TROJAN NUCLEAR PLANT ANALYSES OF PIPE BREAKS,

OUTSIDE CONTAINMENT

PGE-1004

The following information is furnished as a guide for the insertion of new sheets for Amendment 4 into the Trojan Nuclear Plant Analyses of Pipe Breaks, Outside Containment. This material is denoted by use of the revision number and date in the lower outside corner of the page.

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1.0 INTRODUCTION

This report was prepared in response to the Directorate of Licensing letter of December 19, 1972 to Portland General Electric Company, in regard to the consequences of pipe rupture during operation of the Trojan Nuclear Plant. This letter and its attachment titled "General Information Required for Consideration of the Effects of a Piping System Break Outside Containment" as modified by errata dated January 10, 1973, were the basis of this report. Discussions with the Atomic Energy Commission (AEC) Task (4) Force assigned to investigate the problems associated with high energy line pipe breaks outside Containment took place in Bethesda, Maryland on January 22, 1973 and provided further interpretation of the criteria outlined in the AEC letter referenced above. Pertinent correspondence regarding this subject is enclosed herein within Appendix A.

Revision 1 includes an updating of system descriptions and responses to the following AEC Directorate of Licensing questions and positions regarding the Trojan Nuclear Plant Final Safety Analysis Report:

1) Question 3.4 forwarded in the AEC letter of June 29, 1973.

2) Question 10.2 forwarded in the AEC letter of August 10, 1973. (1)

3) Question 3.24 forwarded in the AEC letter of November 30, 1973.

4) Question 10.6 forwarded in the AEC letter of January 18, 1974.

The revision also includes explanations and clarifications discussed in a meeting with AEC representatives on November 27, 1973.

Revision 2 includes an updating of the pipe break analysis within the main steam support structure. (2)

Revision 3 includes updates to Figure 2-4 and Figure 4-2c to reflect the latest Auxiliary Feedwater System configuration.

Revision 4 includes updates of the analyses of main steam and feedwater line ruptures within the Turbine Building and the Main Steam Support Structure. The environmental effects from the main steam and feedwater line breaks are discussed in Topical Report PGE-1025, "Trojan Nuclear Plant Environmental Qualification Program Manual". (4)

5.1 MAIN STEAM LINE RUPTURE

The 28 inch main steam lines carry saturated steam between 557°F and 1107 pounds per square inch absolute (psia) for no-load hot standby, and 530°F and 888 psia for 100 percent load operation. The pipe break criteria, as described in Section 1.2, were used for the analysis of the main steam lines, except for the main steam safety valve header inside the Main Steam Support Structure (MSSS). This portion of piping, which (1) is between the Containment penetration and the second main steam isolation valve, has been analyzed in accordance with the Branch Technical Position - MEB Number 1, "Postulated Failure and Leakage Locations in Fluid System Piping Outside Containment" dated July 1, 1974 (see Appendix A). The piping downstream of the second main steam isolation valve is Seismic Category II. The Seismic Category II portion of the main steam line was analyzed to determine the high stress locations. Using this analysis, which is summarized in Table 5-1, the pipe break locations, shown by circled numbers in Figure 4-1, were postulated. Both a full area longitudinal and a double-ended rupture were considered at these break locations.

5.1.1 AREAS AFFECTED BY A STEAM LINE RUPTURE

The consequences of a steam line rupture would be limited to the Turbine Building and the MSSS, as shown in Figures 4-3a and 4-3b. Equipment, components, and systems located in the Control Building, Auxiliary Building, or the Fuel Building would not be exposed to the effects of a steam line rupture. Equipment, structures, and components important to safety (1) located in areas possibly affected by a steam line rupture are as follows:

1) MSSS.
2) Auxiliary Feedwater System (AFW) and compartments.
3) Emergency diesel generators (EDGs) and compartments.
4) Engineered safety features (ESF) Class 1E switchgear.
5) Main Steam System upstream of the isolation valves.
6) Containment adjacent to the MSSS. (2)

7) Auxiliary feedwater remote control/remote shutdown panel (C-160).
8) Main feedwater isolation valves. (4)
9) Main steam and turbine first-stage pressure transmitters.
10) Train A safety-related cabling.

5.1.2 PIPE WHIP

The methods outlined in Reference 1 were used to analyze the full area pipe breaks postulated above for pipe whips. (1) Because of the large resultant jet thrust forces, plastic hinge formation was assumed for all unrestrained break locations on the steam lines. The methods used for the analysis of the effects of the pipe whip forces on structures are outlined in Appendix B.

Existing pipe whip restraints were reanalyzed and were found adequate to prevent damage to ESF electrical and fluid systems for pipe ruptures at Location 1 as shown in Figure 4-1. (2) These ruptures are located in the Seismic Category I portion of the main steam lines and the restraints provided prevent damage to the Containment structure and to the electrical and mechanical portions of the main steam isolation valves. The analysis of these break locations was identical for all four steam lines. It should be noted that the stress levels at these break locations are below the limits defined in the American Society of Mechanical Engineers (ASME) Section III, Class 2, portion of Section 1B of MEB Number 1. Additionally, pipe whip restraints designed in accordance with Section 2C(1), Appendix A of MEB Number 1, are located immediately downstream of the second main steam isolation valve which are capable of (2) resisting bending and torsional moments.

A pipe rupture is not postulated for the branch connection on the main steam safety valve header designated Locations 2 and 3 on Figure 4-1. This portion of piping, which is between the Containment penetration and the second main steam isolation valve, has been analyzed in accordance with MEB Number 1. In applying these criteria, no pipe breaks have been postulated on the main steam safety valve header piping inside the main steam support structure because: 1) the piping stress levels are below the limits defined in the ASME Section III, Class 2, portion of Section 1B of MEB Number 1, 2) pipe whip restraints designed per the requirements of MEB Number 1, Appendix A, Section 2C(1) are located immediately downstream of the second isolation valves, and 3) inservice inspection will be conducted on 100 percent of all Class 2 welds in this region defined as inspectable in accordance with ASME Section XI, Winter 1972 Addenda. (2)

The pipe whip analysis for Break Location 4 was performed to investigate the possible damage to the auxiliary feedwater area located at Elevation 45 feet, which is partially under the main steam lines. The analysis indicated the need for a pipe restraint to prevent a longitudinal rupture at Location 4 from whipping the pipe down to the floor and collapsing the auxiliary feedwater area root. The restraint was found to be necessary only on the steam line from Steam Generator E-201A. This is because this line is located farthest north of the four steam lines and the impact on the floor of any of the other three lines would not affect the auxiliary feedwater area. (See column numbers on Figures 4-3b and 4-4.)

Pipe restraints for breaks at Locations 5, 6, 7, and 8 and the rest of the Main Steam System were not provided, because any unrestrained pipe motion resulting from a rupture in these areas on all four lines would not jeopardize any equipment, components, or systems important to safety. (1)

The jet forces from a critical crack are not significant enough to create a pipe whip affecting the safety-related items. (1)

<u>5.1.3 JET IMPINGEMENT</u>

The jet impingement force caused by the momentum change of fluid flowing through the break is a function of the upstream fluid conditions, fluid enthalpy, source pressure, pipe flow restrictional friction, and dimensions.

The jet forces acting upon the pipe are computed using the method outlined in Reference 1. The jet forces are assumed to be instantaneous (1) (with zero rise time). The forcing function is assumed to be a straight line which changes so slowly that the variations up to the time of maximum response are negligible. The methods used for the analysis of the effects of jet impingement forces on structures are outlined in Appendix B.

The main steam support structure was analyzed to determine the effects of jet impingement forces on the safety-related equipment located in the (1) area. The support structure was found adequate to withstand the jet impingement loads applied by full area ruptures at Locations 1 and 2. (2) Therefore, the main steam isolation valves are protected from the effects of jet impingement. (1)

It was determined that any jet impingement loading resulting from a critical crack anywhere in the main steam lines or any postulated full (2) area longitudinal or circumferential pipe break in the remainder of the main steam lines would not affect any structures, systems, or components necessary for a safe shutdown due to a steam line break.

5.1.4 COMPARTMENT PRESSURIZATION

The postulated main steam line ruptures in the Turbine Building were (4) analyzed to determine the effects of the resulting compartment pressurization. The various postulated breaks in these piping runs were analyzed (2) to determine the worst case break in the Turbine Building. Compartment pressurization analysis for the main steam support structure will be addressed in a subsequent revision to this report.

The double-ended guillotine main steam line break at Location 4 (see (4) Figure 4-1) was found to be the worst-case steam pipe break in the Turbine Building.

The methods outlined in Appendix D were used to calculate steam mass and energy blowdown rates for a full area main steam pipe rupture.

Using the methodology described in Appendix C, an analysis was performed to predict the peak pressures expected in the various compartments of the Turbine Building following the postulated worst-case steam line rupture. The results of this analysis indicated that in order to ensure acceptable environmental conditions within the safety-related equipment compartments, as well as to preserve the structural integrity of safety-related portions of the building, the following modifications are required:

1) Modification of a portion of the east and south Turbine Building exterior metal siding between Elevations 63 feet and 93 feet such that it will blow out at a Turbine Building internal pressure of approximately 0.2 pounds per square inch gage (psig). Use of blowout-type panels in lieu of permanent removal of the existing metal siding provides the necessary pressure relief, while maintaining the environmental protection normally afforded by an enclosed structure. (4)

2) Modification of the following equipment maintenance/access doors as required to prevent their structural failure: Door 102 to the diesel-driven AFW pump room, Door 106 in the access corridor between the Turbine Building and the railroad bay, Door 109 to the "B" emergency diesel generator compartment, Door 110 at the east end of the railroad bay, and Door 132 to the "A" ESF switchgear room.

3) Installation of backdraft-type dampers in the ventilation exhausts for the following rooms to limit steam intrusion into the safety-related equipment compartments: diesel AFW pump room, steam AFW pump room, and remote shutdown panel room.

4) Structural reinforcement of the smoke exhaust plenum for the "A" ESF switchgear room as required to prevent collapse due to the steam line break pressure transient.

5) Installation of a flapper-type damper in the ventilation intake opening of the remote shutdown panel room to limit steam intrusion into the room. (4)

6) Structural reinforcement of the ventilation intake duct for the steam AFW pump room as required to prevent collapse due to the steam line break pressure transient.

5.1.5 FLOODING FROM STEAM LINE BREAK

The Turbine Building contains the following safety-related equipment:

1) Emergency diesel generators located at Elevation 45 feet in the diesel generator compartments. (1)

2) Auxiliary feedwater pumps and piping located at Elevation 45 feet in the auxiliary feedwater compartments.

3) Class 1E switchgear in the Turbine Building switchgear room located at Elevation 63 feet.

4) Auxiliary feedwater remote control/remote shutdown panel (C-160) located in its own compartment at Elevation 45 feet. (4)

Each of the rooms containing this equipment is isolated from the others and from the other portions of the Turbine Building. Therefore, this equipment will not be affected by failures outside the rooms except where flooding would be allowed to continue to a point above the 45-foot elevation.

The design basis internal flooding rate for the Turbine Building is designed is 500,000 gallons per minute (gpm), which is assumed to occur following a circulating water system rupture. Since this design basis flooding rate far exceeds the maximum blowdown rate calculated for the worst-case steam line rupture, there would be no flooding of ESF equipment due to a main steam line break in the Turbine Building. (4)

There is no safety-related equipment that would be affected by flooding in the main steam support structure as the result of a main steam line break. (1) (2)

5.1.6 ENVIRONMENTAL EFFECTS

The environmental effects of a main steam line rupture in either the Turbine Building or the main steam support structure are discussed in Reference 2. (4)

5.2 FEEDWATER LINE RUPTURE

The four 14 inch feedwater lines carry water at 300°F and 1140 psig at no-load condition and 440°F and 920 psig at 100 percent load. The pipe (2) break criteria as described in Section 1.2 were used for the analysis. The feedwater lines from the feedwater pumps to the check valve outside the Containment penetration are classified as Seismic Category II. The Seismic Category II portion of the Feedwater System from the discharge of the feedwater pumps to the inlet nozzle of the sixth-stage feedwater heaters and from the discharge nozzle of the seventh-stage feedwater heaters to the Containment penetration, was analyzed to determine the high stress location. Using this analysis, which is summarized in Table 5-2, the pipe break locations identified by circled numbers in Figure 4-2 were postulated. A full area longitudinal and a double-ended circumferential rupture were both considered at these break locations.

5.2.1 AREAS AFFECTED BY A FEEDWATER LINE RUPTURE (1)

The consequences of a feedwater line rupture would be limited to the Turbine Building and the main steam support structure, as shown in Figures 4-3a and 4-3b. Equipment, components, and systems located in the Control Building, Auxiliary Building, or the Fuel Building would not be exposed to the effects of a feedwater line rupture. Safety-related (1) equipment located in the Turbine Building and the main steam support structure is listed in Section 5.1.1.

5.2.2 PIPE WHIP

The methods outlined in Reference 1 were used to analyze postulated full area feedwater pipe breaks for pipe whip. Because of the large resultant (1) jet thrust force, plastic hinge formation was assumed for all break locations in the feedwater lines. The methods used for the analysis of the effects of pipe whip forces on structures are outlined in Appendix B.

Pipe ruptures at Locations 9, 10, 11, 12, 13, and 14 were analyzed (2) because of their proximity to the auxiliary feedwater pump compartment, as shown in Figure 4-4. Because of the pipe orientation, pipe whip motion would be away from auxiliary feedwater area for Break Locations 9, 10, 11, and 12. Pipe Break Locations 13, 14, 15, 16, and 17 are at Elevation 83 feet and above. At these elevations there are no components, equipment, or systems important to safety which could be affected by feedwater pipe whip. Therefore, no pipe whip restraints are necessary in these areas.

The feedwater piping from Break Locations 15 and 16 through the sixth and seventh stage feedwater heaters and to the flow elements located on the 14 inch feedwater lines to the Containment at Elevation 73 feet passes through areas where no safety-related equipment is located. Because of its physical isolation from any safety-related components, equipment, or systems, pipe whip restraints are not necessary for any of the piping described above.

Analysis of pipe whip due to the postulated ruptures at Break Locations 18 and 19 revealed that no components, equipment, or systems important to safety could be affected by a feedwater pipe whip. The analysis for Break Locations 18 and 19 is identical to the break analysis for the other three 14 inch feedwater lines in the main steam support structure.

The jet forces from a critical crack are not significant enough to create pipe whip which could affect safety-related structures or equipment.

5.2.3 JET IMPINGEMENT

The jet impingement force caused by the momentum change of fluid flowing through the break is a function of the upstream fluid conditions, fluid enthalpy, source pressure, pipe flow restrictional friction, and dimensions.

The jet forces acting upon the pipe are computed using the method outlined in Reference 1. The jet forces are assumed to be instantaneous (with zero rise time). The forcing function is assumed to be a straight line which changes so slowly that the variation, up to the time of the maximum response, is negligible. The methods used for the analysis of the effects of jet impingement forces on structures are outlined in Appendix B.

The feedwater piping from the feedwater pump discharges through the sixth- and seventh-stage feedwater heaters and to the flow elements located on the four 14 inch lines, as shown in Figure 4-4, and is routed through areas without any safety-related equipment, components, or systems. Because of its physical isolation jet impingement effects from any full area or critical crack break in the piping described above could not damage equipment or systems necessary for a safe reactor shutdown.

The main steam support structure is designed to withstand the jet impingement loads arising from a full area pipe rupture at Break Locations 18 and 19 without affecting any components, equipment, or systems important to safety.

The auxiliary feedwater compartment was analyzed for the effects of a critical crack in either of the two main feedwater pump discharge lines which pass on both sides of the compartment as shown in Figure 4-4. The auxiliary feedwater compartment was found to be able to withstand loadings from a critical crack in a feedwater line anywhere in the vicinity. There were no postulated full area breaks in the feedwater system that could cause an additional load on the auxiliary feedwater pump compartment.

5.2.4 COMPARTMENT PRESSURIZATION

The postulated main feedwater line ruptures in the Turbine Building were analyzed to determine the effects of the resulting compartment pressurization. Because of the lower energy release rate associated with a feedwater line break, the Turbine Building compartment pressurization would be less than that already presented in the pressure analysis discussed in Section 5.1.4.

Compartment pressurization analysis for the main steam support structure will be addressed in a subsequent revision to this report. (4)

5.2.5 FLOODING

As with the flooding associated with a main steam line break discussed in Section 5.1.5, flooding from a feedwater pipe break in the Turbine Building is enveloped by the design basis flooding resulting from a circulating water system rupture. Therefore, no ESF equipment would be affected by flooding as a result of a feedwater pipe rupture in the Turbine Building. Furthermore, there is no safety-related equipment that would be affected by flooding in the main steam support structure from a main feedwater line break. (4)

5.2.6 ENVIRONMENTAL EFFECTS

The environmental effects of a main feedwater pipe break in either the Turbine Building or the main steam support structure are discussed in Reference 2. (4)

7.0 REFERENCES

1. BN-TOP-2 (Revision 1), Design for Pipe Break Effects, September 1973, Bechtel Power Corporation. (1)

2. PGE-1025, Trojan Nuclear Plant Environmental Qualification Program Manual. (4)

APPENDIX C

COMPARTMENT PRESSURE ANALYSIS FOR TURBINE BUILDING

(4)

Compartment Pressure Analysis for Turbine Building

Introduction

This appendix describes the modeling technique used in evaluating a main steam line rupture in the Turbine Building. A feedwater line break in the Turbine Building was evaluated using the RELAP 5/MOD 1 Code. This code is considered commonly known, and a description is therefore not included here.

Modeling techniques used in evaluating high energy pipe ruptures in the main steam support structure are discussed in Portland General Electrical Topical Report PGE-1025.

Model Description

A main steam line rupture in the Turbine Building was evaluated using Bechtel's FLUD (NE017) Version 7 Code, Thermofluid Dynamics for a System of Interconnected Compartments.

FLUD is a computer code used to calculate pressure and temperature transients in a network of interconnected compartments which is subjected to postulated pipe break accidents. Compartments are regions that are characterized by relatively complete mixing and low fluid velocities; flow paths are regions that connect compartments and have relatively higher fluid velocities. FLUD is similar to the existing COPDA computer code[1] in that it performs the same kind of calculations and has similar options. It is different from COPDA in that it allows modeling of convective heat transfer and steam condensation using the Uchida[2] heat transfer coefficient (or a constant heat transfer coefficient selected by the user); it can be used to model heating and ventilating system flows where fans are present; it can model time-dependent variations in atmospheric pressure, temperature, and relative humidity; and it can model variable flow path areas. (4)

A discussion of the assumptions made in FLUD and of their limitations is presented below.

The FLUD Validation Report[3] describes features and options of the code and the various benchmark problems run to verify FLUD. Detailed instructions on the execution and use of the FLUD program on Bechtel's Univac computer system are presented in the FLUD User's Manual[4].

Summary of Assumptions and Solution Approach

1. Assumptions Made by FLUD

   The meaning, implications, and rationale for the assumptions made in the analytical development are discussed in detail in this section. The significant assumptions used in the FLUD calculations are:

   a. Thermodynamic equilibrium exists at all times in the compartment volume.
   b. The compartment volume contains a homogeneous mixture of steam, air, and water.
   c. Air is treated as an ideal gas, and steam is treated to second order in the virial equation of state.
   d. Flows between compartments are calculated using quasi-steady-state or an implicit technique.
   e. Condensation is treated by using either a Uchida[2] or a constant heat transfer coefficient as selected by the user.

   Assumptions 1 and 2

   Thermodynamic equilibrium means that the air, steam, and water components of each compartment atmosphere are at the same temperature and are homogeneously mixed. Thus, there are no temperature, pressure, or density gradients in the compartment during a given time step. This assumption can be satisfied by choosing compartment volumes small enough or integration time steps large enough so that (4) the relaxation time for the compartment is less than the calculation time step. The assumption of equilibrium greatly reduces the complexity of the governing thermodynamic equations, thus avoiding consideration of nonequilibrium thermodynamics. This assumption can be further justified empirically, because its adequacy has been demonstrated by comparing existing subcompartment analysis codes with many Containment experiments.[5]

The assumption of homogeneous mixing of the air, steam, and water in a compartment implies that there is no water dropout, and thus, no consideration of liquid sump formation. For a large class of problems where high enthalpy steam blowdown is the driving force for compartment pressurization or where rapid flashing is present, this assumption has been observed to be well founded.[5] The steam or flashing water forms a mist of very fine water droplets with insignificant dropout during the times of interest.

For cases where substantially subcooled fluid is being released or for cases where long-term pressure and temperature transients are desired, FLUD gives the user the option of dropping out the liquid (non-flashing) portion of the blowdown fluid rather than mixing it into the compartment atmosphere. The liquid portion of the blowdown is removed from the compartment. This has the effect of maintaining the compartment atmosphere at the saturation point. This option yields slightly lower compartment peak pressures than if homogeneous mixing were assumed, but it gives much more reasonable estimates of the compartment temperature, particularly for long-term transients such as for equipment qualification problems. (4)

Assumption 3

The assumption that air is treated as an ideal gas and steam is treated to second order in the virial equation of state agrees well with the respective air and steam tables. This assumption simplifies the calculation immensely, because time-consuming steam table look-ups are avoided.

Assumption 4

The use of an implicit flow calculation scheme is in keeping with the practice of other existing state-of-the-art thermohydraulic computer programs used in nuclear safety analysis. This method is based on the governing equations of mass momentum and energy conservation which describe the flow. This method and the quasi-steady state flow method also used by FLUD adequately describes the range of flow regimes for which FLUD is used as demonstrated by the favorable comparison with available test data and with the results of other computer programs.[4]

Assumption 5

Condensing heat transfer is modeled using a heat transfer correlation developed by Uchida[2] from measurements of relatively quiescent steam condensing on a vertical flat plate in the presence of variable amounts of air. The correlation is applicable to the extent that the actual situation is similar to the original experiment. Effects on condensation such as compartment turbulence or steam impingement are not considered by this correlation, and thus, its application to these situations is approximate only. The effects of turbulence increase the rate of condensing heat transfer. Thus, the use of the Uchida correlation is considered conservative during the blowdown portion of the transient. (4)

2. FLUD Solution Method

Since FLUD is concerned with calculating transient pressures and temperatures in a system of interconnected compartments, the tracking of mass and energy within the system is of great importance. FLUD uses the mass and energy in a given compartment to calculate the state point (pressure and temperature) of that compartment. The state point in turn is used to calculate the subsequent mass and energy flow rates except for the implicit flow method where a relationship between pressure and energy is used. To advance the calculation through a given transient, the flows of mass and energy are advanced in a discrete, finite difference manner through a given time step. Thus, the main FLUD calculation loop proceeds as follows:

a. Calculate the new system state point from the existing mass and energy.
b. Calculate mass and energy derivatives (flows and heat transfer rates).
c. Integrate the mass and energy derivatives over one time step to determine new masses and energy.

References

1. Braddy, R. W., and J. W. Thiesing, Subcompartment Pressure and Temperature Transient Analysis, BN-TOP-4, Bechtel Power Corporation, 1976. (4)

2. Uchida, H., et al, Evaluation of Post-Incident Cooling Systems of Light Water Power Reactors, Third International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1964.

3. NE017, FLUD, Thermofluid Dynamics for a System of Interconnected Compartments, Validation Report, Revision 1, Bechtel Eastern Power Corporation, June 1986.

4. NE017, FLUD, Thermofluid Dynamics for a System of Interconnected Compartments, Users Manual, Revision 2, Bechtel Eastern Power Corporation, June 1986.

5. COPDA, Bechtel Power Corporation; DDIF-1, Combustion Engineers; WARLOC, Sargent & Lundy; THREED, Stone & Webster; COMPRESS, United Engineers & Constructors; TMD, Westinghouse; MNODE, Gilbert Commonwealth.

APPENDIX D

STEAM LINE BREAK IN THE TURBINE BUILDING (4)

Steam Line Break In the Turbine Building

Introduction

The following outlines a method for obtaining mass flow rates which may be used for determining local pressures resulting from a steam line break in the Turbine Building. The flow rates obtained using this procedure are defensible upper bound values for any break location in the Turbine Building. Note that they are intended to be used for local short-term compartment pressure calculations and are not applicable for calculating long-term mass and energy releases, thrust loads, or jet impingement forces. Also note that in the method that follows, back flow from the intact steam lines (and steam generators) is included. The temperature effects of a steam line break are discussed in Portland General Electric Topical Report PGE-1025.

Basis for the Calculations

(4)

Since detailed flow rate calculations for steam line breaks in the Turbine Building are a function of plant piping layout and break location, the effort required for transient blowdown analyses for all cases involving assessment of consequential damage resulting from the break becomes quite prohibitive. For this reason, it is desirable to obtain defensible upper bound flow rates which are independent of break location.

The limiting plant condition in terms of both steam generator mass inventory and initial secondary system pressure are obtained when the plant is at hot standby. Because of the high flow rates associated with a steamline break, frothing in the steam generator causes a rapid increase in water level, resulting in a large decrease in the quality of fluid expelled from the steam generator. Although the enthalpy of this low quality fluid is less than that of dry steam, the critical mass flow rate is higher due to the higher pressure, resulting in a net increase in the energy release rate from the break. Current evaluations show this to be the limiting case for determining maximum pressure in vented compartments. The blowdown can be broken up into time required for both forward and backward flow from a double-ended guillotine break. Maximum pressures are reached very quickly following the rupture, and it is found that the piping inventory determines the magnitude of the maximum compartment pressures. The mass flow production of the steam generators only plays a role in determining peak temperature values as discussed in PGE-1025.

Computational Method

The piping, both upstream and downstream of the break, may act as a reservoir during the decompression following the break. The flow is calculated using a method of characteristics computer program, Bechtel's PATHFINDER code, as discussed in the following. In the analysis, the blowdown flow rate after reaching its peak value was conservatively assumed to remain constant until the piping inventory was depleted. The peak value was verified with Moody's chart. (4)

Description of PATHFINDER Code

PATHFINDER

SIMULATION OF THE FLOW OF AN IDEAL GAS

BETWEEN TWO RESERVOIRS USING THE

METHOD OF CHARACTERISTICS

It has long been known that the method of characteristics (MOC) when applied to transient fluid flow problems offers many advantages: it is the most accurate of any of the finite difference methods for simulating fluid flow, criteria for stable solutions are firmly established, transient two-phase flow with heat transfer is easily handled, and the method lends itself to the simulation of flow in very complex piping systems. The PATHFINDER computer program uses the method of characteristics to simulate fluid flow in order to accurately simulate the flow of an ideal gas between two reservoirs.

The basic equations governing fluid motion are essentially nonlinear (more precisely, quasi-linear), hyperbolic, partial differential equations. Because of this basic nonlinearlity, exact solutions are rare and are usually self-similar solutions. This class of solutions. This class of solutions result from the reduction of the governing partial differential equations to ordinary differential equations by virtue of a high degree of symmetry. Therefore, recourse is made to numerical techniques for the solution of the fluid equations of motion.

We explicitly assume the flow is one-dimensional and adiabatic. The equations governing fluid flow are the conservation equation for mass,

$$\frac{\partial p}{\partial t} = \frac{\partial}{\partial z}(\rho u) = 0 \qquad [1]$$

for momentum

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial z} + \frac{1}{\rho}\frac{\partial p}{\partial z} + g\sin\theta + F = 0 \qquad [2]$$

and for energy

$$\frac{\partial}{\partial t}[\rho(e+\frac{u^2}{2})] + \frac{\partial}{\partial z}[\rho u(h=\frac{u^2}{2})] + \rho ug\sin\theta = 0 \qquad [3]$$

where u is the fluid velocity, p the pressure, h the specific enthalpy, ρ the density, e the specific energy, and the remaining variables have standard meanings. The variable F represents the flow resistance per unit mass and includes the frictional resistance at the pipe-fluid boundary, as well as the localized losses:

$$F = \frac{1}{2}\left[\frac{4f}{D} + \frac{K}{L}\right] u|U| \qquad [4]$$

where f is the Fanning friction factor, D the pipe diameter, and K/L the local losses per unit pipe length.

The mass, momentum, and energy conservation equations are quasi-linear, hyperbolic, partial differential equations, and a closed form solution, is in general, not possible. Solution of these partial differential

(4)

equations (PDEs) via the method of characteristics consists of their transformation into ordinary differential equations (ODEs). A consequence of such a transformation is that the resulting ODEs are valid only along specific space-time trajectories known as characteristics.

This transformation results in six equations: two propagation equations, one transport equation, and three equations describing the trajectories of propagation and transport. The propagation of pressure and velocity in the direction of positive flow is:

$$\frac{dp}{dt} + \rho a \frac{du}{dz} = -a^2 \left[\frac{\partial \rho}{\partial h}\right]_p uF - \rho a \; [F + g \sin\theta] = K, \qquad [5]$$

while the equation describing the trajectory of this propagation, the C_+ characteristic, is:

$$\frac{dz}{dt} = u + a. \qquad [6]$$

The equation describing the propagation of pressure and velocity in the direction of negative fluid flow is:

$$\frac{dp}{dt} - \rho a \frac{du}{dz} = -a^2 \left[\frac{\partial p}{\partial h}\right]_p uF + \rho a \; [F + g \sin\theta] = L, \qquad [7]$$

and the equation describing the trajectory of this propagation, the C- characteristic, is:

$$\frac{dz}{dt} = u - a. \qquad [8]$$

Energy is transported rather than propagated; the equation describing the transport of thermal energy (expressed in terms of enthalpy) is:

$$\frac{dh}{dt} - \frac{1}{\rho}\frac{dp}{dt} = uF = M, \qquad [9]$$

(4)

and the equation describing the trajectory of energy transport, the C_D characteristic, is:

$$\frac{dz}{dt} = u. \qquad [10]$$

In the above equations describing pressure propagation and energy transport, the parameters K, L, and M represent losses due to flow resistance and heat transfer. (For this simulation study, heat transfer was neglected.)

Since the three conservation equations (Eqs[1] - [3]) contain four unknowns (p, u, h, ρ), an additional equation must be specified. For this additional equation, we choose the equation of state for an ideal gas which expressed the fluid density p in terms of fluid pressure p and specific enthalpy h:

$$\rho + \rho\,(p,h) = \frac{k}{[k-1]}\,\frac{p}{h} \qquad [11]$$

(4)

where k is the ratio of specific heats.

The junction between the two reservoirs and the flow path constitute two separate boundary conditions for the flow path. Gas is either flowing from or to, out from or into, a reservoir. For the case where the flow is from the reservoir into the flow path, the pressure at the flow path boundary is assumed to undergo an isentropic expansion:

$$\frac{p}{P_o} = \left[1 + \frac{k-1}{2}\left(\frac{u}{a}\right)^2\right]^{-1} \qquad [12]$$

where P_o is the bulk average reservoir pressure. The variables p, u, and a are the pressure, fluid velocity, and sonic speed at the entrance to the flow path.

For flow from the flow path into the reservoir, the junction pressure is taken to be the bulk average reservoir pressure for subsonic flow [(u/a) < 1]. For sonic flow [(u/a) = 1], the junction pressure is greater than the reservoir pressure. (4)

APPENDIX E

FEEDWATER LINE BREAKS IN THE TURBINE BUILDING AND BLOWDOWN LINE BREAKS OUTSIDE CONTAINMENT

(4)

Feedwater Line Breaks in the Turbine Building and Blowdown Line Breaks Outside Containment

Introduction

The following outlines methods for obtaining mass and energy discharge rates following a feedwater line in the Turbine Building or a blowdown line rupture outside the Containment. The methods for calculating mass and energy discharge rates result in conservative upper-bound values which shou d be used for the calculation of short-term compartment pressures resulting from piping rupture. The discharge rates calculated by these methods should not be used for calculating long-term and energy releases, thrust loads, or jet impingement forces. The temperature effects of a feedwater line break are discussed in Portland General Electric Topical Report PGE-1025.

Basis for the Calculations

1. Feedwater System

   Under normal operating conditions, the feedwater system will contain pressurized, subcooled water. The assumption of a double-ended guillotine break under these conditions results in a decompression wave propagating through the system at sonic velocity with the pressure behind the wave corresponding to saturation pressure of the liquid. Because of the very low compressibility of subcooled water, subcooled blowdown cannot be sustained for more than a few milliseconds, and the total mass release under subcooled blowdown conditions is quite small. Following this extremely short term initial phase, the pressure will correspond to saturation pressure of the feedwater.

   The net mass flow rate through a feedwater line break was developed using the RELAP 5/MOD 1 code. The limiting conditions were obtained assuming the highest feedwater temperature to be expected at that location under normal conditions.

(4)

2. Blowdown System

Since the blowdown system piping consists of much smaller lines than the feedwater system, as well as less interconnecting piping, the effects of friction losses in the piping are included in the calculation. The blowdown flow rate is calculated using the results of Moody's[2] evaluation of blowdown of a reservoir through connected piping. The steam generator pressure at no load conditions is used to determine the mass flow rate for saturated liquid.

Computational Method

The zero loss maximum blowdown flow rate for saturated liquid based on the Moody[1] correlation has been fit to a simple function of pressure to obtain the following relation:

$$G = 250\, P^{1/2} \qquad 300 < P < 1200 \text{ pounds per square inch absolute (psia)} \qquad \text{(E-1)}$$

where

P = Saturation pressure of the liquid, psia

G = Mass velocity, pounds mass per square foot second (lbm/ft^2-sec)

This function may be used to calculate G_o for the blowdown line rupture.

Definitions:

$A_{P_{fw}}$ = cross-sectional area of pipe at break location, square feet.

P_{sat} = saturation pressure corresponding to feedwater temperature at full load.

P_{SG}^{NL} = no load secondary system pressure (this is consistent with a plant trip from full load near the time of a feedwater line rupture).

C = sonic velocity of compressed water - 4500 feet per second. (4)

L^{SG} = length of pipe between steam generator and break, feet.

L_P = length of pipe between nearest main feedwater pump and break, feet.

W_F = forward flow, from break, pounds mass per second.

W_B = back flow from break, pounds mass per second.

Since the blowdown system consists of smaller piping than the feedwater system with less interconnected piping which may act as reservoirs during the blowdown, the effect of line resistance may be included in the procedure.

Neglecting line resistance can lead to overpredicting the blowdown rate by a factor of two to five. Allowance for resistance, however, results in a best-estimate blowdown rate with a possible uncertainty of ± 40 percent. For an upper-bound prediction of the blowdown rate, the appropriate relation is, therefore,

$$G_i = 1.4 \times 250 \times P \times G_i/G_o = 350\ P\ G_i/G_o,$$

where G_i/G_o is a function of f L/D and is shown on Figure 1.

The flow rate is determined by:

$W = A_p \times 350\ (P^{NL}_{SG})^{1/2}$, $0 < t < t_1 < t$ seconds starting new loads where t_1 is the time required to discharge the piping volume between the break and a steam generator and leg.

$$W = A_p \times 350\ (P^{NL}_{SG})^{1/2} \times (G_1/G_o),\ t1 < t \text{ seconds}$$

where G_1/G_o is taken from Figure 1 as a function of piping resistance f L/D.

(4)

Figure 1 is a condensed version of the results given in Reference 2, which is applicable over the parameter range of interest. If credit is taken for a flow area in the line that is smaller than the flow area of the pipe, such as a partially closed valve, the mass velocity should be determined assuming zero resistance, ie:

$$W = A_v \times 350\ (P\ \overset{NL}{SG})^{1/2}$$

where A_v is the flow area of the restriction.

Forward and reverse flow out the break should be determined separately and summed. (4)

The energy release is determined by multiplying the mass flow rate by the enthalpy of the fluid being expelled.

<u>References</u>

1. F. J. Moody, "Maximum Flow Rate of a Single Component, Two-Phase Mixture", Journal of Heat Transfer, Trans. ASME, Series C, Volume 86, February 1965, P. 134.

2. F. J. Moody, "Maximum Two-Phase Vessel Blowdown from Pipes", Journal of Heat Transfer, August 1966, P. 285.