WSRC-RP-89-47, Rev 1

LARGE BREAK FREQUENCY FOR THE SRS PRODUCTION REACTOR PROCESS WATER SYSTEM (U)

by

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A paper proposed for presentation
Second DOE Natural Phenomena Hazards Mitigation Conference
Knoxville, TN
October 3-5, 1989

and for publication in the Proceedings of the meeting

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ABSTRACT

The objective of this paper is to present the results and conclusions of an evaluation of the large break frequency for the process water system (primary coolant system), including the piping, reactor tank, heat exchangers, expansion joints and other process water system components. This evaluation was performed to support the ongoing PRA effort and to complement deterministic analyses addressing the credibility of a double-ended guillotine break.

This evaluation encompasses three specific areas: the failure probability of large process water piping directly from imposed loads, the indirect failure probability of piping caused by the seismic-induced failure of surrounding structures, and the failure of all other process water components. The first two of these areas are discussed in detail in other papers. This paper primarily addresses the failure frequency of components other than piping, and includes the other two areas as contributions to the overall process water system break frequency.

The most vulnerable components are the expansion joints. The large break frequency for the expansion joints is estimated to be 9.7×10^{-6} per reactor-year. This break scenario is equivalent in severity to a double-ended guillotine break of the adjoining pipe. A limited break with restricted flow area is a much more likely failure scenario for these components, with an estimated frequency of 5.6×10^{-3} per reactor-year.

The combined large break frequency for the entire process water system under directly imposed loads is about 1.5×10^{-5} per reactor-year. Added to this is the indirect failure probability. Although the indirect failure probability was calculated specifically for the piping, it serves as a rough estimate of the indirect threat to the entire process water system. This source contributes 7.8×10^{-7} per reactor-year (median estimate) for L or K reactor. Differences in the reactor building for P reactor lead to slightly different results.

INTRODUCTION

The Savannah River Site (SRS) production reactors operate at low temperature and pressure. The material of construction for the primary pressure boundary is Type 304 stainless steel. These reactors were built in the 1950's, and have undergone various modifications and upgrades since that time. The Reactor Materials Program was initiated in 1985 to characterize the integrity of the process water system (primary coolant system) and estimate the remaining useful lifetime of the reactors. One subtask of this program was to estimate the failure frequency for each component of the process water system. This paper reviews and summarizes the failure frequency estimates. The failure frequency for the piping (by both direct and indirect means) is discussed in detail in companion papers and is summarized herein for completeness.

DISCUSSION

The process water system loop is comprised of the reactor tank (including outlet nozzles), main circulation pump, two heat exchangers, inlet nozzles to the tank plenum and the interconnecting piping. In addition, the process water system contains valves, expansion joints and flanges. The failure frequency of each of these components has been evaluated and is discussed separately below.

The main concern of this paper is the frequency of a sudden large break of the primary pressure boundary. Loss of coolant through pump shaft seals or valve stem leakage are of no concern to this evaluation. Likewise, a through-wall crack with its ensuing leakage is not of concern here, unless it could lead to a rupture before being detected and corrected.

The SRS production reactors have been operating successfully for approximately 35 years. Due to their age, history and various unique features they do not lend themselves readily to standard probabilistic analyses. In particular, while failure analyses of piping has been developed in great detail for commercial reactors and could be adapted to SRS reactor piping, no comparable analytical tools are readily applicable to SRS reactor components such as the reactor tank or expansion joints. For this reason, the failure frequency estimates discussed in this paper have been developed in part from engineering judgment. Several consultants, with vast experience in the industry, have assisted with these evaluations. Comparison to industry experience or statistical treatment of operating data is included where relevant information is available; however, in many cases the operating conditions and unique design features of the SRS reactors limit the applicability of such data from other sources. Further discussion of the basis for the component failure frequencies is given in reference [1].

HEAT EXCHANGERS

The SRS reactors each have 12 horizontal once-through heat exchangers. Portions of the heat exchanger pressure boundary that contact the primary coolant are the inlet and outlet heads and the tubes. A failure of one or several tubes does not constitute a severe accident in terms of a threat to the core. The primary source of a large LOCA from the heat exchangers is the inlet or outlet heads. Each head is held in place by 84 staybolts. Seventy-two C-clamps around the periphery provide additional restraint, although restraint is not their primary purpose. Figure 1 illustrates the heat exchanger and details of the head configuration.

During 720 heat exchanger-years of experience at SRS with the current heat exchanger design there have been 77 cases of cracking in the heads, primarily in the inlet heads. Nine of these cracks leaked. The ductile behavior of the austenitic stainless steel in the heat exchanger heads, and the sensitive leak detection system provide high confidence that cracking will not lead to large failures. On the basis of engineering judgment, the failure frequency for the heat exchangers is estimated to be 1×10^{-7} per heat exchanger-year.

REACTOR TANK

The reactor tank wall is constructed of 0.5 inch thick stainless steel plate. Because of the similarity between the tank and the process water piping, the probability of cracking and leakage is expected to be similar to the corresponding value for the piping. However, the likelihood of a catastrophic failure is extremely low, based on mechanistic analyses showing the tank would leak before breaking. On this basis, the tank failure frequency is judged to be similar to or less than values typically cited for power reactor vessels. In general, power reactor PRA's use the WASH-1400 value for pressure vessel failure of 2.7×10^{-7}. Therefore, a value of 3×10^{-7} is appropriate for the SRS reactor tanks.

PLENUM INLET NOZZLES

The plenum inlet nozzles are constructed of wrought plate and stainless steel castings which are welded together with internal flow vanes. The flow vanes act to reinforce the nozzle against pressure loads. The inherent toughness of the material and the sensitive leak detection system provide high confidence that a crack would not lead to sudden rupture. Therefore, the failure scenario of concern is the failure of the flow vane attachment (the vanes are attached by either staybolts or fillet welds) combined with a severe overpressurization accident.

Among the 5 SRS reactors (three of which remain operational) there are approximately 750 nozzle-years of successful operation without a failure. Statistical treatment of this data produces a median estimate of the failure frequency of 3.1×10^{-4} per year. This estimate is controlled by

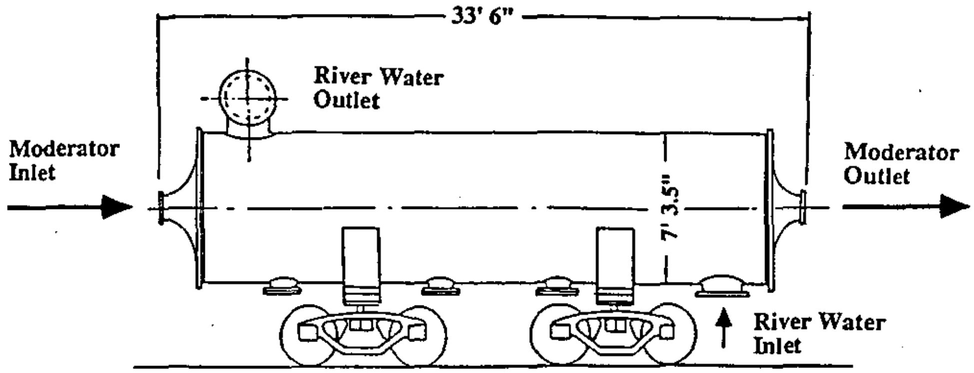

Figure 1a. Heat Exchanger Configuration

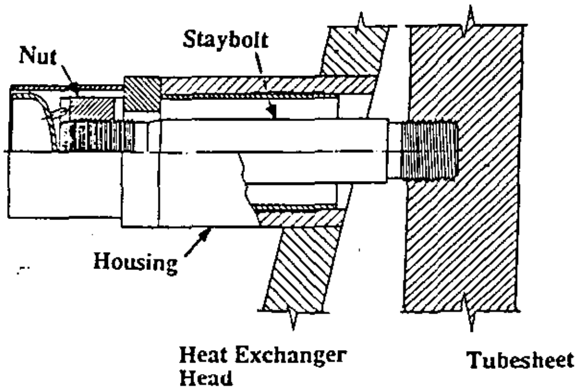

Figure 1b. Detail of Heat Exchanger Staybolt

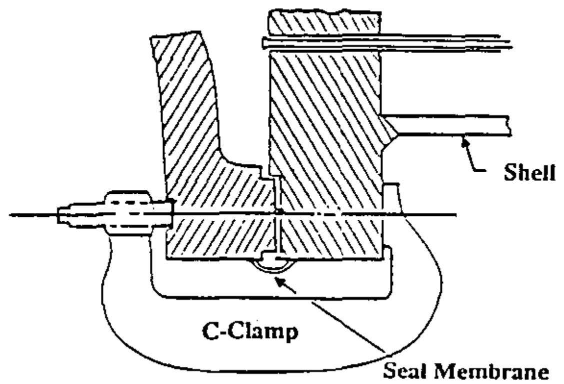

Figure 1c. Detail of Heat Exchanger C-Clamp

the relatively low number of operating years. A review of additional data supports a much lower estimate.

Several original casting defects exist in the nozzle castings. These are inspected periodically and have shown no significant change. No other degradation has been observed in the nozzles, although accessibility to the flow vanes is difficult and non-destructive examination in the cast sections is of limited reliability. Nevertheless, efforts are in progress to verify the integrity of the entire nozzle, including flow vanes. Service conditions are generally mild, with low operating stresses. On this basis, the failure frequency is estimated to be less than 1×10^{-8} per nozzle-year. Verification of the flow vane attachment integrity will further enhance nozzle integrity and provide support for a lower estimate.

EXPANSION JOINTS

Unlike commercial power reactors where expansion joints are limited to application outside the primary system, the SRS reactors contain expansion joints as part of the primary pressure boundary. The expansion joints contain stainless steel convolutes. The expansion joint convolutes are the only part of the primary pressure boundary for which analyses have not demonstrated a leak-before-break (LBB) capability. As such, the possibility of a sudden rupture of the convolutes is assumed to present a very real threat.

Approximately 2250 expansion joint-years of operating experience in the primary system has been developed at SRS. There have been 19 leaks in SRS expansion joints, but no breaks. Most of these leaks were induced by fatigue during the early years of operation. Subsequent modifications greatly reduced the incidence of leakage. With no breaks in the operating history, a statistical treatment gives an estimate of the true failure rate. Assuming failures are randomly distributed in time, we have the expression:

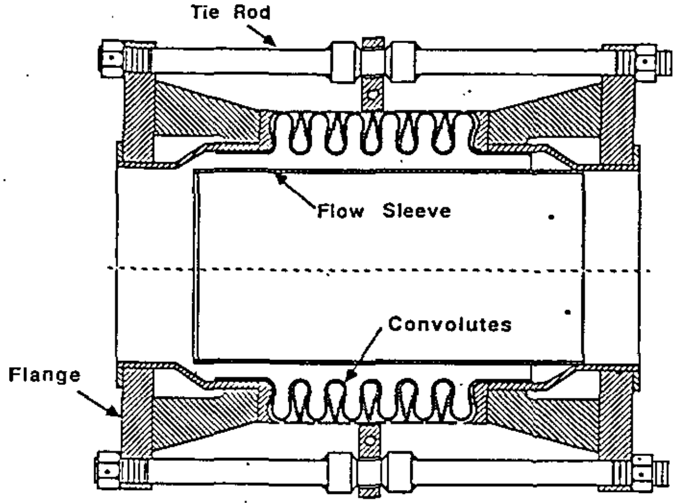

Figure 2. Expansion Joint Design

$\lambda = 1 - (Pr)^{1/m} = 1 - (0.5)^{1/2250} =$
3.1×10^{-4} per expansion joint-year.

Taking Pr equal to 0.5 represents a 50% probability of obtaining zero breaks in m expansion joint-years.

Failure of the convolutes alone will not produce a large break, due to the presence of an internal flow sleeve (see Figure 2). A large break would require either of two additional events: (1) the flow sleeve is not present (due to prior failure or a previous omission of the sleeve), or (2) the external restraints (tie rods) fail and allow the joint to stretch out. Stretchout of the joint is assumed to lead to convolute failure at the same time. Inspection of the flow sleeves and their attachment welds provides confidence that the probability of a missing sleeve is no greater than 10^{-3} per expansion joint-year, based on engineering judgment. The evaluation of external restraints conservatively considers only the tie rods and ignores any contribution from nearby supports and components. Based on a statistical treatment of tie rod experience (three tie rod failures, but none leading to joint failure) and inspections to verify current tie rod integrity, the probability of joint stretchout is estimated to be 2.3×10^{-7} per expansion joint-year at a 50% confidence level. Combining these numbers provides an overall estimate of a expansion joint large break break:

$Pr(EJ) = (3.1 \times 10^{-4}) \times (1 \times 10^{-3}) + 2.3 \times 10^{-7} =$
5.4×10^{-7} per expansion joint-year.

Additional discussion of expansion joints may be found in references [1] and [2].

PUMPS AND VALVES

Due to the functional requirements on pumps and valves for rigidity, these components are typically much thicker than required by the ASME Code from a pressure boundary standpoint. Leakage through seals and valve packing is common, but such leaks in most cases are small and will not be considered here. The valve and pump bodies are made of cast stainless steel. This material contains sufficient ferrite to render them not susceptible to intergranular stress corrosion cracking. Because of the structural overdesign of these components in order to meet functional requirements, a pump or valve would most likely fail as a result of bolting failure; either the flange bolting, valve bonnet bolting or pump suction cover bolting. In general, as one or more bolts failed, the joint would tend to open and allow leakage, thus leading to early detection of the condition.

The failure frequency estimate for the valves is based on failure of the bolted joints. Counting the bonnet bolting and one-half of each end flange as part of the valve gives two bolted joints per valve. Using the failure frequency for flanged joints developed below, the valve failure frequency becomes $2 \times (5 \times 10^{-9}) = 1 \times 10^{-8}$ per valve-year. An O-ring seal in the pump suction cover might prevent detection of such leakage, however. Therefore, the pump failure frequency is higher, or 1×10^{-7} per pump-year.

FLANGED JOINTS

The process water system contains flanged joints, both B16.5 150 and 300 Class, connecting various components to the piping and connecting pipe segments. There have been, or are now, an estimated 30 million B16.5 150 or 300 Class joints, 6 NPS and larger, in service throughout the world over the past 60 years. A review of available information has failed to identify any breaks in 6 NPS or larger B16.5 joints [3]. Assuming that any breaks would be distributed randomly in time and applying the statistical treatment presented above for expansion joints, the failure frequency for flanged joints is 1×10^{-7} per joint-service life. This value is based on a 95% upper bound confidence level. Assuming an average useful service life of 20 years gives a failure frequency of 5×10^{-9} per joint-year.

PROCESS WATER PIPING

The piping is mentioned here for completeness. Details are provided in two companion papers [4,5]. Piping failure is evaluated for two cases; as a result of loads acting directly on the pipe, and as a result of seismic loads acting indirectly, such that the failure of a nearby component or building structure leading to the failure of the piping. The piping direct failure frequency is estimated to be 1.6×10^{-6} per reactor-year.

The indirect failure frequency was evaluated for seismic loads ranging up to 1.5g peak ground acceleration. For this extreme case, the median failure frequency is 7.8×10^{-7} per year for L and K reactors, and 1.3×10^{-6} for P reactor. The different value for P reactor is due to a difference in the reactor building, which affects the building fragility.

RESULTS

A summary of the failure frequency for each component is given in Table 1. The total direct large break frequency for the process water system is obtained by summing each individual contribution. As seen from Table 1, the expansion joints contribute approximately two-thirds of the total direct failure frequency. The acceptability of this contribution is assessed in terms of the risk it presents. Preliminary results from a level 1 PRA for the SRS reactors show that a large break in the expansion joint contributes no more than 28% of the total core damage frequency [6]. The failure frequency for each of the remaining components is extremely low, on the order of 10^{-6} or less.

The indirect failure frequency was developed specifically for the piping. However, those indirect failure scenarios which threaten the piping also threaten other components. Similarly, there would be few failure scenarios that threaten other components that do not also threaten the piping. Therefore, the indirect piping failure frequency approximates the indirect failure frequency for the entire process water system.

Table 1. Summary of Component Failure Frequencies

Component	No. Components Per Reactor	Failure Frequency (per year) Per Component	Per Reactor
Process Water Piping (Direct)	---	---	1.6×10^{-6}
Heat Exchangers	12	1×10^{-7}	1.2×10^{-6}
Main Tank	1	3×10^{-7}	3×10^{-7}
Plenum Inlet Nozzles	6	1×10^{-8}	6×10^{-8}
Expansion Joints	18	5.4×10^{-7}	9.7×10^{-6}
Pumps	6	1×10^{-7}	6×10^{-7}
Valves	28	1×10^{-8}	2.8×10^{-7}
Flanged Joints (4 NPS and Larger)	144	5×10^{-9}	7.2×10^{-7}
Total (Direct)			1.5×10^{-5}
Indirect (1.5g, median)	7.8×10^{-7}, L and K reactors 1.3×10^{-6}, P reactor		

CONCLUSIONS

The failure frequencies for each component in the process water system of the SRS production reactors has been evaluated. This work has been performed in support of the SRS PRA effort and as an adjunct to deterministic analyses of the integrity of the process water system. The probabilistic analyses, combined with the deterministic analyses, strongly support the conclusion that a sudden large break in the process water system is incredible.

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ACKNOWLEDGEMENT

The information contained in this article was developed during the course of work under Contract No. DE-AC09-76SR00001 (now Contract No. DE-AC09-88SR18035) with the U. S. Department of Energy.