3L Evaluation of Postulated Ruptures in High Energy Pipes

3L.1 Background and Scope

An evaluation of the dynamic effects of fluid dynamic forces resulting from postulated ruptures in high energy piping systems is required by SRP 3.6.1 and 3.6.2. The criteria for performing this evaluation is defined in Subsections 3.6.1 and 3.6.2 of this PSAR and in the USNRC Standard Review Plans and ANS 58.2, which are referenced in the PSAR.

This Appendix defines an acceptable procedure for performing these evaluations. The procedure is based on use of analytical methodology, computer programs and pipe whip restraints used by GE, but it is intended to be applicable to other computer programs and to pipe whip restraints of alternate design.

The evaluation is performed in four major steps:

(1) Identify the location of the postulated rupture and whether the rupture is postulated as circumferential or longitudinal.

(2) Select the type and location of the pipe whip restraints.

(3) Perform a complete system dynamic analysis or a simplified dynamic analysis of the ruptured pipe and its pipe whip restraints to determine the total movement of the ruptured pipe, the loads on the pipe, strains in the pipe whip restraint, and the stresses in the penetration pipe.

(4) Evaluate safety-related equipment that may be impacted by the ruptured pipe or the target of the pipe rupture jet impingement.

The criteria for locations where pipe ruptures must be postulated and the criteria for defining the configuration of the pipe rupture are defined in Subsection 3.6.2. Also defined in Subsection 3.6.2 are: (1) the fluid forces acting at the rupture location and in the various segments of the ruptured pipe, (2) the jet impingement effects including jet shape and direction and jet impingement load.

The high energy fluid systems are defined in Subsection 3.6.2.1.1 and identified in Tables 3.6-3 and 3.6-4. Essential systems, components and equipments, or portions thereof, specified in Tables 3.6-1 and 3.6-2 are to be protected from pipe break effects which would impair their ability to facilitate safe shutdown of either of the Lungmen plants.

The information contained in Subsections 3.6.1 and 3.6.2 and in the USNRC SRPs and ANS 58.2 is not repeated in this Appendix.

3L.2 Identification of Rupture Locations and Rupture Geometry

3L.2.1 Ruptures in Containment Penetration Area.

Postulation of pipe ruptures in the portion of piping in the containment penetration area is not allowed. This includes the piping between the inner and outer isolation valves. Therefore, examine the final stress analysis of the piping system and confirm that, for all piping in containment penetration areas, the design stress and fatigue limits specified in Subsection 3.6.2.1.4.2 are not exceeded.

3L.2.2 Ruptures in Areas other than Containment Penetration.

(1) Postulate breaks in Class 1 piping in accordance with Subsection 3.6.2.1.4.3.

(2) Postulate breaks in Classes 2 and 3 piping in accordance with Subsection 3.6.2.1.4.4.

(3) Postulate breaks in seismically analyzed non-ASME Class piping in accordance with the above requirements for Classes 2 and 3 piping.

3L.2.3 Determine the Type of Pipe Break

Determine whether the high energy line break is longitudinal or circumferential in accordance with Subsection 3.6.2.1.6.1.

3L.3 Design and Selection of Pipe Whip Restraints

3L.3.1 Make Preliminary Selection of Pipe Whip Restraint

The load carrying capability of the GE U-Bar pipe whip restraint is determined by the number, size, bend radius and the straight length of the U-bars. The pipe whip restraint must resist the thrust force at the pipe rupture location and the impact force of the pipe. The magnitude of these forces is a function of the pipe size, fluid, and operating pressure.

A selection of one of the standard GE pipe whip restraints is made by matching the thrust force at the rupture location with a pipe whip restraint capable of resisting this thrust force.

3L.3.2 Prepare Simplified Computer Model of Piping-Pipe Whip Restraint System.

Prepare a simplified computer model of piping system as described in Subsection 3L.4.2.1 and as shown in Figures 3L-1 and 3L-2. Critical variables are length of pipe, type of end condition, distance of pipe from structure and location of the pipe whip

Locate the pipe whip restraint as near as practical to the ruptured end of the pipe but establish location to minimize interference to Inservice Inspection.

3L.3.3 Run “Pipe Dynamic Analysis” (PDA)

Run the PDA computer program using the following input:

(1) The information from the simplified piping model, including pipe length, diameter, wall thickness and pipe whip restraint location.

(2) Piping information such as pipe material type, stress/strain curve and pipe material mechanical properties.

(3) Pipe whip restraint properties such as force-deflection data and elastic plastic displacements.

(4) Force time-history of the thrust at the pipe rupture location.

3L.3.4 Select Pipe Whip Restraint for Pipe Whip Restraint Analysis.

PDA provides displacements of pipe and pipe whip restraint, pipe whip U-bar strains, pipe forces and moments at fixed end, time at peak load and lapsed time to achieve steady state using thrust load and pipe characteristics.

Check displacements at pipe broken end and at pipe whip restraint and compare loads on the piping and strains of pipe whip restraint U-bars with allowable loads and strains. If not satisfied with output results rerun PDA with different pipe whip restraint parameters.

3L.4 Pipe Rupture Evaluation

3L.4.1 General Approach

There are several analytical approaches that may be used in analyzing the pipe/pipe whip restraint system for the effects of pipe rupture. This procedure defines two acceptable approaches.

(1) **Dynamic Time-History Analysis With Simplified Model**—A dynamic time history analysis of a portion of a piping system may be performed in lieu of a complete system analysis when it can be shown to be conservative by test data or by comparison with a more complete system analysis. For example, in those cases where pipe stresses in the containment penetration region need not be calculated, it is acceptable to model only a portion of the piping system as a simple cantilever with a fixed or pinned end or as a beam with both ends fixed or with one end pinned and one end fixed.

When a circumferential break is postulated, the pipe system is modeled as a simple cantilever, the thrust load is applied opposite the fixed (or pinned) end and the pipe whip restraint acts between the fixed (or pinned) end and the thrust load. It is then assumed that all deflection of the pipe is in one plane. As the pipe moves a resisting bending moment in the pipe is created and later a restraining force at the pipe whip restraint. Pipe movement stops when the resisting moments about the fixed (or pinned) end exceed the applied thrust moment.

When a longitudinal break is postulated, the pipe system has both ends supported. To analyze this case, two simplifications are made to allow the use of the cantilever model described above. First, an equivalent point mass is assumed to exist at D (Figure 3L-2) instead of pipe length DE. The inertia characteristics of this mass, as it rotates about point B, are calculated to be identical to those of pipe length DE, as it rotates about point E. Second, an equivalent resisting force is calculated (from the bending moment-angular deflection relationships for end DE) for any deflection for the case of a built-in end. This equivalent force is subtracted from the applied thrust force when calculating the net energy.

See Figures 3L-1 and 3L-2 for the models described above.

(2) **Dynamic Time-History Analysis with Detailed Piping Model**—In many cases it is necessary to calculate stresses in the ruptured pipe at locations remote from the pipe whip restraint location. For example, the pipe in the containment penetration area must meet the limits of SRP 3.6.2. In these cases it is required that the ruptured piping, the pipe supports, and the pipe whip restraints be modeled in sufficient detail to reflect its dynamic characteristics. A time-history analysis using the fluid forcing functions at the point of rupture and the fluid forcing functions of each pipe segment is performed to determine deflections, strains, loads to structure and equipment and pipe stresses.

3L.4.2 Procedure For Dynamic Time-History Analysis With Simplified Model

3L.4.2.1 Modeling of Piping System:

For many piping systems, all required information on their response to a postulated pipe rupture can be determined by modeling a portion of the piping system as a cantilever with either a fixed or pinned end. The fixed end model, as shown in Figure 3L-1, is used for piping systems where the stiffness of the piping segment located between A and B is such that the slope of the pipe length, BD, at B, will be approximately zero. The pinned end model, as shown in Figure 3L-1, is used for piping systems where the slope of the pipe length, BD, at B, is much greater than zero. The pinned end model is also used whenever it is not clear that the pipe end is fixed.

A simplified cantilever model may also be used for a postulated longitudinal break in a pipe supported at both ends, as shown in Figure 3L-2. The pipe can have both ends fixed or have pinned end at B and a fixed end at E, as shown in Figure 3L-2. Subsection 3L.4.1(1) discusses the simplification techniques used to allow the use of a cantilever model. A fixed end is used when rotational stiffness of the piping at that location is such that the slope of the pipe at that end is approximately zero. A pinned end is used when the pipe slope at that end is much greater than zero. If it is not clear whether an end is fixed or pinned, the end condition giving more conservative results should be assumed.

The pipe whip restraint is modeled as two components acting in series; the restraint itself and the structure to which the restraint is attached. The restraint and piping behave as determined by an experimentally or analytically determined force-deflection relationship. The structure deflects as a simple linear spring of representative spring constant.

The model must account for the maximum clearance between the restraint and the piping. The clearance is equal to the maximum distance from the pipe during normal operation to the position of the pipe when the pipe whip restraint starts picking up the rupture load. This simplified model is not used if the piping has snubbers or restraints strong enough to affect the pipe movement following a postulated rupture.

3L.4.2.2 Dynamic Analysis of Simplified Piping Model

When the thrust force (as defined in Subsection 3.6.2.2.1) is applied at the end of the pipe, rotational acceleration will occur about the fixed (or pinned) end. As the pipe moves, the net rotational acceleration will be reduced by the resisting bending moment at the fixed end and by the application of the restraining force at the pipe whip restraint. The kinetic energy will be absorbed by the deflection of the restraint and the bending of the pipe. Movement will continue until equilibrium is reached. The primary acceptance criteria is the pipe whip restraint deflection or strain must not exceed the design strain limit of 50% of the restraint material ultimate uniform strain capacity.

The analysis may be performed by a general purpose computer program with capability for nonlinear time-history analysis such as ANSYS, or by a special purpose computer program especially written for pipe rupture analysis such as the GE computer program, “Pipe Dynamic Analysis” (PDA).

3L.4.3 Procedure For Dynamic Time-History Analysis Using Detailed Piping Model

3L.4.3.1 Modeling of Piping System

In general, the rules for modeling the ruptured piping system are the same as the modeling rules followed when performing seismic/dynamic analysis of Seismic Category 1 piping. These rules are outlined in Subsection 3.7.3.3. The piping, pipe supports and pipe whip restraints are modeled in sufficient detail to reflect their dynamic characteristics. Inertia and stiffness effects of the system and gaps between piping and the restraints must be included.

If the snubbers or other seismic restraints are included in the piping model they should be modeled with the same stiffness used in the seismic analysis of the pipe. However, credit for seismic restraints cannot be taken if the applied load exceeds the Level D rating.

The pipe whip restraints are modeled the same as for the simplified model described in Subsection 3L.4.2.1. For piping designed with the GE U-Bar pipe whip restraints, the selected size and dimensions, and the resulting force-deflection and elastic/plastic stiffness is first determined according to the procedure previously defined in Section 3L.3.

3L.4.3.2 Dynamic Analysis using Detail Piping Model

The pipe break nonlinear time-history analysis can be performed by the ANSYS, or other NRC approved non-linear computer programs. The force time histories acting at the break location and in each of the segments of the ruptured pipe are determined according to the criteria defined in ANS 58.2. The time step used in the analysis must be sufficiently short to obtain convergence of the solution. (GE has shown that for a rupture of the main steam pipe a time step of .001 seconds is adequate for convergence.) The analysis must not stop until the peak of the dynamic load and the pipe response are over.

The primary acceptance criteria are: (1) The piping stresses between the primary containment isolation valves are within the allowable limits specified in Subsection 3.6.2.1.4.2, (2) the pipe whip restraint loads and displacements due to the postulated break are within the design limits, and (3) specified allowable loads on safety-related valves or equipment to which the ruptured piping is attached are not exceeded.

3L.5 Jet Impingement on Essential Piping

Postulated pipe ruptures result in a jet of fluid emanating from the rupture point. Safety-related systems and components require protection if they are not designed to withstand the results of the impingement of this jet. Subsection 3.6.2.3.1 provides the criteria and procedure for: (1) defining the jet shape and direction, (2) defining the jet impingement load, temperature and impingement location and (3) analysis to determine effects of jet impingement on safety-related equipment.

The paragraphs below provide some additional criteria and procedure for the analysis required to determine the effects of jet impingement on piping.

(1) Jet impingement is a faulted load and the primary stresses it produces in the piping must be combined with the stresses caused by SSE to meet the faulted stress limits for the designated ASME class of piping.

(2) If a pipe is subjected to more than one jet impingement load, each jet impingement load is applied independently to the piping system and the load which supplies the largest bending moment at each node is used for evaluation.

(3) A jet impingement load may be characterized as a two part load applied to the piping system—a dynamic portion when the applied force varies with time and a static portion which is considered steady state.

> For the dynamic load portion, when static analysis methods are used, apply a dynamic load factor of 2. Snubbers are assumed to be activated. Stresses produced by the dynamic load portion are combined by SRSS with primary stresses produced by SSE.

For the static load portion, snubbers are not activated and stresses are combined with SSE stresses by absolute sum.