EGG-M--92256

DE93 005191

COMPONENT EXTERNAL LEAKAGE AND RUPTURE FREQUENCY ESTIMATES[a]

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ABSTRACT

External leakage and rupture frequencies have been generated in a consistent manner from Licensee Event Reports covering U.S. commercial nuclear reactor experience. Recommended frequencies cover a wide variety of components: piping (and elbows), valves, pumps, flanges, heat exchangers, and tanks. Leakages were defined as less than or equal to 50 gpm, and ruptures as greater than 50 gpm. External rupture frequencies are generally factors of 25 or 100 times lower than the external leakage frequencies.

INTRODUCTION

In order to perform detailed internal flooding risk analyses of nuclear power plants, external leakage and rupture frequencies are needed for various types of components - piping, valves, pumps, flanges, and others. However, there appears to be no up-to-date, comprehensive source for such frequency estimates. This paper presents the results of a data search performed to determine such estimates.

METHODOLOGY

External leakage and rupture events for components in nuclear power plants were identified by searching Licensee Event Reports (LERs) contained in Nuclear Power Experience (NPE).[1] NPE is mainly a compilation of LERs from U.S. commercial nuclear power plants. However, the descriptions of events are often given in more detail in NPE compared with the actual LERs. The computer data base for NPE was searched using the following key words: internal leak, external leak, unspecified, flooding, and crack/indication. The search covered the period September 1960 through June 1990. Events identified from the search were reviewed in detail to 1) determine if the event actually involved an external leakage or rupture and 2) classify the event by plant, component and system, failure mode and cause, leakage (if known), and piping size. Leakage was defined as less than or equal to 50 gpm, and rupture as greater than 50 gpm.

The external leakage and rupture data were converted to component leakage and rupture frequencies in a three-step process. First, the ratios of external rupture events to external leakage and rupture events were examined for various components, component sizes, and systems to decide how to group the data. Then, final probabilities of an external rupture, given an external leakage or rupture event, were determined. Finally, by estimating component populations and exposure time, the external leakage and rupture frequencies were obtained.

For both the rupture probabilities and the leakage frequencies, a Bayesian update of a noninformative prior was used.[2] The equations are the following:

$$P_R = (2n + 1)/(2D + 2)$$

$$F_L = (2D + 1)/(2T)$$

where

P_R = mean probability of an external rupture, given an external leakage or rupture

F_L = mean external leakage frequency

n = number of external ruptures

D = number of external leakages and ruptures

T = component exposure time (h).

Component exposure times, not contained in the LERs or NPE, were estimated using a variety of sources. For piping, the report Pipe Break Frequency Estimation for Nuclear Power Plants was used.[3] For pumps and valves, In-Plant Reliability Data reports were used.[4,5] For other types of components, generic estimates were used.

[a]Work supported by the U.S. Department of Energy, Assistant Secretary for Nuclear Energy, under DOE Idaho Field Office Contract DE-AC07-76ID01570.

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RESULTS

The recommended component leakage and rupture frequency estimates are presented in Table 1. Also shown in Table 1 are the numbers of events found in NPE upon which to estimate the frequencies. Finally, recommended error factors (EFs) are also presented. (An error factor is the 95th percentile value divided by the 50th percentile value of a distribution.) The EFs were not derived from the data analysis. Rather, the EFs are based on the judgement and the belief that rupture frequency estimates are more uncertain than leakage frequency estimates. A lognormal distribution is suggested for the frequency estimates.

Comparisons of the recommended leakage and rupture frequency estimates with other sources are shown in Table 2. A review of Table 2 indicates that the recommended values from this paper are in general lower than most of the other sources.

DISCUSSION

Review of the leakage and rupture events identified from NPE indicated the following:

- There appears to be no significant differences in frequencies between piping with diameters less than three inches and larger piping.
- There appears to be no significant difference between pressurized water reactor (PWR) and boiling water reactor (BWR) component external leakage and rupture frequencies.
- It is possible to distinguish between external rupture frequencies for components in primary coolant systems (PCSs) and external rupture frequencies for components in other systems. This difference may be the result of better inspection and leak detection methods for PCS components. (No significant differences in external leakage frequencies exist between the two classes of components.)
- External rupture frequencies generally are factors of 25 or 100 times lower than external leakage frequencies and are dependent on the type of component and whether the component is in the PCS.
- The reduced reporting requirements for LERs, initiated in 1984, affect the number of events being reported each year. Therefore, external leakage and rupture frequency estimates were based on data from 1960 through 1983.

More details on the data search, the methodology, and the results can be found in Reference 6.

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Table 1. Recommended component external leakage and rupture frequencies.

Component/Failure Mode	Mean Frequency (Error Factor)	Number of Events
Piping (including elbows)		
Leakage	3.0E-9/h-ft(10)	591
Rupture	1.2E-10/h-ft(30)(non-PCS)[a]	17
	3.0E-11/h-ft(30)(PCS)[b]	0
Valve		
Leakage	1.0E-8/h(10)	170
Rupture	4.0E-10/h(30)(non-PCS)	7
	1.0E-10/h(30)(PCS)	0
Pump		
Leakage	3.0E-8/h(10)	50
Rupture	1.2E-9/h(30)(non-PCS)	2
	3.0E-10/h(30)(PCS)	0
Flange		
Leakage	1.0E-8/h(10)	167
Rupture	1.0E-10/h(10)(non-PCS)	1
	1.0E-10/h(10)(PCS)	0
Heat exchanger		
Tube		
Leakage	1.0E-7/h(10)	60
Rupture	4.0E-9/h(30)(non-PCS)	1
	1.0E-9/h(30)(PCS)	0
Shell		
Leakage	1.0E-8/h(10)	2
Rupture	4.0E-10/h(30)(non-PCS)	0
	1.0E-10/h(30)(PCS)	0
Tank		
Leakage	1.0E-8/h(10)	12
Rupture	4.0E-10/h(30)(non-PCS)	2
	1.0E-10/h(30)(PCS)	0

a. For components not in the primary coolant system
b. For components in the primary coolant system

Table 2. Component external leakage and rupture frequency comparisons.

Component Failure Mode	External Leakage and Rupture Mean Frequency Estimates: Recommended	WASH-1400[a]	Seabrook PRA[b]	Shoreham PRA[c]	LER Reports[d]	Piping Study[e]
Piping (elbows included)						
Leakage	3.0E-9/h-ft(10)[f]	8.5E-9/h-ft(<3in)[g] or 8.5E-10/h-ft(>3in)	-	8.5E-11/h-ft(<3in) or 8.5E-12/h-ft(>3in)	-	9.5E-11/h-ft
Rupture	1.2E-10/h-ft(30) (non-PCS)[h]	4.3E-10/h-ft(<3in) or	-	4.3E-12/h-ft(<3in) or	-	-
	3.0E-11/h-ft(30) (PCS)	4.3E-11/h-ft(>3in)	-	4.3E-13/h-ft(>3in)	-	-
Valve						
Leakage	1.0E-8/h(10)	2.7E-8/h	-	2.7E-8/h	2.5E-8/h to 1.3E-7/h	-
Rupture	4.0E-10/h(30) (non-PCS)	-	-	1.4E-9/h	-	-
	1.0E-10/h(30) (PCS)					
Pump						
Leakage	3.0E-8/h(10)	-	-	3.0E-9/h	4.3E-7/h to 3.5E-6/h	-
Rupture	1.2E-9/h(30) (non-PCS)	-	-	1.5E-10/h	-	-
	3.0E-10/h(30) (PCS)					
Flange						
Leakage	1.0E-8/h(10)	2.5E-6/h	-	-	-	-
Rupture	1.0E-10/h(30) (non-PCS and PCS)	-	-	-	-	-
Heat Exchanger						
Tube						
Leakage	1.0E-7/h(10)	-	1.9E-6/h	-	-	-
Rupture	4.0E-9/h(30) (non-PCS)	-	-	-	-	-
	1.0E-9/h(30) (PCS)					
Shell						
Leakage	1.0E-8/h(10)	-	-	-	-	-
Rupture	4.0E-10/h(30) (non-PCS)	-	-	-	-	-
	1.0E-10/h(30) (PCS)					
Tank						
Leakage	1.0E-8/h(10)	-	-	-	-	-
Rupture	4.0E-10/h(30) (non-PCS)	-	2.7E-8/h	-	-	-
	1.0E-10/h(30) (PCS)					

a. Median values in report were converted to means using the reported error factors (range factors) and assuming a lognormal distribution.[7]
b. From Seabrook PRA.[8]
c. From Appendix G of the Shoreham PRA.[9]
d. See Reference 6 for a summary of estimates derived from these reports on pumps and valves.[10,11]
e. From data in Table 15 of Reference 3, assumed 36,000 ft of non-PCS piping in PWRs and 19,000 ft in BWRs.
f. Suggested error factor in parentheses. A lognormal distribution is assumed.
g. Assumes 20 feet per section of pipe. Leakage value is rupture value times 20.
h. PCS = primary coolant system.

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3/25/93