SAFETY EVALUATION OF LOW-PRESSURE PIPING SYSTEM
DESIGN FOR THE INTERSYSTEM LOCA CONDITION
IN THE ABWR

1 INTRODUCTION

In SECY-90-016 dated January 12, 1990, the NRC staff resolved the intersystem loss-of-coolant accident (ISLOCA) issue for advanced light water reactor plants by requiring that low-pressure piping systems that interface with the reactor coolant pressure boundary be designed to withstand full reactor coolant system (RCS) pressure to the extent practicable. The General Electric Company (GE) provided a proposed implementation of the issue resolution for the ABWR in a letter from J. Fox (GE) to C. Poslusny (NRC) dated October 8, 1992.

In this safety evaluation, the staff has evaluated the GE proposal for implementing the ISLOCA resolution for the ABWR. Specifically, the staff has evaluated the minimum pressure for which low-pressure systems should be designed to ensure reasonable protection against burst failure should the low-pressure system be subjected to full RCS pressure. In establishing the minimum design pressure, the following goals were used as the basis for selection:

(1) The likelihood of rupture (burst) of the pressure boundary is low*;

(2) The likelihood of intolerable leakage of flange joints or valve bonnets is reasonably low although some leakage might occur;

(3) Some piping components might undergo gross yielding and permanent deformation.

2 LOW-PRESSURE PIPING DESIGN

To achieve the above objectives, the staff evaluated, first, on a qualitative basis, several possible ratios of the low-pressure system design pressure (P_d) to the RCS normal operating pressure (P_v) to establish the margins on burst and yield of the piping. The results of the staff's evaluation are depicted in Table 1 for typical carbon steel (A106 Grade B) and stainless steel (SA312 Type 304) material and are discussed below for three ratios of the design pressure to the reactor vessel pressure (P_d/P_v). A margin of 1.0 or less represents the condition where burst or yielding is likely to occur. The higher the margin, the less likely it is for burst or yielding to occur. The low-pressure piping systems are assumed to be designed to the rules of the ASME Boiler and Pressure Vessel Code, Section III, Subarticle NC/ND-3600 for Classes 2 and 3 piping systems.

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* The NRC staff used a goal of approximately 10 percent failure probability (or conversely, a goal of 90 percent survival probability) for rupture.

Enclosure

Table 1 - Margins for Straight Pipe

Material	Temp °F	P_d/P_v	S ksi	S_v ksi	S_u ksi	S_y ksi	Margins on Burst	Margins on Yield
SA106 Grade B	100	1/2	15	30	60	35.0	2.00	1.34
	500	1/2	15	30	60	28.3	2.00	1.08
	100	1/3	15	45	60	35.0	1.33	0.89
	500	1/3	15	45	60	28.3	1.33	0.72
	100	1/4	15	60	60	35.0	1.00	0.67
	500	1/4	15	60	60	28.3	1.00	0.54

Material	Temp °F	P_d/P_v	S ksi	S_v ksi	S_u ksi	S_y ksi	Margins on Burst	Margins on Yield
SA312 Type 304	100	1/2	18.8	37.5	75.0	30.0	1.70	0.92
	500	1/2	15.9	31.8	63.5	19.4	1.70	0.70
	100	1/3	18.8	56.3	75.0	30.0	1.13	0.61
	500	1/3	15.9	47.7	63.5	19.4	1.13	0.47
	100	1/4	18.8	75.0	75.0	30.0	0.85	0.46
	500	1/4	15.9	63.6	63.5	19.4	0.85	0.35

S = allowable stress per ASME Code, Section III for Class 2 piping

S_v = hoop stress at $P = P_v$
= $S/(P_d/P_v)$

S_u = ultimate tensile strength; from Section III, Table I-3.1 and I-3.2

S_y = yield strength; from Section III, Table I-2.1 and I-2.2

Margin on Burst Pressure = $F \times S_u \times (P_d/P_v)/S$
where F = 1.00 for SA106 Grade B
F = 0.85 for SA312 Type 304

Margin on Yield Pressure = $1.15 \times S_y \times (P_d/P_v)/S$

Piping Integrity at Pd/Pv = 1/2 (ASME Code Service Level D)

When P_d/P_v is equal to one-half, the margins on burst and yield are equivalent to approximately those of the ASME Boiler and Pressure Vessel Code, Section III Service Level D condition. For carbon steel pipe, this ratio will provide a margin of 2.0 on burst and 1.08 on yield for a pipe at 500 °F. For stainless steel piping, a ratio of one-half will

provide a sufficient margin on burst (1.7). However, a small amount of yielding is likely to occur with a margin of 0.70 at 500 °F. No leakage of the pressure boundary is likely to occur at P_d/P_v equal to one-half.

As a result, a ratio of one-half will ensure the pressure integrity of the low-pressure piping system with ample margin.

Piping Integrity at Pd/Pv = 1/3

When the ratio, P_d/P_v, is reduced to one-third, the margins for carbon steel piping are lowered to 1.33 and 0.72 for burst and yield at 500 °F, respectively. For stainless steel piping, the margins are 1.13 and 0.47 for burst and yield at 500 °F, respectively. At these margins, it is expected that burst failure will not occur in either carbon steel or stainless steel piping. However, significant amount of yielding might occur in stainless steel piping at all temperatures and in carbon steel piping at 500 °F. Where the carbon steel piping is at a lower temperature, some yielding might occur although to a lesser extent. The consequence of significant pipe yielding (without bursting) is that gross, permanent distortion might occur in the piping components thereby resulting in some leakage through flanges, or valve bonnets. However, it is not expected that such leakage would be uncontrollable or intolerable.

In summary, a ratio of one-third will ensure the pressure boundary of the low-pressure piping although a significant amount of pipe yielding and some leakage through flanges and valve bonnets is likely to occur.

Piping Integrity at Pd/Pv = 1/4

At P_d/P_v equal to one-fourth, the pressure integrity of carbon steel piping becomes questionable, and for stainless steel piping, it is likely that burst failure will occur. Prior to bursting, the piping system would undergo gross plastic deformation, experience a significant amount of leakage at flanges, valve bonnets, and pump seals, and possibly lose some pipe supports due to the radial expansion of the pipe.

Therefore, at P_d/P_v equal to one-fourth, the ability of the low-pressure piping system to withstand full RCS pressure is questionable for carbon steel piping and unlikely for stainless steel piping systems.

The staff further evaluated, on a quantitative basis, the survival probabilities of the low-pressure piping at various design pressures using the methodology described in NUREG/CR-5603, "Pressure-Dependent Fragilities for Piping Components," dated October 1990. Calculations were performed by Idaho National Engineering Laboratory under contract with the NRC's Office of Nuclear Regulatory Research.

The INEL calculations led to results similar to the qualitative conclusions discussed above. A temperature of 350 °F was used in the calculations of the following survival probabilities. Using a temperature of 500 °F, the survival

probabilities decreases about 2-5 percent for the different materials and design pressures. For carbon steel piping (SA-105 Grade B material), the survival probability was approximately 94 percent at the design pressure proposed by GE of 350 psig (roughly equivalent to $P_d/P_v = 1/3$). When the design pressure is increased to 400 psig (or approximately $P_d/P_v = 0.4$), the survival probability increases to 99 percent.

For stainless steel piping (Type 304 material), the survival probability at the GE-proposed design pressure of 350 psig (or approximately $P_d/P_v = 1/3$) was about 70 percent. At a design pressure of 400 psig (or approximately $P_d/P_v = 0.4$), the survival probability increases to about 87 percent.

Using the results described above, the staff finds that the GE-proposed design pressure of 350 psig is sufficient for carbon steel piping, but would result in a survival probability of approximately 70 percent for stainless steel piping. At a design pressure of 410 psig, the survival probability for stainless steel piping increases to approximately 89 percent. Therefore, the staff finds that a ratio of $P_d/P_v = 0.4$ nearly achieves the staff's goal of a 90 percent survival probability under ISLOCA conditions and provides a sound basis for establishing the design pressure of low-pressure systems interfacing with the RCS pressure boundary.

It should be noted, however, that the survival probabilities are based on the minimum wall thickness as calculated using Equation (3) in the ASME Boiler and Pressure Vessel Code, Section III, Subsubarticle NC/ND-3640. The wall thickness thus calculated does not account for manufacturing tolerances or the use of the next heavier commercial wall thickness available which would increase the piping wall thickness and substantially increase the survival probability as well. Furthermore, when standard weight piping wall thicknesses are used (i.e., schedule 40 pipe up to and including 10-inch nominal pipe size), the survival probabilities at a design pressure 400 psig are above 99 percent for both carbon and stainless steel piping. Currently operating boiling water reactor plants typically use, as a minimum, standard weight piping for the low-pressure piping systems that interface with the reactor coolant pressure boundary. Therefore, for the ABWR, the staff concludes that the use of standard weight piping will provide a bounding design for the ISLOCA condition.

3 VALVES IN LOW-PRESSURE SYSTEMS

For the valves in the low-pressure piping systems (excluding the pressure isolation valves), the selection of the valve class rating is a primary factor for designing against full RCS pressure. For example, ANSI B16.34 valves are supposed to be shop-tested to 1.5 times their 100 °F rated pressure. This would mean for a Class 300 A216 WCB (cast carbon steel) valve, the test pressure is $1.5 \times 740 = 1110$ psig. For Class 150, the valve test pressure is $1.5 \times 285 = 427.5$ psig.

Clearly, the Class 300 valve that is tested to a pressure of 1110 psig would be expected to withstand an RCS normal operating pressure of 1040 psia (or 1025 psig). However, it should not be assumed that the valve in the low-pressure system would be able to operate with this full RCS pressure across

the disk.

Therefore, the staff finds that a Class 300 valve is adequate for ensuring the pressure of the low-pressure piping system under full RCS pressure (i.e., 1025 psig) but no credit should be taken to consider these valves operable under such conditions without further justification.

4 OTHER COMPONENTS IN THE LOW-PRESSURE SYSTEMS

For other components in the low-pressure systems, such as pumps, tanks, heat exchangers, flanges, and instrument lines, the staff finds that establishing an appropriate safety factor involves several complicating factors related to the individual component design. These factors include requirements for shop hydrotests, the method to determine the pressure class rating of the component, the specific material used for bolting and the bolt tension applied, or whether the component is qualified by test or analysis.

The staff is of the opinion that designing such components to the GE-proposed design pressure of 350 psig (or approximately one-third of the normal operating RCS pressure) might not provide sufficient margin to burst failure because of the uncertainties in their design as discussed above. Therefore, the staff's position is that the remaining components in the low-pressure systems should also be designed to a design pressure of 0.4 times the normal operating RCS pressure (i.e., 410 psig). The staff believes that the margins to burst for these remaining components are at least equivalent to that of the piping at its minimum wall thickness since these components typically have wall thicknesses greater than that of the pipe minimum wall thickness. Specific components that cannot meet these guidelines should be identified to the staff for review on a case-by-case basis by the COL applicant as a part of its COL application.

5 CONCLUSIONS

On the basis of the above discussions, the staff finds for the ABWR that the design pressure for the low-pressure piping systems that interface with the RCS pressure boundary should be equal to 0.4 times the normal operating RCS pressure of 1025 psig (i.e., 410 psig), and the minimum wall thickness of the low-pressure piping should be no less than that of a standard weight pipe. The design is to be in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Subarticle NC/ND-3600. Furthermore, the staff will continue to require periodic surveillance and leak rate testing of the pressure isolation valves per Technical Specification requirements as a part of the inservice inspection program.

As stated in SECY-90-016, for those low-pressure systems for which designing to withstand full reactor pressure, as discussed above, is not practical, the design should provide (1) the capability for leak testing of the pressure isolation valves, (2) valve position indication that is available in the control room when isolation valve operators are deenergized, and (3) high-pressure alarms to warn control room operators when rising RCS pressure approaches the design presure of attached low-pressure systems and both isolation valves are closed.

Using these minimum design guidelines, the staff concludes that:

(1) the likelihood of the low-pressure piping rupturing under full RCS pressure is low,
(2) the likelihood of intolerable leakage is low under ISLOCA conditions although some leakage might occur at flanges and valve bonnets, and

(3) some piping components might undergo gross yielding and permanent deformation under ISLOCA conditions.

Because of the likelihood of piping system distortion, the staff finds that a visual inspection of the low-pressure piping system after it has been subjected to the full RCS pressure is necessary to identify those components that might require replacement, repair, or further detailed analysis prior to restart. The minimum design pressure and pipe wall thickness for the low-pressure piping systems should be identified as a Tier 1 commitment for the ABWR. An ITAAC should be developed to ensure that the design specifications for the low-pressure piping system adequately define the pressure design requirements and minimum pipe wall thicknesses for protection against the ISLOCA condition.

Contingent upon GE revising its SSAR and submitting Tier 1 commitments and ITAAC as identified above, the staff concludes that there is reasonable assurance that the low-pressure piping systems interfacing with the reactor coolant pressure boundary are structurally capable of withstanding the consequences of an intersystem loss-of-coolant accident.