reactor.

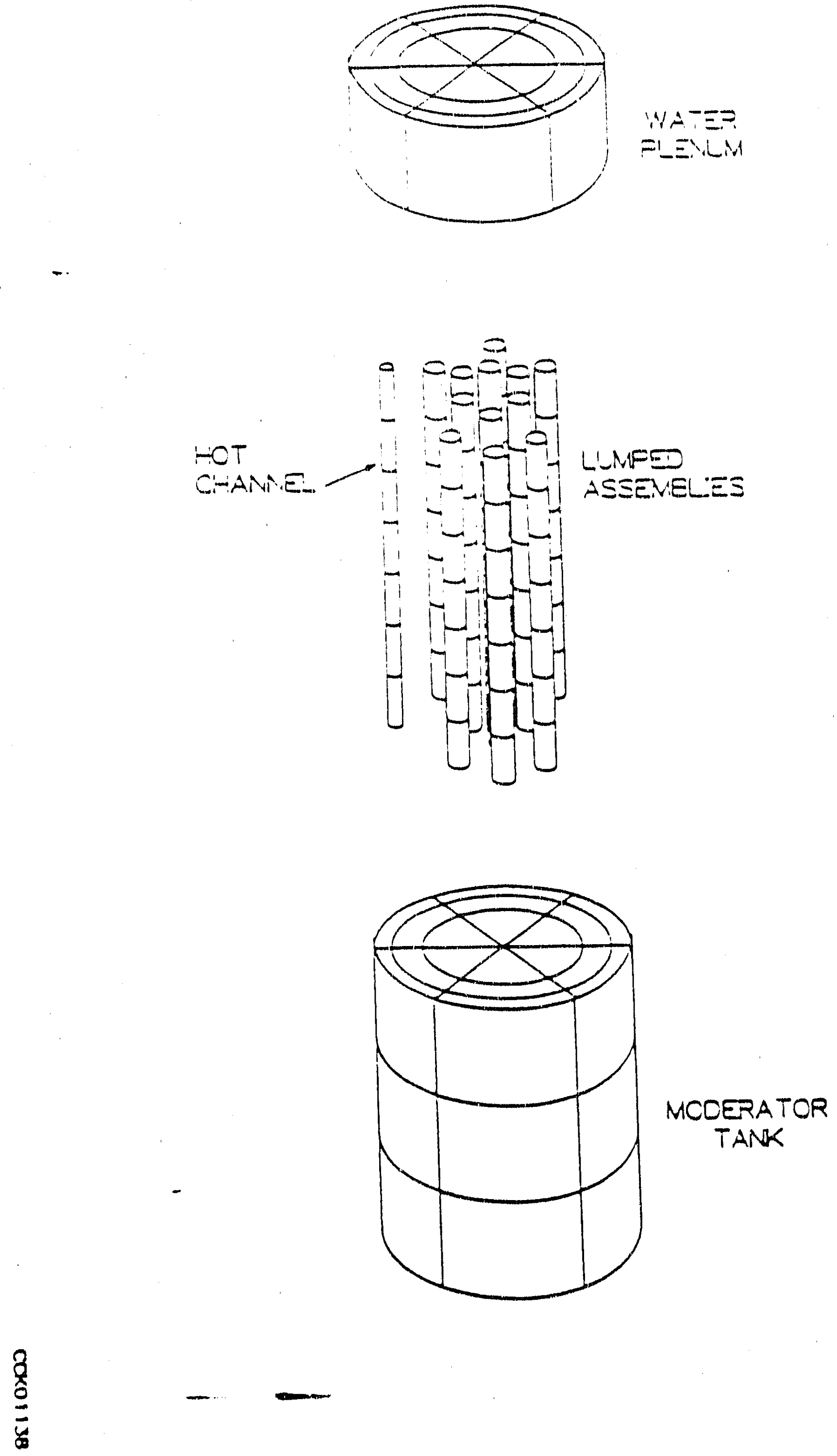

Figure 3. Schematic of the three-dimensional tank, water plenum, and fuel assemblies.

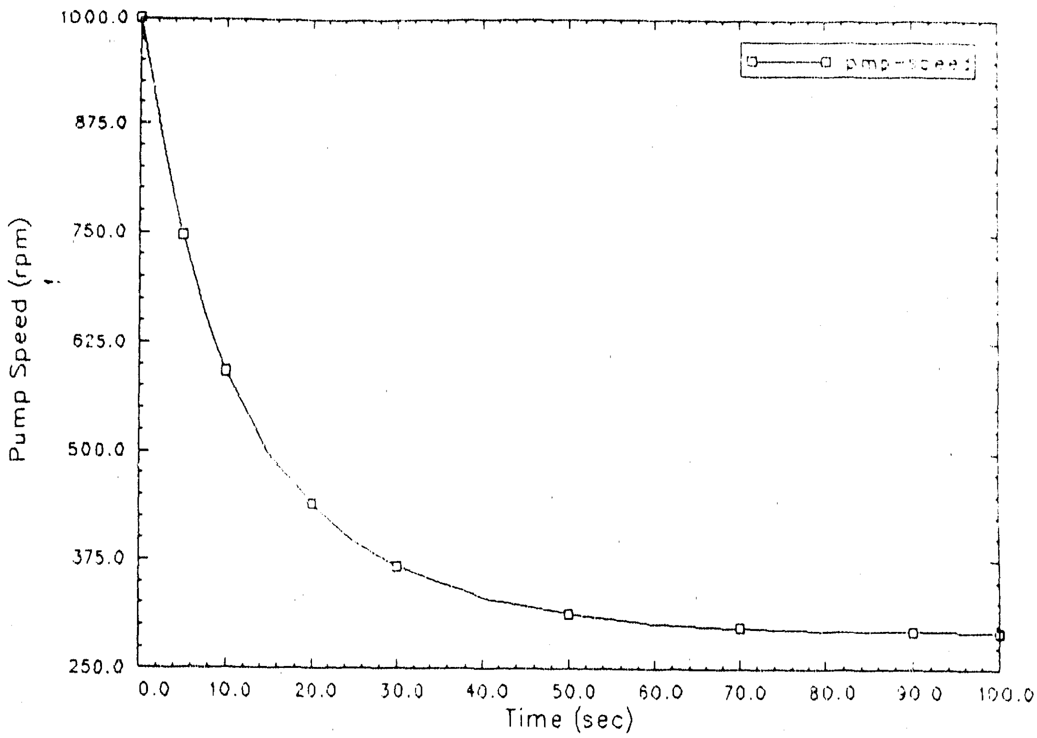

Figure 4. L-Reactor ac motor coastdown.

pump aspiration in the calculation. Pump aspiration is a vortex-related phenomenon which cannot be represented by discrete, one-dimensional volume models. As an approximation, introduction of noncondensible voids into the lowest tank volumes at the appropriate tank level causes some air to be transported into the loops, thereby simulating pump aspiration. As long as the middle tank volumes contain liquid, the bottom volumes are liquid solid, and no air can reach the pumps. But when level falls into the bottom volumes, the resulting two-phase mixture is drawn into the loops. A tank model with a bottom volume height of 2 ft was first implemented in the two-loop, one-dimensional RELAP5 model for the pre-test planning predictions for the 1989 L-Reactor tests.[6] The "dc tank nodalization" for the three-dimensional model was incorporated into the deck for the design modification evaluations.

Fast Shutdown System

A fast (100 ms) reactor scram was included in the input deck, but it did not noticeably alter the thermal-hydraulic response of the RELAP5 fuel assemblies. This is because of the fuel assembly flow path lumping, which tends to smear any localized hydraulic response due to the fast scram. Therefore, the thermal-hydraulic system response is not discernably different from a model with the unmodified scram.

Elevated Plenum Inlet Piping

The purpose of the elevated piping is to mitigate a DEGB LOCA occurring near the plenum inlet. The design is intended to provide additional static pressure head during the first few seconds following a DEGB LOCA to improve the margin to flow instability, and provide a means for maintaining static liquid level above the top of the plenum following moderator tank level recovery. Figure 5 illustrates the concept; the elevated piping extends 6 ft above the top of the plenum. The design includes two guard vessels. One surrounds the plenum and extends several feet above it to provide containment for breaks on the downward leg connected to the plenum nozzle, and the other is a clamshell device enclosing the pump suction and discharge piping, thus providing containment for breaks in the vicinity of the tank outlet or pump. The enclosed piping includes the vertical section of the pump discharge leg but not the horizontal leg over the top of the heat exchangers. RELAP5 calculations were performed for a

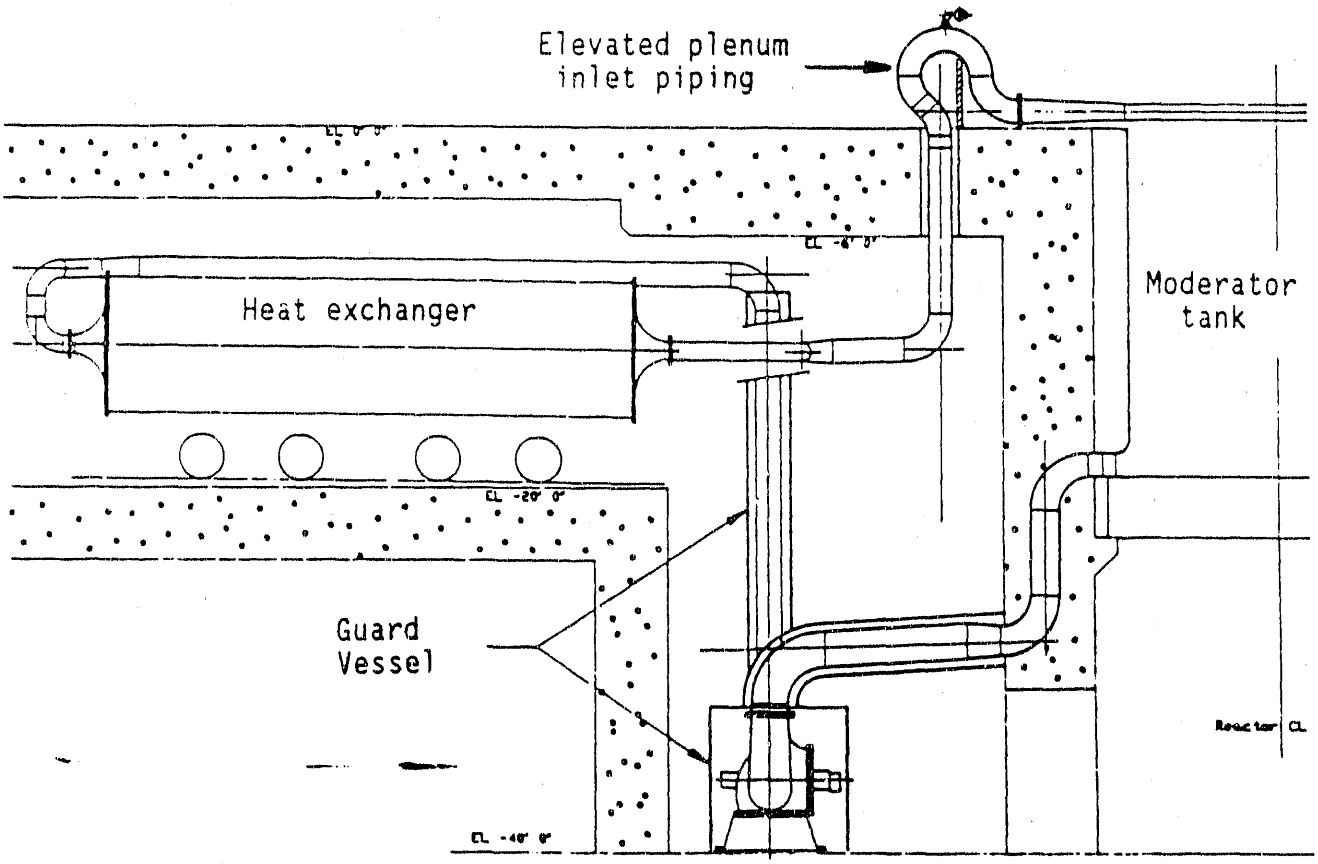

Figure 5. Elevated piping with guard vessels, elevation view.

DEGB LOCA at the plenum inlet (at the top of the elevated piping leg), and at the pump discharge (at the top of the vertical section of piping where the clamshell enclosure terminated). No pump suction break calculation was performed, because the clamshell enclosure provides containment for this break; it is then bounded by the prediction for the pump discharge break location.

Rotovalve and Pump Suction Valve Closure

RELAP5 DEGB LOCA calculations were performed considering automatic closure of isolation valves in the broken loop. Three break locations (pump suction, pump discharge, and plenum inlet) were considered with closure of: (a) the rotovalves and (b) the pump suction valve, for a total of six calculations. The valves were tripped on the reactor scram signal with delay times of 2 s; closure times were 10 and 30 s for the rotovalves and pump suction valve, respectively.

Thus, a total of eight DEGB LOCA calculations were performed to evaluate the performance of the three design modification concepts. All calculations included the fast shutdown system and the 2-s ac pump trip. The design calculations were compared to results of previous calculations for the present reactor configuration, which all used the three-dimensional, six-loop K-Reactor model and the 2-s ac pump trip. These previous results were preliminary scoping calculations and are not documented. The models used were predecessors of the present model, so they were not exactly the same; for example, the vacuum breaker and blanket gas system models were modified based on the RELAP5/TRAC comparison study, subsequent to all the reference calculations used in the comparison. Nevertheless, these reference calculations should provide representative responses of the unmodified SRS reactor system for comparison purposes. Details of the comparisons are presented below.

RESULTS AND DISCUSSION

Plenum Inlet Breaks

Results of the plenum inlet DEGB LOCA calculations for the three design modification concepts were compared to results of a K-Reactor plenum inlet break calculation.[a] Figure 6 compares moderator tank level responses for the four cases. For all calculations, ECS systems 1 and 5 were actuated at 10.8 ft tank level. For all cases except rotovalve closure, moderator tank level dropped to 5 ft, thereby causing ECS 4 actuation.

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a. R.A. Dimenna and J.S. Bollinger, "RELAP5 calculation of K-Reactor plenum inlet break with ac pump trip, using three-dimensional, six-loop model."

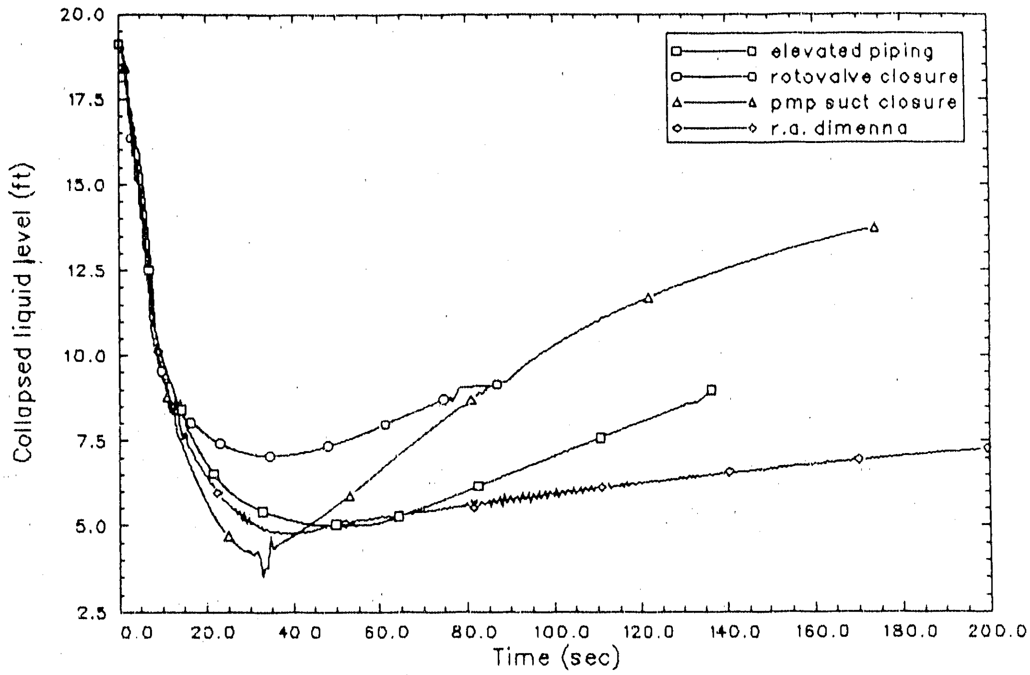

Figure 6. Moderator tank level for plenum inlet breaks.

Thereafter, tank levels recovered; minimum tank level predicted for the rotovalve closure case was 7 ft, and ECS 4 was never actuated. For the reference case, tank level recovered to greater than 7 ft at 200 s. All three modification concepts showed improvements in tank level recovery response. The elevated piping design showed the least improvement. Its advantage was primarily due to less plenum-side break flowrate because of additional head of piping. Rotovalve and pump suction valve closures both resulted in isolation of the loop-side break. Of these two designs, rotovalve closure is faster and was therefore more effective. Thus, for the plenum inlet break, tank level recovery is enhanced with design modifications; valve closure is more effective than elevated piping for recovering system inventory.

Plenum voiding was predicted for the elevated piping calculation, as for the reference case, as shown in Figure 7. For the elevated piping design, plenum voiding was predicted after about 45 s (similar to the reference case) but recovered, returning to zero at 125 s, and thus represented an improvement in predicted response. There was no plenum voiding predicted for the rotovalve or pump suction valve closure cases.

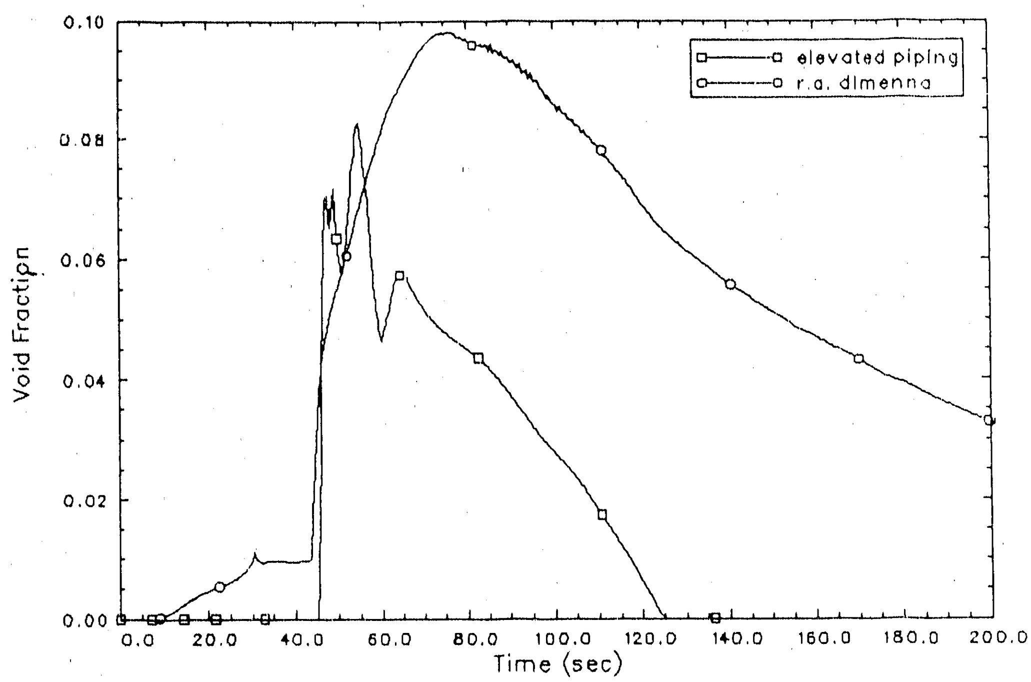

Figure 7. Plenum center void fraction responses for elevated piping design modification and reference case.

Pump Discharge Breaks

Results of the pump discharge DEGB LOCA calculations for the three design modification concepts were compared to results of a reference, K-Reactor calculation.[a] Figure 8 compares the predicted tank level responses for the reference calculation and the three proposed designs. Moderator tank level recovery was predicted for either rotovalve or pump suction valve closure. Rotovalve closure isolated the break from the heat exchanger side, and broken loop ECS flow was directed into the plenum. Tank level recovered from about 5 ft with the addition of ECS from 3 systems. Pump suction valve closure isolated the pump-side of the break; tank level recovered from about 4 ft.

The response for the elevated piping calculation was similar to that of the reference case; the main difference was the time to empty the moderator tank to the two-foot level. Tank level recovery was not predicted for either calculation.

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a. R.A. Shaw, "Calculation of pump discharge break with pump trip using RELAP5 three-dimensional, six-loop model."

One criterion for a successful design modification was to avoid plenum vacuum. Predicted sub-atmospheric plenum pressure response is associated with break locations between the pump and the heat exchanger outlet, because of the siphon between the plenum and the break location. It is recognized as a potential problem because it may cause air to be drawn from the gas space past the USH piston ring into the plenum and into a nearby assembly, resulting in a flow reduction (up to a factor of five) in that assembly. This phenomenon was observed during the simulated LOCA test in L-Reactor.[7] The threshold vacuum, or the value at which this leakage starts to occur, was about 1 to 2 psid for Mark 16B assemblies in L-Reactor. The USH piston ring flow path is not in the RELAP5 model, and its effects are not predicted. Therefore, the only indicator of incipient, random, local assembly flow reduction is predicted plenum vacuum. Figure 9 compares the plenum (inside ring) pressure predictions to atmospheric pressure. The predicted response with rotovalve closure indicates pressure slightly less than atmospheric pressure between 65 and 120 s. For the pump suction valve closure case minimum pressure was less: about 14.0 psi at 65 s (about 0.7 psi vacuum). Vacuum for these cases should be less than the threshold value. For the elevated piping and reference cases the minimum pressure values are about 12.0 and 11.7 psi, respectively (2.7 and 3.0 psi vacuum). Vacuum for these cases are greater than the expected threshold. Therefore, vacuum-related assembly flow reduction may occur for pump discharge breaks without valve closure, and should not occur for the loop valve closure designs.

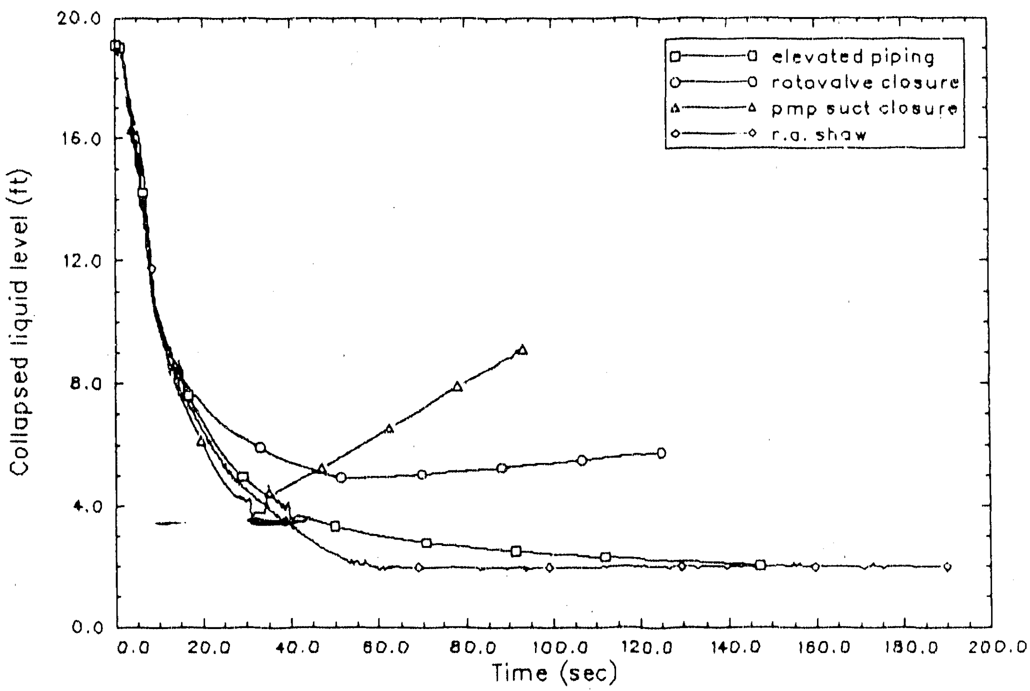

Figure 8. Moderator tank level for pump discharge breaks.

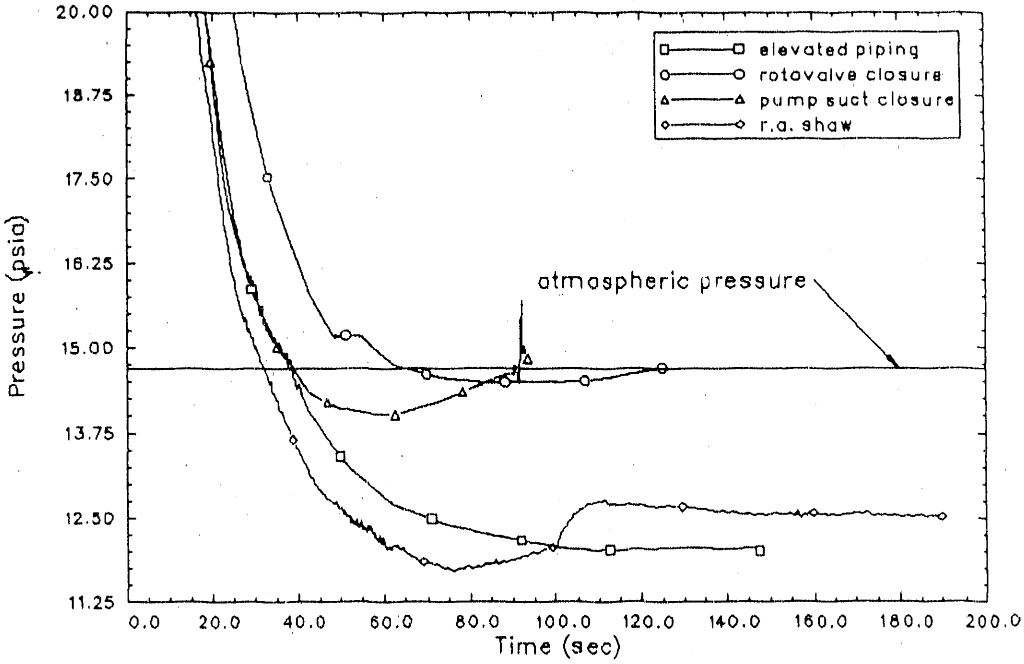

Figure 9. Predicted plenum pressure response comparison for pump discharge breaks.

Pump Suction Breaks

This break location was only analyzed for the rotovalve and pump suction valve closure designs. For the latter, the break location was chosen downstream of the pump suction valve to evaluate the effect of pump suction valve closure. Results of the pump suction DEGB LOCA calculations for the valve closure design concepts were compared to results of a reference, K-Reactor calculation.[a] Figure 10 shows tank level response for the three calculations. Pump suction valve closure isolates any break between the valve and the pump; the pump impeller effectively isolates the loop-side of the break. Moderator tank level recovery is predicted with a minimum level of greater than 8 ft. Consequences of unisolable breaks (between the tank outlet and the isolation valve) are not affected by valve closure. Predicted tank level for the rotovalve closure design were nearly the same as for the reference case. The difference was break location: the reference case break was located at the moderator tank muff, which results in higher initial break flowrate and faster tank level decrease. Table 2 summarizes the system behavior for of

a. C.B. Davis, "RELAP5 calculation of pump suction break with pump trip using three-dimensional, six-loop model."

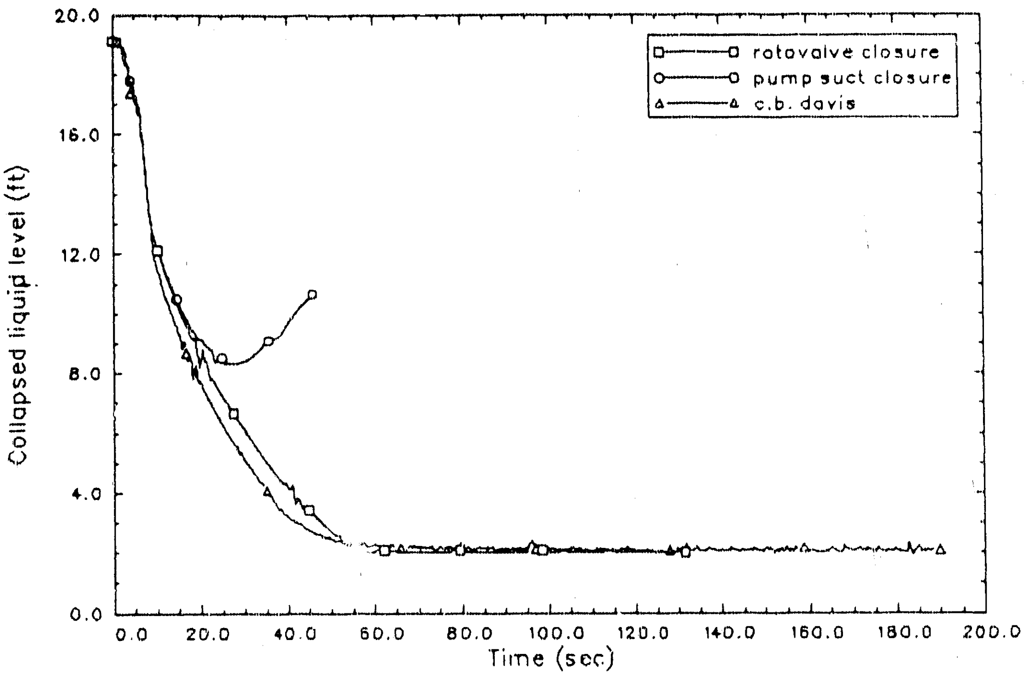

Figure 10. Moderator tank level for pump suction breaks.

each proposed design modification in response to DEGB LOCA transients.

CONCLUSIONS

The hypothetical advantage of the elevated piping design is its passive nature. It does not require component activation to accomplish its objective. The elevated piping design demonstrated satisfactory performance for plenum inlet and pump suction breaks, but did not achieve moderator tank recovery following a pump discharge break. Additional (active) measures are required to recover from this accident.

The rotovalve closure design demonstrated satisfactory response for plenum inlet and pump discharge breaks. It has no perceptible effect on the pump suction break. The pump suction valve isolation design demonstrated satisfactory system response for all breaks downstream of the valve. It has no effect on the hypothetical break between the moderator tank muff and the valve.

A combination of features is recommended to ensure favorable moderator tank level performance. The elevated piping concept, without additional options, does not provide the tank level recovery achieved by the valve closure designs. Rotovalve closure designs reduce system inventory losses in all but pump suction line breaks and improve moderator tank level recovery response.

Table 2. Results of DEGB LOCA calculations for proposed modifications.

Proposed design modification	Break location		
	Plenum inlet	Pump discharge	Pump suction
Elevated plenum inlet piping with guard vessels	• Tank level recovery from 5 ft • Plenum voiding 40-125 s • No plenum vacuum	• No tank level recovery • Plenum voiding not predicted • Plenum vacuum may starve fuel assemblies	• Pump suction piping enclosed in clamshell. • Pump discharge location is more severe
Rotovalve closure	• Tank level recovery from 7 ft • No plenum voiding • No plenum vacuum	• Broken loop ECS flow not lost • Tank level recovery from 5 ft • No plenum voiding • Plenum vacuum not significant	• No tank level recovery • Rotovalve closure has no effect
Pump suction valve closure	• Tank level recovery from 4 ft • No plenum voiding • No plenum vacuum	• Tank level recovery from 4 ft • Plenum voiding not predicted • Plenum vacuum not significant	• Break isolated if on loop side of valve • Tank level recovery from 8 ft

If a single valve closure design were implemented, the pump suction valve closure design should be chosen, because it provides improved response characteristics for all breaks downstream.

The worst break location, based on moderator tank level recovery considerations, is the unisolable pump suction break (in the short section of piping between the pump suction valve and the reactor concrete shield). The only design feature which offers protection for a DEGB LOCA at this location is the clamshell enclosure. To be effective, the design must be such that a single event cannot rupture both the pump suction pipe and the clamshell.

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3. C. B. Davis, A Comparison of RELAP5 and TRAC LOCA Calculations for the K-14.1 Charge at SRS, EGG-EAST-8608, June, 1989.

4. M. A. Bolander and C. B. Davis, Benchmarking the Six-Loop, Three-Dimensional RELAP5 L-Reactor Model with Savannah River Reactor Test Data, EGG-EAST-8556, June 1989 (Draft).

5. M. J. Giess, "L-area AC Motor Coast-down Test," RTR-2553, May 26, 1988.

6. R. A. Shaw et al., RELAP5 Calculations for Tests to be Conducted in the L-Reactor at the Savanah River Plant, EGG-EAST-8461, April 1989.

7. J. M. Steimke, "Simulated Loss of Coolant Accident Test," DPST-84-815, October 5, 1984.

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