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The Probability of Intersystem LOCA: Impact Due to Leak Testing and Operational Changes

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ABSTRACT

The Reactor Safety Study (WASH-1400) identified the potential intersystem LOCA (event V) in a pressurized water reactor as a significant contributor to the risk resulting from core melt. In this scenario, check valves fail in the injection lines of the residual heat removal or low pressure injection systems, allowing high pressure reactor coolant to enter low pressure piping outside containment. Subsequent failure of this low pressure piping would result in loss of reactor coolant outside containment and subsequent core meltdown. Similar scenarios are also possible in boiling water reactors.

This report evaluates various pressure isolation valve configurations used in reactors to determine the probability of intersystem LOCA. It is shown that periodic leak testing of these valves can substantially reduce intersystem LOCA probability. Specific analyses of the high pressure/low pressure interfaces in the Sequoyah (PWR) and Alan B. Barton (BWR) plants show that periodic leak testing of the pressure isolation check valves will reduce the intersystem LOCA probability to below 10^{-6} per year.

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PREFACE

It should be noted that there is uncertainty regarding the component failure rates used in this analysis, and consequently, there are signifiant error bands around the absolute values of the event probabilities quoted with this study. However, the results do provide guidance in that they give indications of the relative reductions in event probability which occur from various actions. When specific probabilistic goals are referred to in this study, they are intended to be considered as working goals only within the context of this study and are not meant to be considered as absolute numerical requirements. Rather, the numerical results provide insight into what actions are required for various reductions in event probabilities. This then, becomes one source of information aiding the staff in the formulation of pressure isolation criteria. However, this document is an analytical exercise and should not be construed as accepted Commission policy.

THE PROBABILITY OF INTERSYSTEM LOCA:
IMPACT DUE TO LEAK TESTING AND OPERATIONAL CHANGES

1. INTRODUCTION

The Reactor Safety Study (Ref. 1) identified the potential intersystem LOCA (WASH-1400 event V) in a pressurized water reactor (PWR) as a significant contributor to the risk resulting from core melt. In this scenario, check valves in the injection lines of the reactor heat removal (RHR) or low-pressure injection (LPI) systems fail allowing the high-pressure reactor coolant to communicate with the low-pressure piping outside of containment. Rupture of the low-pressure system would result in loss of reactor coolant outside of containment and subsequent core meltdown. A later study (Ref. 2) discussed alternate computational methods for assessing intersystem LOCA probabilities. Recent ASME Section XI testing requirements (Ref. 3) have also had an impact on the intersystem LOCA probability because the code requires the periodic exercise of motor-operated valves.

These studies addressed pressurized water reactors only. A similar LOCA scenario is possible in boiling water reactors where failure of check valves could result in rupture of the RHR piping.

In this report, the staff evaluated various pressure isolation configurations used in reactors to determine the probability for intersystem LOCA. The pressure isolation configurations of interest to this study are those in which two or three valves form a boundary between high- and low-pressure systems. These configurations are shown in Figure 1.

Section 2 of this study presents a general discussion of the intersystem LOCA event and the basic analytical techniques used here. In Section 3, each of the valve configurations shown in Figure 1 are investigated to determine the probability of an intersystem LOCA occurring through that particular interface. Modifications are suggested in plant operating procedure and component testing frequency to reduce the LOCA probability to approximately 10^{-7} per reactor year for each individual interface. This value was chosen to assure that, when the probabilities of all interfaces are summed for the total plant intersystem LOCA probability, the result would approach 10^{-6} per reactor year.

In Section 4 of this study, two commercial nuclear plants are reviewed using the results from Section 5. Because the total intersystem LOCA probability was above 10^{-6} due to the number and type of interfaces present, further leak testing was recommended to reduce this probability. The specific frequency of testing may vary depending on the number and type of interface configurations in a plant. Based on the results of this study, it is recommended that the check valves be tested at least

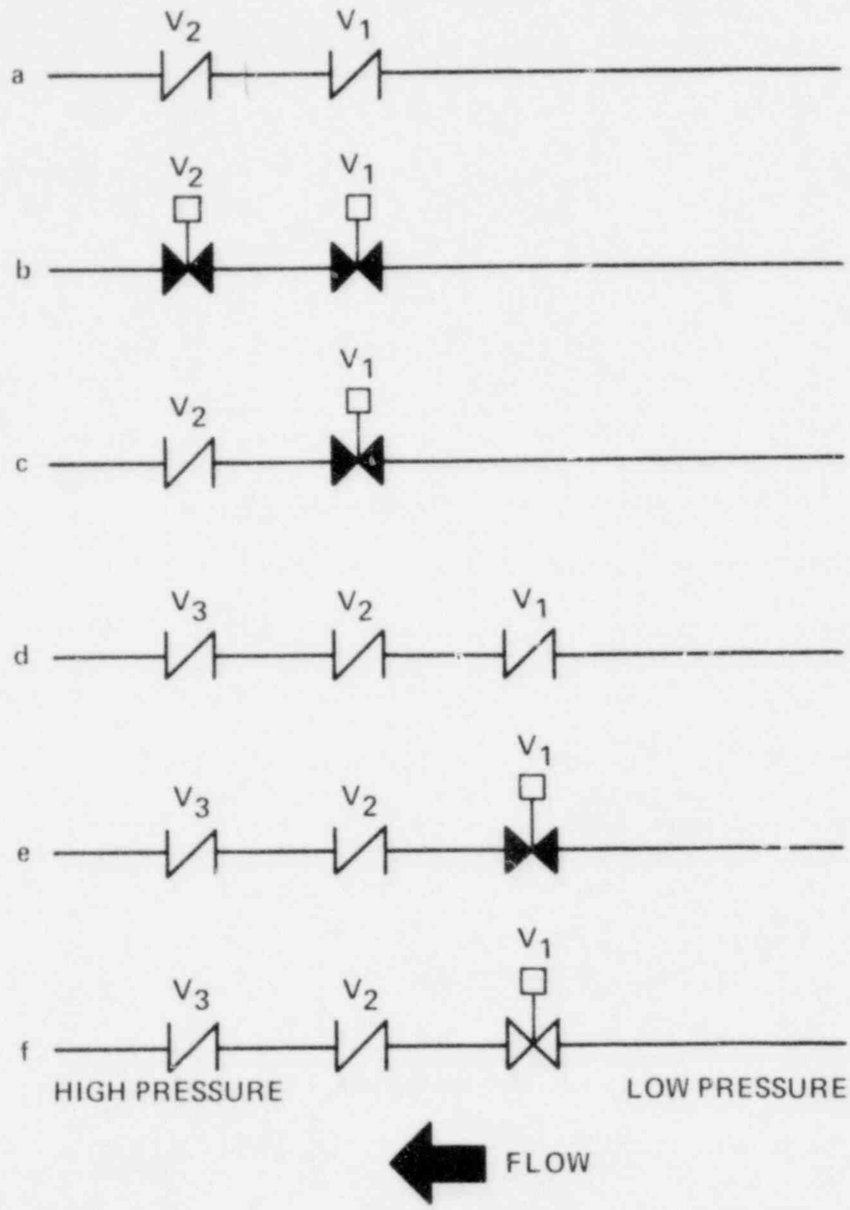

Figure 1. Isolation Configurations.

yearly as noted in Table 1. Each plant should be evaluated individually to determine if additional testing is required. As discussed in Section 4, it may be necessary to leak test certain check valves whenever the valves are disturbed.

2. BACKGROUND

An intersystem LOCA would occur when all the isolation valves between high- and low-pressure systems fail in an open condition. For a system using only check valves, these valves are assumed to fail from either of two modes--leak or rupture. In the leak failure mode,* it is postulated that after the valve has been exercised it does not reseat and establish a pressure boundary. The reactor safety study assigned a probability of 2.6×10^{-3} per year per valve to this type of check valve failure based on available data. This information is presented in Appendix 3, Table 2-1, of WASH-1400 (Ref. 1).

In addition to failure by the leak mode, a check valve can fail to perform its isolation function because of rupture of its disk. This instantaneous rupture was estimated by the reactor safety study to occur with a probability of 8.8×10^{-5} per year per valve. The failure mode

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*By leak it is meant that the valve has failed to the extent that it will pass gross amounts of leakage.

Table 1. Estimated LOCA Probabilities

Valve Configuration	Original Probability No Testing	Revised Probability	Revisions to Operating Procedures
1a	9.5×10^{-6}	4.7×10^{-7}	Leak test every two years
		2.4×10^{-7}	Leak test every year
1b	1.8×10^{-4}	4.2×10^{-9}	Lock valves closed and leak test every two years
1c	1.0×10^{-5}	2.5×10^{-7}	Leak test every year
1d	3.0×10^{-6}	7.4×10^{-9}	Leak test every two years
1e	2.8×10^{-4}	4.7×10^{-7}	Leak test every two years
		2.4×10^{-7}	Leak test every year
1f	9.6×10^{-6}	4.7×10^{-7}	Leak test every two years
		2.4×10^{-7}	Leak test every year

that dominates the intersystem LOCA probability is dependent upon the specific isolation valve configuration, which is discussed in Section 3 of this study.

Some of the isolation configurations shown in Figure 1 include motor-operated valves. This type of valve does not exhibit the leak mode of failure because the valve is under positive control by its motor operator and because position indication is provided. Any small seat leakage that did occur is not expected to be large enough to cause the event. Its failure mode, therefore, is rupture of the valves internals, with an assumed probability being the same as for check valve rupture.

As discussed in the preceding, an intersystem LOCA would occur when the valves performing an isolation boundary function between high- and low-pressure systems fail in a manner that allows significant flow rates between the two systems. For an isolation boundary that is comprised of two valves in series, the probability of failure (Q) over a time interval can be determined by the following (Ref. 1):

$$Q = \int_{o}^{t} \lambda_1 dt' \int_{t'}^{t} \lambda_2 dt'' \qquad (1)$$

where λ_1 is the failure probability for valve 1 and λ_2 is the failure probability for valve 2. Q is the probability of valve 1 failing first (that is, by leakage) and valve 2 then failing (such as, rupturing). In Equation 1, the exponential expression for component failure, $1-e^{-\lambda t}$, is approximated by the first-order term λt. This is valid for small values of λt. Integration of the preceding equation yields the following expression for system failure:

$$Q = \frac{\lambda_1 \lambda_2 t^2}{2} \qquad (2)$$

This expression provides the cumulative frequency of an intersystem LOCA at an interface for any time interval. To arrive at a yearly average for use in comparison of various system configurations (assuming no periodic testing), the expression can be evaluated for the expected life of the plant t = 40 years and divided by 40. This value provides a linearized average for intersystem LOCA probability. The per-year average obtained from this technique provides a bounding limit for estimating intersystem LOCA probability.

To arrive at the total intersystem LOCA probability, all significant high-pressure to low-pressure interfaces are considered, with the probabilities per interface being summed to give a system failure probability. The generally accepted probability of other high-consequence events is of the order of 10^{-6} per reactor year. To be consistent, the total intersystem LOCA probability should be less than this. When evaluating the various isolation configurations in the first section of this study, a target figure of 10^{-7} per reactor year was used. This was done so that, when all individual isolation points are summed to give the resulting total event probability, the value would approach our 10^{-6} goal.

In cases where the probabilities do not meet the target values for single isolation configurations, periodic leak testing of the valves provides the needed reduction in intersystem LOCA probabilities. This occurs because testing reduces the rate of growth of the intersystem LOCA probability. Figure 2 shows the cumulative probability of having an intersystem LOCA with and without testing.

This analysis assumes that the failure mechanism of the valves has a rate that is independent of time. Because relative risk accuracies are required to arrive at relative merits of the valve configurations. This is a reasonable assumption.

In addition, the testing concept has validity because the failure mode, which has the largest impact on intersystem LOCA probability and is usually the leak mode, may occur when the valves have been cycled. Therefore, leak testing the valve after cycling will assure that it is in a closed position and result in the type of behavior shown in Figure 2. Total probability, however, is dependent on how many interfaces are present. In Section 4, additional leak testing is recommended to achieve total plant probability less than 10^{-6} per reactor year.

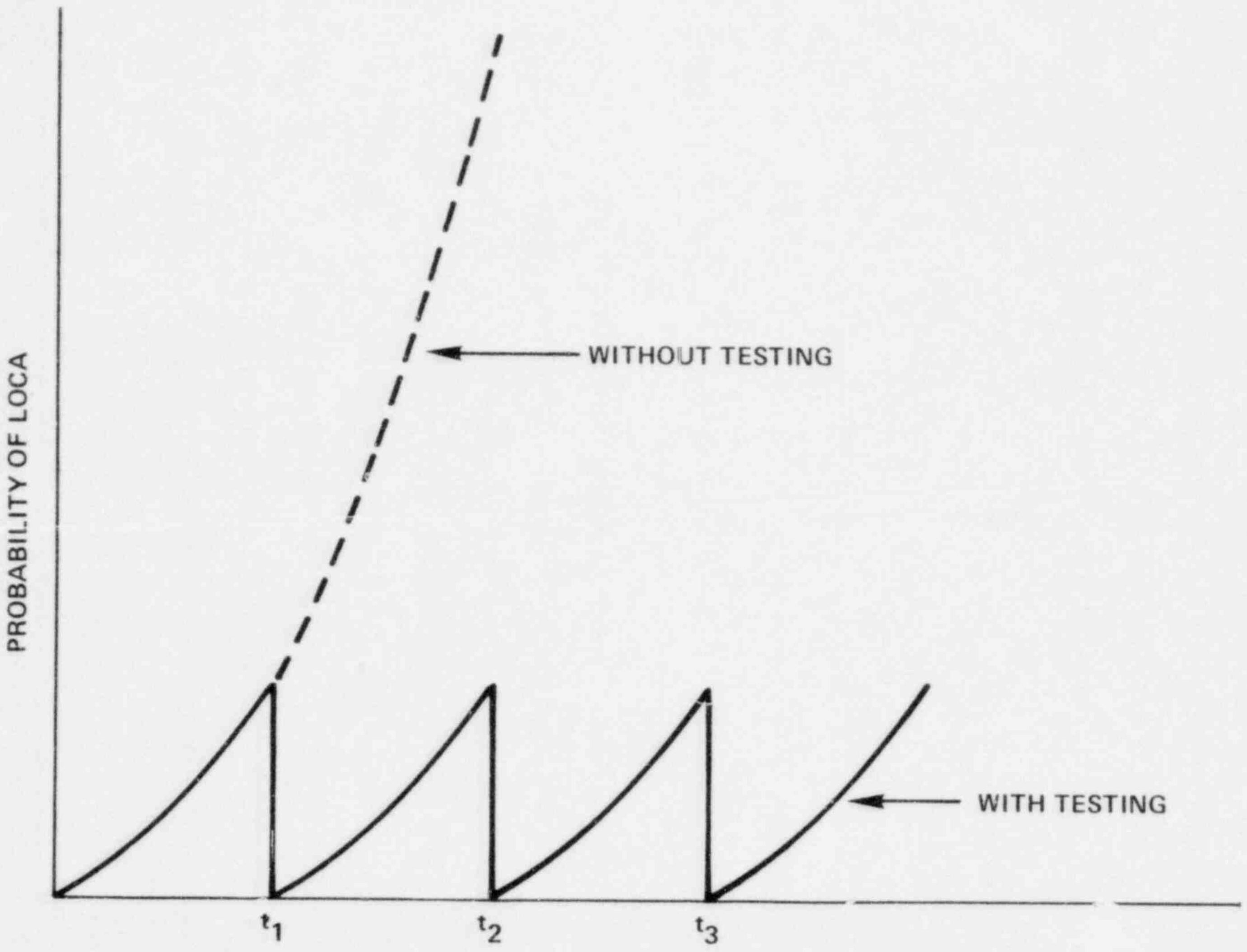

Figure 2. Cumulative Probability of Intersystem LOCA With and Without Testing.

3. ANALYSIS OF SPECIFIC ISOLATION CONFIGURATIONS

3.1 Configuration 1a, Two Check Valves in Series

From Equation 2, we know that the probability for failure of two valves in series is

$$Q = \frac{\lambda_1 \lambda_2 t^2}{2} \qquad (3)$$

where λ_1 is the failure probability of valve 1 and λ_2 is the failure probability of valve 2.

Because individual c[illegible] valves can experience two modes of failure, leak, or rupture, an intersystem LOCA could occur from any of three failure combinations: leak-leak, leak-rupture, or rupture-rupture. That is, an intersystem LOCA would occur if both valves leaked, one leaked and the other ruptured, or both ruptured. Conceptually, the probability for each of these failure modes is evaluated by Equation 2, and the results are summed for all failure mode combinations to determine the total intersystem LOCA probability for an isolation configuration of two check valves in series.

However, there are a few operational constraints that must be considered. Because the leak failure mode for a check valve could occur when the system is depressurized for refueling or maintenance, a leak-leak failure would be detected at reactor startup and, therefore, is not considered a contributor to core melt. If both valves have failed in the leak-open position, fluid would be discharged through the low-pressure system safety relief valves when the system is pressurized and result in plant shutdown.

Therefore, the failure combinations that are considered in calculating intersystem LOCA probabilities are leak-rupture and rupture-rupture. From Equation 2, the probability of system failure due to leak-rupture is

$$Q = \frac{\lambda_{leak}\, \lambda_{rupture}\, t^2}{2} \qquad (4)$$

However, because, in addition to V_1 leaking and V_2 rupturing, you could also get V_2 leaking and V_1 rupturing, the actual probability is twice the preceding value.

The probability of system failure due to the rupture-rupture mode of R_2R_1 is

$$Q = \frac{\lambda_{rupture}\, \lambda_{rupture}}{2}\, \frac{t^2}{}$$

Because R_1 could also rupture first, the R_1R_2 sequence must also be considered, and the actual probability is twice the preceding value.

$$Q = \{\lambda_\ell \lambda_r + \lambda_r^2\} \quad t^2 \qquad (5)$$

For a periodic test interval of T years, the average probability $\bar{Q}(T)$ per reactor year is

$$\bar{Q}(T) = \{\lambda_\ell \lambda_r + \lambda_r^2\} \; T$$

In the following, WASH-1400 (Ref. 1) failure rates of $\lambda_1 = 2.6 \times 10^{-3}$ per year and $\lambda_r = 8.8 \times 10^{-5}$ per year are used.

Evaluating Equation 5 for the 40-year life of the plant and assuming no periodic testing, the failure rate $\bar{Q}$ (T=40) is 9.5×10^{-6} per reactor year, which is above the target value. To bring the failure probability into line with desired goals, it is recommended that these valves be classified to Category AC as defined in Section XI of the ASME Code (Ref. 3). This category of valves has a requirement for leak testing once every two years. This leak testing would give failure probability for $\bar{Q}$ (T=2) of 4.7×10^{-7} per reactor year. A one-year leak-testing interval would reduce the probability to 2.4×10^{-7} per reactor year, which is close to our target value of 1×10^{-7} per reactor year.

To obtain maximum benefit, the leak testing should be scheduled to immediately follow pressurization of the reactor coolant system after a refueling outage or cold shutdown.

3.2 Configuration 1b, Two Closed Motor-Operated Valves in Series

Figure 1b shows a system configuration that includes two motor-operated valves (MOV) in series. Because the ASME Code, Section X requires that all Category A and B valves be cycled every 90 days, it is only necessary that one of the valves be ruptured to fail the low-pressure system. This is because the other nonruptured valve would be opened periodically to satisfy the operability testing requirements.

The probability of one valve failing is $\lambda_r t$. Because either of the valves could have ruptured, intersystem LOCA probability for this configuration is $2 \times 8.8 \times 10^{-5} = 1.8 \times 10^{-4}$ per reactor year. The intersystem LOCA probability could be reduced by leak testing valve 1 prior to stroking valve 2. In this case, intersystem LOCA probability is the probability of a valve rupturing, which is extremely small ($<10^{-8}$), during the short time needed for a test. However, even if the valves are not scheduled for stroking, there is the possibility that they would be opened by operator error during plant operations.

To account for human error, consider λ_e to be the failure rate per year for the operator inadvertently opening the valve and not correcting his error. Because the MOVs have two failure modes, rupture (R) and inadvertent opening (E), the average probability can be calculated considering the following failure sequences with the indicated evaluations:

$$\begin{aligned} R_1R_2: &\quad 1/2\ \lambda_r\lambda_r t^2 \\ R_2R_1: &\quad 1/2\ \lambda_r\lambda_r t^2 \\ E_1R_2: &\quad 1/2\ \lambda_e\lambda_r t^2 \\ R_1E_2: &\quad 1/2\ \lambda_r\lambda_e t^2 \\ E_1E_2: &\quad \lambda_e t p_e \end{aligned} \tag{6}$$

The term p_e is the probability that the operator inadvertently opens the remaining valve given he has opened the first valve. The probability p_e accounts for any dependency between the acts.

The NRC Probabilistic Analysis Staff has suggested that 1×10^{-4} per year (approximately 1×10^{-8} per hour) is an appropriate estimate of λ_e for this application. If we evaluate the above expressions with λ_e and t = 90 days (=1/4 yr interval due to inservice testing) and multiply the above numbers by 4 to obtain per-year values, we obtain the following:

R_1R_2: 9.7×10^{-10}/reactor year

R_2R_1: 9.7×10^{-10}

E_1R_2: 1.1×10^{-9}

R_1E_2: 1.1×10^{-9}

E_1E_2: $1 \times 10^{-4}\ p_e$

Changing the human error rate by a given factor will change the above values by the same factor. Any value of p_e greater than 10^{-3} will cause the sum of the above modes to be above our target value because the probability of E_1E_2 alone will equal 1×10^{-7} per reactor year.

The Probabilistic Analysis Staff has given the opinion that experience suggests the value of p_e to be greater than 1×10^{-3}. Therefore, we must eliminate the possible predominance of the double operator error failure mode (E_1E_2). Possible solutions are that the valves be locked closed while the plant is pressurized or be mechanically interlocked so that both cannot be opened at the same time.

Assuming that the valves are interlocked so that the E_1E_2 failure mode is eliminated, intersystem LOCA probability is calculated by summing the first four components of Equation 6, which yields a value of 4.2×10^{-9} per reactor year. Alternatively, the two MOVs could be locked closed, in which case the intersystem LOCA probability would be determined by evaluating the first three components of Equation 6 for t = 2 years if leak testing was performed biannually.

3.3 Configuration 1c, One Check Valve in Series with a Normally Closed Motor-Operated Valve

The valve configuration shown in Figure 1c includes one check valve in series with a normally closed MOV. In compliance with Section XI of the ASME Code in which the MOV is required to be cycled every 90 days, the intersystem LOCA probability is

$$Q = (\lambda_L + \lambda_r)t \tag{7}$$

because a LOCA could occur if the check valve is either leaking or ruptured when the motor valve is cycled. This probability is above the target value of 10^{-7} per reactor year as noted in Section 3.2. Therefore, the MOV should not be cycled without first verifying the condition of the check valve or closing a second complementary MOV.

Having eliminated the impact of periodic testing of the MOV, the intersystem LOCA probability reduces to the case of two valves in series that have the following failure combinations:

L_2R_1	$1/2\ \lambda_\ell \lambda_r t^2$
R_1R_2	$1/2\ \lambda_r \lambda_r t^2$
R_2R_1	$1/2\ \lambda_r \lambda_r t^2$
L_2E_1	$1/2\ \lambda_\ell \lambda_e t^2$
R_2E_1	$1/2\ \lambda_r \lambda_e t^2$

Assuming no leak testing for the valves and evaluating at t = 40 years gives an intersystem LOCA probability $\overline{Q}(T = 40)$ of 1.0×10^{-5} per reactor year. This is above the target value. To bring the failure probability into line with desired goals, it is recommended that these valves be leak tested once per year, which would then reduce the probability to $Q(T=1)$ of 2.5×10^{-7} per reactor year.

3.4 Configuration 1d, Three Check Valves in Series

Figure 1d shows a system that includes three check valves in series. The probability for intersystem LOCA for this arrangement is determined by an extension of Equation 1.

$$Q = \int_0^t \lambda_1 dt' \int_{t'}^t \lambda_2 dt'' \int_{t''}^t \lambda_3 dt''' \qquad (8)$$

$$= \frac{\lambda_1 \lambda_2 \lambda_3 t^3}{6}$$

where valve 1 fails before valve 2 which fails before valve 3.

With three check valves in series, the following system failure combinations are possible (Ref. 2):

$L_1L_2R_3$	$L_1R_2L_3$	$L_1R_2R_3$	$R_1L_2L_3$
$L_1R_3L_2$	$L_1L_3R_2$	$L_1R_3R_2$	$R_1L_3L_2$
$L_2R_3L_1$	$R_2L_3L_1$	$R_2R_3L_1$	$L_2L_3R_1$
$L_2L_1R_3$	$R_2L_1L_3$	$R_2L_1R_3$	$L_2R_1L_3$
$R_3L_1L_2$	$L_3L_1R_2$	$R_3L_1R_2$	$L_3R_1L_2$
$R_3L_2L_1$	$L_3R_2L_1$	$R_3R_2L_1$	$L_3L_2R_1$
$R_1L_2R_3$	$R_1R_2L_3$	$R_1R_2R_3$	
$R_1R_3L_2$	$R_1L_3R_2$	$R_1R_3R_2$	
$L_2R_3R_1$	$R_2L_3R_1$	$R_2R_3R_1$	
$L_2R_1R_3$	$R_2R_1L_3$	$R_2R_1R_3$	
$R_3R_1L_2$	$L_3R_1R_2$	$R_3R_1R_2$	
$R_3L_2R_1$	$L_3R_2R_1$	$R_3R_2R_1$	

The three-leak sequence has been neglected because it would be detected at startup.

This gives an intersystem LOCA probability of 3.0×10^{-6} per reactor year, which is higher than the target value of 10^{-7} per reactor year for a single isolation point. A failure risk of 7.4×10^{-9} per reactor year results with the requirements that these check valves are to be categorized type AC according to ASME Code, Section 11, and leak tested every two years.

3.5 Configuration 1e, Two Check Valves and a Closed Motor-Operated Valve

The valve configuration shown in Figure 1e consists of two check valves in series with a normally closed MOV. This would appear to offer the same level of safety as in the case of three check valves. However, due to periodic operability test requirements, it actually has greater probability of LOCA occurrence than the two-check-valve situation because the leak-leak failure mode of the check valves must now be considered. This failure mode would be discovered at startup if it were not for the closed MOV. Therefore, intersystem LOCA probability for a single isolation point such as this, assuming the MOV is cycled per periodic operability test requirements, is 2.8×10^{-4} per reactor year and is above the target value.

Even if the check valves are leak tested once per year, intersystem LOCA probability is reduced to only 6.8×10^{-6} per reactor year. To reduce the probability levels to acceptable values, the MOV should be left open while the plant is pressurized (Ref. 3). This would identify a leak-leak failure mode to the operator and thereby eliminate it from consideration in overall risk. In this case, intersystem LOCA probability would be reduced to the values calculated for two check valves in series as in Section 4.1 of 4.7×10^{-7} per reactor year if leak tested every two years, or 2.4×10^{-7} per reactor year if leak tested every year.

3.6 Configuration 1f, Two Check Valves in Series with a Normally Open Motor-Operated Valve

Figure 1f shows the configuration of two check valves in series with an open motor-operated valve. The intersystem LOCA probabilities for this system are the same as for the two check valves in series discussed in Section 3.5.

3.7 Results

Table 1 summarizes the intersystem LOCA probabilities calculated in this study. It should be noted that the "original" probabilities were calculated assuming that (1) periodic operability tests are being performed for motor-operated valves and (2) no periodic leak testing of check valves is being performed. In actuality, the staff has issued guidelines to make plant operating personnel aware of potential problems and, in some cases, check that valves are leak tested.

4. PLANT APPLICATIONS

4.1 Pressurized Water Reactor

The results given in Table 1 were applied to the Sequoyah Nuclear Plant. The FSAR piping diagrams were used to determine the valve isolation configurations found in the injection paths of the emergency core cooling

(ECC) system. The charging and boron injection systems were excluded from the study because they were rated at reactor design pressure. The accumulators were excluded because a break in those systems would not result in coolant being lost outside of containment.

The upper head injection (UHI) system has been included in this analysis, even though it is not clear that rupture of this system would lead to the core melt sequences (see Section 1). However, rupture of the UHI lines outside the containment would result in some loss of primary coolant, which could cause a problem in meeting net positive suction head requirements for safety injection pumps during recirculation. Because of the uncertain consequences of this accident, it has been included in the intersystem LOCA calculations, even though the inclusion of this system has a minimal effect on the total probability.

The intersystem LOCA probabilities were then summed for the individual isolation configurations to give a total plant probability. The results are given in the following:

System	Number of Interfaces	Type of Interface	Intersystem LOCA Prob. Original No Testing	Revised[a]
Reactor heat removal	4	Two check valves	3.8×10^{-5}	9.6×10^{-7}
Safety injection				
Cold leg	4	Two check valves	3.8×10^{-5}	9.6×10^{-7}
Hot leg	6	Two check, closed motor	1.7×10^{-3}	1.4×10^{-6}
Upper head injection	4	Two check	3.8×10^{-5}	9.6×10^{-7}
		Total Probability =	1.8×10^{-3}	4.3×10^{-6}

[a]Leak testing frequency of once per year.

As can be seen, the leak testing requirements proposed in Section 3 reduce the risk of intersystem LOCA by approximately three orders of magnitude. However, the total risk of 4.3×10^{-6} per reactor year is still above the desired value of 1.0×10^{-6}. To reduce the risk still further, it is necessary to eliminate the "leak" mode of failure for check valves as a credible failure mechanism. This is the dominating contributor to intersystem LOCA for most situations.

The potential for the leak mode of failure occurs when check valves are unseated. Therefore, if these check valves are leak tested whenever flow takes place in the interfacing systems (and just prior to repressurization of the RCS), the leak mode of failure can be eliminated from consideration. In that case intersystem LOCA probabilities are as follows.

System	Number of Interfaces	Type of Interface	Intersystem LOCA Prob.
Reactor heat removal	4	Two check valves	1.5×10^{-8}
Safety injection			
Cold leg	4	Two check valves	1.5×10^{-8}
Hot leg	6	Two check, closed motor	4.5×10^{-13}[a]
Upper head injection	4	Two check	1.5×10^{-8}
		Total Probability =	4.5×10^{-8}

[a]The value is this low because the motor valve is locked closed and not exercised except at cold shutdown. Therefore, $R_3R_2R_1$ is the only possible failure mode. If it was opened for testing every 90 days, the value would reduce to the case indicated in the table for two check valves.

This operating practice reduces intersystem LOCA probability to quite a low level. The general leak testing schedule (other than testing following flow) could probably be relaxed from once per year to once every two years.

4.2 Boiling Water Reactor

The results given in Table 1 were applied to the Alan R. Barton Nuclear Plant. The PSAR piping diagrams were used to determine the valve isolation configurations found in the injection paths of the emergency core cooling (ECC) systems.

The intersystem LOCA probabilities were summed for the individual isolation configurations to give a total plant probability. The results are given in the following:

System	Number of Interfaces	Type of Interface	Intersystem LOCA Prob. Original No Testing	Intersystem LOCA Prob. Revised[a]
RCIC	1	2 check valves	9.5×10^{-6}	2.4×10^{-7}
RHR	5	1 check, 1 motor	5.0×10^{-5}	1.3×10^{-6}
HPCS	1	2 check, 1 motor	2.8×10^{-4}	2.4×10^{-7}
LPCS	1	2 check, 1 motor	2.8×10^{-4}	2.4×10^{-7}
		Total Risk =	6.2×10^{-4}	2.0×10^{-6}

[a]Leak testing frequency of once per year.

As in the case of the PWR, the total risk is above the desired goal of 1.0×10^{-6} per reactor year. The largest component of total risk comes from the RHR system. If, in addition to the procedural changes recommended in Section 3, the RHR check valves are leak tested every time they are disturbed, the leak mode of failure can be eliminated from consideration. In this case, the five preceding RHR interfaces give a value of 4.1×10^{-8}

per reactor year and the total risk is reduced to 7.6×10^{-7} per reactor year, which is acceptable.

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16. ABSTRACT *(200 words or less)*

The Reactor Safety Study (WASH-1400) identified the potential intersystem LOCA (event V) in a pressurized water reactor as a significant contributor to the risk resulting from core melt. In this scenario, check valves fail in the injection lines of the residual heat removal or low pressure injection systems, allowing high pressure reactor coolant to enter low pressure piping outside containment. Subsequent failure of this low pressure piping would result in loss of reactor coolant outside containment and subsequent core meltdown. Similar scenarios are also possible in boiling water reactors.

This report evaluates various pressure isolation valve configurations used in reactors to determine the probability of intersystem LOCA. It is shown that periodic leak testing of these valves can substantially reduce intersystem LOCA probability. Specific analyses of the high pressure/low pressure interfaces in the Sequoyah (PWR) and Alan B. Barton (BWR) plants show that periodic leak testing of the pressure isolation check valves will reduce the intersystem LOCA probability to below 10^{-6} per year.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

Intersystem LOCA, Leak Testing

17b. IDENTIFIERS/OPEN-ENDED TERMS

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