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Big Rock Point Plant
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EVALUATION OF HIGH ENERGY PIPE BREAK INSIDE CONTAINMENT FOR THE BIG ROCK POINT NUCLEAR PLANT

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1.1, 1.2	0	↑	↑	PCR	5.1, 5.2	0	WVW	TRM	PCR
2.1 thru 2.13	0				6.1 thru 6.9	0	TRM	PHG	
3.1 thru 3.19	0	WVW	TRM		7.1, 7.2	0	↑	↑	
4.1 thru 4.11	0	↓	↓		8.1 thru 8.7	0	WVW ↓	TRM ↓	↓
T.4-1	0	TRM	PHG						
T.4-2	0	TRM	PHG						
T.4-3	0	↑	↑						
T.4-4	0	WVW	TRM						
T.4-5	0								
T.4-6	0	↓	↓	↓					

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(continuation)

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PAGE	REV	PRE-PARED	ACCURACY CHECK	CRITERIA CHECK	PAGE	REV	PRE-PARED	ACCURACY CHECK	CRITERIA CHECK

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TABLE OF CONTENTS
VOLUME I

TABLE OF CONTENTS (Cont'd)
VOLUME II

TABLE OF CONTENTS (Cont'd)

VOLUME III

VOLUME IV

1.0 INTRODUCTION

The purpose of this report is to present the results of the analysis for effects of pipe breaks inside containment for the Big Rock Point Nuclear Power Plant. Analysis for the effects of postulated pipe break inside containment is required by the U.S. Nuclear Regulatory Commission (NRC) as part of the Systematic Evaluation Program (SEP) for Big Rock Point (see Reference 11). The criteria used in selection of breaks and methods of analysis are similar to those presented to Consumers Power Company (CPCo) in Reference 10, and are discussed in Sections 2.0 and 3.0.

The evaluation was conducted in three phases, each of which is described in the Project Plan (Reference 14). Phase I resulted in the selection of analysis methods and criteria in accordance with criteria supplied by the NRC as outlined in Reference 11.

The objective of Phase II of the project, as specified in the Project Plan (Reference 14), was to evaluate the effects of postulated pipe breaks for a typical high energy piping system, using the criteria and methods selected in Phase I. The recirculation system risers and downcomers in the Recirculation Pump Room were chosen for the Phase II analysis since postulated breaks in these lines were considered to be the most severe for determining the effects on systems required for safe shutdown of the plant. Phase III consisted of analyzing the remaining high energy piping inside the containment.

This report presents the results of the analysis of the recirculation system breaks as well as the remainder of the high energy piping inside containment performed in Phase III of the Project.

2.0 DISCUSSION OF CRITERIA

This section discusses the general criteria to be used for the Big Rock Pipe Break Evaluation.

Included are criteria for selection of break locations, pipe whip and jet impingement criteria and structural analysis criteria. Table 2-1 lists the high energy lines studied in this report.

2.1 Selection of Break Locations

Reference 11 allows any of three different methods to be used in the selection of high energy pipe break locations. Of these, the Effects Oriented and Simplified Mechanistic approaches have been used for the analysis of Big Rock Point.

2.1.1 Effects Oriented Approach

In general, the Effects Oriented approach requires that breaks be postulated for each high energy piping run as follows:

1. A circumferential break at each terminal end of the run.
2. A longitudinal break at the point which produces the most critical jet impingement loading on each component of each essential (safety-related) system.

3. A circumferential break at the point which produces the most critical pipe whip loading on each component of each essential (safety-related) system.

The Effects Oriented approach has been used in systems where the locations of intermediate pipe welds could not be determined or in locations where potential breaks were determined to have unusually severe consequences.

2.1.2 Simplified Mechanistic Approach

This approach postulates breaks at terminal ends, at each pipe fitting (such as elbows, tees, valves, and flanges), and at each weld. Wherever possible, this approach was used to limit the number of breaks selected.

TABLE 2-1

HIGH ENERGY PIPING SYSTEMS CONSIDERED FOR PIPE BREAK INSIDE CONTAINMENT

PIPING SYSTEM	LINE SIZES	LOCATION
Recirculation (MRS)	4", 5", 14", 17", 20", 24"	Recirculation Pump Room
Main Steam (MSS)	8", 12"	Recirculation Pump Room, Steam Tunnel
Feedwater (FWS)	8", 10"	Recirculation Pump Room, Steam Tunnel
Steam Drum and RPV Level Instrumentation (MSS)	1.5", 2"	Recirculation Pump Room
Core Spray (CSS)	4"	Recirculation Pump Room
Control Rod Drive (CRD)	1 1/2", 2"	Recirculation Pump Room, CRD accumulator Room, CRD pump Room
Shutdown Cooling (SCS)	6", 8"	Recirculation Pump Room
Reactor Cleanup (RCS)	3"	Recirculation Pump Room, Clean-up Demin. Pump Room

TABLE 2-1
(Continued)

HIGH ENERGY PIPING SYSTEMS CONSIDERED FOR PIPE BREAK INSIDE CONTAINMENT

PIPING SYSTEM		LINE SIZES	LOCATION
Reactor Depressurization	(RDS)	2", 6", 12"	Recirculation Pump Room, Emergency Condenser Area
Emergency Condenser	(ECS)	4", 6", 12"	Recirculation Pump Room, Emergency Condenser Area
Liquid Poison	(LPS)	2", 3"	Emergency Condenser Area, Control Rod Drive Room, Recirculation Pump Room
Redundant Core Spray	(RDC)	4"	Reactor Cavity

2.2 Pipe Whip Criteria

NRC Branch Technical Position MEB 3-1 states that "Pipe whipping should be assumed to occur in the plane defined by the piping geometry and configuration, and to cause pipe movement in the direction of the jet reaction." In addition, the force vector due to blowdown is assumed, in MEB 3-1, to be along the pipe centerline at the break plane for circumferential breaks. NUTECH followed the intent of MEB 3-1, however, because of certain conditions at Big Rock Point, planar motion was treated conservatively as discussed below.

The planar assumption is very reasonable for piping systems where pipe whip is limited to small displacements, such as in new plants where pipe whip restraints are used. However, at Big Rock Point, some postulated breaks could result in large displacements, with the severed pipe possibly impacting several successive targets and thereby potentially changing its direction of motion following each impact. Further, since the pipe could undergo continuous plastic deformation, the orientation of the jet thrust force could change in a generally unpredictable manner. Thus, NUTECH considered the possibility of out-of-plane motion after initial impact. However, as the results discussed in Section 4.0 illustrate, this consideration had little effect on the overall conclusions of this report.

Pipe whip due to slot breaks was generally not considered, since:

1. the slot break locations were chosen for worst jet impingement effects, and
2. the most damaging pipe whip effects generally resulted from circumferential breaks.

For the special case of the Tunnel Room, the pipe motion due to longitudinal breaks was considered, since this type of pipe failure would result in potentially high loads on the containment penetration.

For the case of a whipping pipe impacting smaller target pipes, the smaller target pipe was assumed to fail under impact. For the case of a whipping pipe impacting a larger target pipe, no failure was assumed to occur unless the larger pipe had a smaller wall thickness. No pipe whip was assumed to occur in pipes of 1" Nominal Pipe Size (NPS) or less. No secondary effects due to the smaller pipe failure were considered, except for the potential contribution to a total Reactor Coolant Pressure Boundary (RCPB) break area greater than 3 square feet, as required in Reference 12. In addition, if the smaller line was part of a safety system as defined in Reference 11, or part of the primary coolant boundary its failure was noted and documented.

Cable trays were assumed to fail under any type of pipe whip impact since they have negligible load carrying capacity. Also mechanical equipment, such as operating valves, were assumed to become inoperable (fail) under pipe whip impact.

Normal plant operating conditions for temperature and pressure were considered in developing the blowdown thrust forces to be used. For the case of recirculation piping breaks, the energy applied to the whipping pipe was so large that there was no need to consider other system conditions. Such consideration would not change the conclusions of the analysis.

To simplify the analysis, the mass of water in the piping was ignored. Much of the water in the vicinity of the break will flash into steam, making its effective mass insignificant. In addition, the remaining water in the line will not significantly alter the results of the analysis since it is close to the pipe hinge point, and its effect on the pipe's rotational inertia is small. Dead weight loads acting on the severed pipe were ignored, since they were very small in comparison to the pipe thrust loads.

2.3 Jet Impingement and Blowdown Force Criteria

In general, the jet impingement loads due to pipe breaks were calculated in accordance with the methods set forth in ANSI-176, Reference 1. The two methods applicable to this project are summarized in Appendix C; a simplified, conservative method for "first-cut" analysis, and a slightly more detailed method for situations requiring more accuracy. The assumptions used for both methods are given. Possible refinements to ANSI-176 criteria were explored. These were:

1. Shadowing of the target by structures located between the break and the target.
2. Deflection of the water jet due to gravity.
3. Condensation in the steam jet for targets far from the break.

None of these refinements were found to have a significant effect on the jet impingement loads, so the basic ANSI-176 criteria were not altered.

As discussed earlier, slot (longitudinal) breaks were considered as the prime cause of fluid jets in the Big Rock Point pipe break study, and circumferential breaks were studied for pipe whip effects. Jets also occur when a circumferential break separates and the pipe begins to whip. However, as the conclusions of this report show, the analysis effort for the Recirculation Pump Room shows that virtually every target in the room is affected by one or more pipe whip impacts or slot break jets. Therefore, jets from circumferential breaks were not considered in any detail in the Recirculation Pump Room. In other areas, if jets from circumferential breaks were found to impact safety-related equipment, this was noted.

In addition to the criteria discussed above, the following additional jet impingement criteria were applied to this project:

1. No slot breaks were assumed to occur in piping smaller than 4" NPS (Reference 11).
2. Cable trays were assumed to fail under any type of jet load since they have a negligible load carrying capacity.
3. Instrument tubing was assumed to fail under jet loading if it was less than 5D from the break, where D is the diameter of the broken pipe. This was a reasonable assumption considering the small size of the tubing.
4. The effect of jet impingement was considered on target lines both larger and smaller than the broken line.

5. The break was assumed to open instantaneously, such that the jet impact load could be treated as a step function, with a maximum dynamic load factor (DLF) of 2 (Reference 1).
6. Power operated or electrically actuated valves were assumed to become inoperable as a result of jet impingement on the valve.

2.4 Structural Analysis Criteria

Jet forces which result from a pipe break may affect adjacent structures and equipment from either direct impingement of the fluid emanating from the break, or from impact of the severed pipe on items in the trajectory of the pipe. The determination of the fluid forces and a rigorous analysis of the structural response of the items subjected to the fluid forces can be a very time-consuming effort.

As a general rule, therefore, all analyses for the effects of breaks, throughout the project, were performed with simplified, conservative techniques. The purpose of this approach is to obtain as many conclusions as quickly as possible. In those cases where a "first-cut" analysis was found to be inconclusive, a more refined analysis was considered, along with other alternatives, such as rerouting piping, structural modifications, etc.

To minimize the analytical effort, the jet thrust and the impingement force were assumed to build up instantaneously and remain constant at their maximum value, in accordance with the simplified method described in Reference 1.

In analyzing for jet impingement loads, a maximum Dynamic Load Factor (DLF) of 2, to account for the suddenly applied jet load, was considered. This factor appropriately accounts for the dynamic effects of the assumed load function so long as the system remains elastic. When the use of a DLF of 2 produced failure of the target but a DLF of 1 indicated the target could accommodate the jet, additional analyses were performed. Failure of the target with a DLF of 1 leads to the conclusion that the target cannot withstand the imposed load without failure.

For the other areas, the screening techniques discussed in Section 3.5 were applied to determine if a given target could withstand the effects of jet impingement or if further analysis was needed.

In performing the analysis for the structures impacted by whipping pipes, the general criteria for missile impact from Reference 2 were used.

For impact into structural steel, the following criteria were used:

1. Structural steel is A-36 with a yield strength of 36 ksi.
2. For the type of impacted steel structures studied, the material ductility ratio is 20 (Reference 2).
3. All impacts are considered to be plastic collisions i.e., the coefficient of restitution is zero.
4. The energy absorption due to deformation of the pipe at the impact location was ignored. Energy absorption due to plastic bending of the pipe prior to impact was considered.
5. A lower-bound effective mass was used for the target structure.
6. Dead weights of steel targets was ignored for "first-cut" analysis, since they were very small compared to impact loads.

Criteria 3, 4 and 5 were chosen to simplify the analysis, and generally resulted in conservative impact loads.

For impact into concrete structures, the following criteria were used:

1. A plastic collision was assumed.

2. $f_y = 40$ ksi for rebar and $fc' = 3$ ksi for concrete compressive stress. These are typical values for concrete.
3. The ductility ratio for concrete is 10 (Reference 2).

To determine the stresses from jet impingement forces acting on piping, the following criteria were used:

1. Pipe spans were assumed to act as simply supported beams. Standard beam equations (Reference 7) were used.
2. Pipe support spacing was based on data given in ASA B31.1-1955 (Reference 17), the original Code of Construction.
3. Piping materials used were ASTM A-376 TP 304 and A-106 Gr. B (Reference 16).
4. Ultimate strengths are 63.3 ksi and 60.0 ksi, respectively, for stainless and carbon steel. For convenience of calculation, 63.3 ksi was used for both materials. This had no impact on results.
5. The NSSS piping analyses performed using an ultimate strength of 63.3 ksi are conservative. The NSSS stainless steel piping is of several different materials, all having an ultimate strength of 70.0 ksi or greater.
6. Line sizes, schedules, and thicknesses are per CPCo Inservice Inspection isometrics.

3.0 METHODS OF ANALYSIS

This section describes how the criteria discussed in Section 2.0 were applied to the analysis of effects from postulated breaks in high energy piping inside the Big Rock Point Containment.

The analysis procedure consisted of defining the location of potential breaks, establishing an identification for the break, and then performing calculations to show the effect of the jet or whipping pipe on selected targets.

The methods of analysis described in References 1 and 2 were followed. These methods are described in this Section, with additional details provided in Appendices B and C. In most cases, the results were conclusive enough so that more sophisticated techniques were not needed. In some cases, the calculations required were identical to or judged similar enough to previously done calculations such that additional calculations were not necessary. In other cases, conclusions could be drawn by inspection.

3.1 Targets Considered

Targets required for safe shutdown of the plant were identified by CPCO and grouped according to the type of high energy pipe break for which they were required. NUTECH located these targets in the various rooms and areas inside containment along with the high energy lines in these same locations.

Complete lists of targets considered in the analysis for each room or area are in Tables 4-1 through 4-6. These lists were compiled from information provided in References 12 and 13.

3.2 Location of Breaks

The most difficult portion of the evaluation was the reconstruction of design information so that safety targets and their relationship to high energy lines could be determined. This has been accomplished through the use of layout maps to locate the high energy lines in relation to safety targets as defined in Tables 4-1 through 4-6. These maps also provided a useful tool to visualize the trajectories of whipping pipes and jets. The maps served as the basis for the pipe whip and jet location sketches used in Appendices D and E.

The analysis was conducted on a break-by-break basis. As discussed in Subsection 2.1, both the Effects Oriented and Simplified Mechanistic Approach were used to select break locations. For the specific case of breaks in the recirculation system, break locations were initially chosen using the Effects Oriented Approach. However, these break locations have, in many cases, been transferred to weld joints since it was discovered that there are circumferential pipe welds close to most of the chosen break locations. This had no impact on analysis results such as targets affected, number of breaks chosen, etc.; but it will allow for a much more logical approach for defining solutions to the identified problems. The reasoning for this, of course, is that pipe breaks are much more likely at pipe weld joints.

In some cases, several different whipping pipes, such as the recirculation risers, could have hit the same targets. These have all been considered to illustrate as many potential problem areas as possible. For circumferential breaks, calculations and sketches showing the break and the pipe whip targets are presented in Appendix D. The set of calculations and sketches stand together as one package for each break.

The location of longitudinal (slot) breaks was made using an analysis similar to that for circumferential breaks. Jet impact calculations are grouped by break number for piping targets. For cable tray targets, the jet impact point was determined by the layout maps. No calculations were performed for cable trays since they are assumed to fail for any jet impact, as discussed in Subsection 2.3.

3.3 Break Identification

Each break has been assigned an identification number using a system which can be followed on the whole project. The system utilizes the basic CPCo line number followed by a break identifier. For example, 14-MRS-103-TB1 indicates the break considered was the first terminal break (TB1) in 14" riser #103. All breaks considered are listed by number in the pipe break evaluation matrices in Appendix A. All calculations in Appendices D and E are organized using this numbering scheme as well.

3.4 Pipe Whip Analysis Methods

Pipe whip has been considered for circumferential breaks. The break is assumed to open instantaneously, a conservative assumption currently required by NRC. The jet force on the severed end of the pipe was taken to be a constant 1.26 PA, where P = pipe pressure, and A = pipe flow area, as discussed in Reference 1. The multiplier of 1.26 is the maximum thrust coefficient for a water-filled line, such as the recirculation piping. In the absence of a unique and time-consuming time-history blowdown analysis for each break location, the use of 1.26 PA for the thrust load is adequate for the analysis performed, albeit conservative. As will be discussed later, reducing the level of conservatism will generally not change the conclusions reached in the analysis.

The broken pipe was treated as a rigid cantilever, fixed at its terminal end. The thrust load was applied at the free end and a plastic moment was assumed to form at the fixed end. The thrust force was assumed to always be parallel to the pipe axis at the break location, and the pipe was assumed to move in one plane until impact with adjacent structure or equipment occurred. Subsequent out-of-plane motion was considered, depending on the location of affected safety targets.

For many breaks the pipe moved through a large displacement. Consequently, the impact velocity of the pipe into adjacent structures usually was quite high. The method chosen to calculate the impact velocity of the pipe is simple and reasonably conservative. As discussed in Sections 4 and 5, the use of more refined techniques would not have materially changed the conclusions of this report for those cases. For other cases, such as the main steam and feedwater piping in the Tunnel Room, the piping passed through pipe restraint structures which would limit pipe motion. However, the effectiveness of these structures is dependent on their load carrying capacity. As the results discussed in Section 4.0 indicate, these analysis results are not as clear as those for other cases. Impact velocity of the pipe was calculated as follows:

Work Done in Moving Pipe = Kinetic Energy of Pipe at Impact

Work Done = $(M_B - M_P)\theta$

Kinetic Energy = $1/2\ (I\dot{\theta}^2)$

Solving for $\dot{\theta}$, we find

$$\dot{\theta} = \left(\frac{2(M_B - M_P)\ \ \theta}{I}\right)^{1/2} \tag{1}$$

Velocity at Impact

$$V = \dot{\theta}R_R \text{ , where} \tag{2}$$

R_R = Impact Point Radius (distance from the impact point to the hinge point)

θ = Angle of rotation of pipe from initial position to impact point, radians

M_B = The applied moment, $F_B R_B$; F_B = blowdown force (1.26PA) and R_B = distance from the blowdown force to the hinge point.

M_P = Plastic moment capacity of the pipe

M_p = $\sigma_y \frac{(do^3 - di^3)}{6}$; where σ_y = pipe material yield strength, and do and di are the pipe outer and inner diameters, respectively.

$\dot{\theta}$ = Rotational velocity of pipe at impact

It should be noted that $M_B >> M_p$ for all breaks considered in the study.

Once V is known, the effect of impact into adjacent structures can be determined using the methods of Section 3.6.

3.5 Jet Impingement Analysis Methods

The methods, as well as the criteria, specified in ANSI 176 (Reference 1) were used for the calculation of fluid jets. The basic assumption of a 10° jet divergence angle was used for the first look at jet impingement. This is a conservative assumption, but requires significantly less work than calculation of a unique angle for each break. Where use of this conservative method left the conclusion of the structural analysis in doubt, the more difficult, less conservative method was used. In most cases, the results of the jet analysis using the 10° divergence angle was conclusive; more analysis was not necessary.

As a result of the large number of breaks considered in the analysis of large recirculation LOCA's, the need for a simplified method of performing jet impingement analysis became obvious. Therefore, jet impingement charts were developed and used wherever possible for piping response analysis. These charts were developed for the simplified 10° jet case and covered the whole range of break and target pipe sizes at Big Rock Point. Use of the charts enabled a rapid determination of whether a particular break-target combination clearly caused a problem, was no problem, or required further analysis. The charts and a discussion of their bases and use are contained in Appendix C.

The details of the basic methods used for jet impingement analysis are contained in Appendix C.

3.6 Structural Analysis Methods

Descriptions of the different types of structural response evaluations for various targets subjected to pipe whip impact and jet impingement loads are discussed in this section.

3.6.1 Target Response to Pipe Whip Impact

The simplified impact analysis method described in this section is useful for cases where the pipe whip impact forcing function is not known, and where local deformation of the pipe and target structure cannot be determined without extensive nonlinear analysis. The method is conservative in terms of overall failure in that energy absorption of the pipe, during impact, is ignored. Use of the method involves comparing the maximum strain energy that the target can absorb to the residual kinetic energy of the pipe and target after impact. It was used for analysis of all structural targets within the recirculation pump room, as well as in the other areas where appropriate.

Details of the method are presented in Reference 2. A summary follows.

Conservation of momentum is first applied to the pipe and target.

$$M_m V_{m1} = M_m V_{m2} + M_t V_t \qquad (3)$$

Where:

M_m = Missile (pipe) mass. M_m is taken as the mass of the pipe overhang beyond the contact point plus 1/3 of the mass from the contact point to the hinge point (See Appendix B2, page B2-2).

M_t = Target effective mass

For pipes impacting steel beams, M_t is taken as $M_t = (D + 2d)\ w/g$ (4)

(Reference 3)

Where:

D = Contact area diameter

d = Depth of beam

w = Unit weight of impacted beam

g = Acceleration due to gravity.

For impact into concrete slabs (the recirculation room walls), M_t is taken as:

M_t = wAT/g, where (5)

w = Weight per cubic foot of concrete

A = The effective impact area. Generally A = (Dx + T) (Dy + T) where

Dx = Impact dimension in X direction

Dy = Impact dimension in Y direction

T = Wall thickness

for pipe impact, Dx = Dy = D of the pipe

The kinetic energy of the pipe and target after impact can then be calculated by

$$KE = 1/2\ (M_m V_{m2}^{\ 2}) + 1/2\ (M_t V_t^{\ 2}) \qquad (6)$$

The energy absorption capability of the target is then found from

$$S_E = P_u \delta_y\ (\mu - 1/2) \qquad (7)$$

Where

P_u = Static collapse load

δ_y = Elastic displacement under a static load

μ = Allowable ductibility ratio of target

The target withstands impact when SE is greater than KE.

For steel beam targets, a collapse load P_u is typically calculated as:

$$P_u = \frac{K\ M_u}{L} \qquad (8)$$

where K is a constant whose value depends on the load configuration, and M_u is the ultimate moment capacity of the beam.

δ_y is calculated as the maximum elastic deflection due to application of P_u using standard beam deflection formulae. The exact equation for δ_y will, in each case, depend upon the beam end conditions and method of load application.

End connections of beams in the Recirculation Pump Room are not likely to fail under pipe whip loads unless the point of impact is very close to one of the beam ends. The end connections of the beam are designed to have approximately the same static load margins as the beam. When the beam is subjected to a load of extremely short duration (pipe impact), near the center of its span, the beam reaction load is due mainly to the beam inertia, not loads in the end connections. In each of the beam impact cases evaluated in the Recirculation Pump Room, impact occurred far enough away from the beam ends to make consideration of end connections unnecessary.

In some cases, there is also the possibility of a general failure of steel structures after the initial impact failure, due to the instability of the remaining structure under static design loads. An example illustrating when this might occur is the steel platform at El. 597' in the Recirculation Pump Room. In these situations, the beam end connections can be important and were considered.

The other basic types of structures considered in the analysis of pipe break were the pipe supports for the main steam and feedwater piping in the Tunnel Room. These supports are in the form of box-type structures to prevent loads from being transferred to the containment penetrations. Since the pipes pass through these restraints, the gaps between pipe and restraint are small (1" to 3") and the structural analysis methods described above were modified as follows:

Because of the relatively small gap between the support and pipe, a dynamic load factor (DLF) approach was used in lieu of the energy balance approach described above. Since relatively small gaps were being considered, this approximate approach was felt to be suitable to determine the adequacy of the tunnel room pipe restraints. It was decided that, if the restraint could be shown to be adequate to withstand the pipe thrust load with a DLF of 2, the restraint would have a high probability of surviving. As the results show in Appendix D1, the adequacy of these restraints to withstand the loads without failing is doubtful.

For concrete slab targets

$$P_u = 4\pi M_u \qquad (9)$$

where M_u is calculated for reinforced concrete slabs in accordance with Reference 9.

δ_y is calculated for a flat plate with a load applied uniformly in a circle at the center using Reference 19. A detailed calculation is shown for break 14-MRS-105-TB1 on Page B.2-7.

3.6.2 Piping Response to Jet Impingement Loads

Piping subjected to jet loads was analyzed statically, using Dynamic Load Factors as discussed in Section 2.4. The piping was treated as a beam with the appropriate end conditions and the load distributed over the jet impingement area. The various static stress formulas used in these calculations are presented in Appendix B1.

In many cases the data on pipe support locations was not available. For these situations, standard support spacing was assumed (see Reference 17, Table 21a). For the majority of cases, the piping passed or failed by such large margins that the support spacing assumption was not critical.

No attempt was made to evaluate the pipe supports since support details are not available. For the 4" core spray and other small safety-related lines, the pipe supports will likely fail under the jet loads since they were designed only for deadweight loads. Failure of the supports would cause the piping to fail by even higher margins.

3.6.3 Concrete Response to Jet Impingement Loads

Due to the massiveness of the Recirculation Pump Room walls, jet impingement loads on the walls are not critical. A simplified analysis was therefore used. This consisted of comparing the static yield strength of the wall to the jet impingement force multiplied by a DLF of 2.

This analysis was performed in a manner similar to that described for pipe impact (see 3.6.1) whereby the applied jet load on the wall was compared to the maximum load capacity of the wall. Calculation of the wall capacity is discussed in subsection 3.6.1. In the recirculation room analysis, calculations showed the wall has strength margins two or three times the jet load, using conservative methods.

Similar conclusions about the adequacy of the concrete walls and floors in the Tunnel Room could be drawn by comparison to the

Recirculation Pump Room analysis. The pipe sizes and jet forces of piping in the Tunnel Room were less than those for the Recirculation Pump Room so the conclusion of adequacy could be made by inspection. Some concrete impact was found in other areas, such as the Emergency Condenser Area. However, these cases were for much smaller pipe breaks so that, again, the adequacy of the concrete could be made by inspection.

3.6.4 Analysis of Containment Response to Jet Impingement Loads

In the Tunnel Room, it is possible, though unlikely, that the containment shell could be hit by a jet from a main steam or feedwater break near the penetration.

To verify adequacy of the containment, the containment was analyzed for several cases of jet impingement using a static analysis procedure with a dynamic load factor of 2 applied to the jet load. The containment was modeled as a hemisphere, and the computer program BOSOR4 (Appendix G) was used to calculate stresses in the shell due to jet impingement. The use of a hemispherical model was justified for the containment since jet effects are highly localized and were not affected by the portion of the containment not modeled. The BOSOR4 program is a widely used analytical tool and is described in the following paragraph.

The BOSOR4 computer program is employed to obtain stress, stability, and/or natural frequency analyses of segmented, ring-stiffened, branched shells of revolution. The shell may have various meridional geometries, wall constructions, boundary conditions, ring reinforcements, and types of loading, including thermal loading. Specifically, the program can be used to obtain:

a. Axisymmetric stresses and displacements for a series of step-wise increasing thermal or mechanical loads,

b. Critical loads corresponding to axisymmetric collapse,

c. Buckling loads corresponding to nonsymmetric buckling modes for a range of circumferential wave numbers,

d. Vibration frequencies of prestressed shells corresponding to axisymmetric and nonsymmetric modes,

e. Displacements and stresses in nonsymmetrically loaded shells, and,

f. Buckling loads of nonsymmetrically loaded shells.

The BOSOR4 computer program was developed by David Bushnell at Lockheed Missiles and Space Company and is available for public use at Control Data Corporation. Additional information about the program can be obtained from the User's Manual (Appendix G) or from either of the previously mentioned companies.

A description of the containment analysis is contained in Appendix F, and the results of the analysis are discussed in Section 4.0.

As part of the containment evaluation, the effect of a steam jet blowdown into the containment penetration was also considered. The stagnation pressure of the jet inside the penetration was calculated and compared to the design pressure of the penetration bellows. This analysis is described in Appendix E1.

3.6.5 Analysis of Other Structures for Jet Impingement Loads

In the Emergency Condenser Area, the emergency condenser can be hit by jets from breaks in the RDS system. Since the shell forms part of the containment boundary, it was evaluated. The stresses in the condenser shell were calculated using Biljaard's method as outlined in Welding Research Council Bulletin WRC-107, Reference 38. The calculations are described in Appendix E1.

The vent stack for the emergency condenser also forms part of the containment boundary. Jet effects on the vent stack bellows could be determined by inspection, since the bellows cannot withstand any appreciable side load.

3.7 Systems Analysis Methods

As described earlier, References 12 and 13 provided the basis for selection of safety targets within each room or area. Items from these lists provided by CPCo were located (see Table 4-1 through 4-6), and the locations were noted on a layout drawing or map (Reference 21) of the room. For LOCA's, targets which were not safety related for the particular break studied, but which could add to the total primary coolant loop discharge area were also noted.

These maps were used to select pipe breaks such that every safety target is affected by one or more circumferential (pipe whip) or slot break (fluid jets). The maps were then used to visualize the trajectory of the broken pipe or fluid jet such that the impact point could be determined. Once the impact point was determined, the structural evaluation was made. If a target was determined to fail under the applied load from a specific break, this was noted on the pipe whip or jet impingement evaluation matrices in Appendix A.

4.0 RESULTS

For each calculation for a postulated break discussed in Section 3.0, a set of results was determined. These results have been reported by the break number (see Subsection 3.2 for a description of the break numbering system). Results of pipe whip and jet impingement analyses have been tabulated on the "Pipe Whip Matrix" forms, Tables A-1 of Appendix A and on the "Jet Impingement Matrix" forms, Tables A-2 of Appendix A. The results in Appendix A have been summarized in Tables 4-1 through 4-6 by target designation. Tables 4-1 through 4-6 can be used to see which breaks resulted in potential jet or pipe whip damage to identified targets. "Failure" of a target indicates the results are conclusive; that is, performing a more sophisticated analysis will not change the conclusion. The jet force or the pipe impact energy was generally larger by a factor of five (5) or more than necessary to produce component failure. "Probable Failure" indicates a failure margin of approximately two (2) to five (5). In a few cases, more sophisticated analysis may change the results. "Possible Failure" indicates no specific analysis was done. However, the case was similar to an existing one or the conclusion was reached by inspection. In a few cases, particularly in the Tunnel Room, the results of the analysis were not conclusive enough to predict failure or adequacy of the structure. Where the analysis numerical results were inconclusive, this is noted. However, because of experience with analyses of similar structures and an understanding of the behavior of piping during pipe whip, it was possible to draw some conclusions and make recommendations for these cases. The reader should note that the failure category listed in Tables 4-1 through 4-6 may vary slightly from terminology in Appendix A in a few cases. This was done to make some of the descriptions of results more consistent between descriptions for various targets. Since the results described in Appendix A ("failure", "probable failure", etc.) are subjective, these editorial changes did not affect the technical results or the conclusions. Appendix D contains the pipe whip calculations for each break. Appendix C presents the generic jet model used and Appendix B shows the standard method for analyzing jet impingement on piping, and shows a typical calculation for structural response to pipe whip impact. Appendix E contains the jet impingement calculations for each break. Appendix F contains the results of the jet impingement analysis on the containment.

4.1 Recirculation Pump Room Analysis Results

Most calculations for recirculation piping breaks were based on a recirculation system operating pressure of 1115 psia. The design pressure, for analysis purposes, is now 1350 psia. This increase in pressure will not change any of the conclusions in the report. Targets that failed will fail by higher margins; targets that passed, such as the concrete walls, had sufficient margin to absorb the increase in pressure. The exact effect of the pressure change can be determined by taking the ratio of $\frac{1350}{1115}$ in those calculations where pressure was used in determining the loads, and increasing the applied load by that ratio. For all other LOCA breaks, such as mainsteam, small LOCA's etc., 1350 psia was used for the calculations.

4.1.1 Recirculation Break Pipe Whip Results

Due to the large amount of energy available from the unrestrained whipping pipes, most electrical or mechanical targets cannot survive an impact of a whipping recirculation line. Exceptions to this are several cases of recirculation pipe impact into main steam and feedwater piping. For these cases, identified in Appendix A, the target piping is expected to survive the impact.

4.1.2 Jet Impingement Results

Using the Effects Oriented approach, it was generally possible to pick a jet break which caused failure of a selected target. This general conclusion is not entirely applicable to the main steam and feedwater piping. For a number of cases, identified in Appendix A, main steam and feedwater piping targets can survive jet loads from recirculation piping breaks.

The walls of the Recirculation Pump Room were able to withstand jet impingement loadings by a reasonably large margin. For example, for break 14-MRS-105-SB3, the applied load was 344.8 kips compared to a maximum wall capacity of 892 kips.

4.1.3 General Results for Recirculation System Breaks

The results for recirculation system breaks tabulated in Appendices A-E can be summarized as follows:

1. Several pipe whip and jet impacts can be postulated to cause failure of each piece of safety related equipment, pipe or cable tray in the Recirculation Pump Room (Table 4-1), with the exception of the main steam and feedwater lines.

2. The concrete walls of the Recirculation Pump Room can withstand pipe and jet impact without gross failure. In some cases, spalling and scabbing may occur. This may release pieces of concrete from the rear surfaces of the walls into adjoining rooms. This appears to occur particularly for 24" breaks 24-MRS-121-CB1 and 24-MRS-122-CB1. If breaks occurred at these locations, the pipe impact could knock some pieces of concrete into the Control Rod Drive Room under the reactor vessel.

3. Intermediate steel in the room at elevation 597' and 619' will fail under certain types of pipe whip impact.

4. The core spray suction strainer in the Recirculation Pump Room can be disabled or the filter screen can be removed by breaks in the 24" recirculation piping.

5. Some failures of the main steam and feedwater piping, due to recirculation piping breaks, can be postulated.

4.1.4 Pipe Whip Results for Main Steam and Feedwater Breaks

As was determined for recirculation breaks, the 4" core spray piping can fail due to main steam (12-MSS-105) pipe whip and feedwater (10-FWS-201) pipe whip.

Feedwater pipe whip in the Recirculation Pump Room will also cause failure of RPV level instrumentation line 1.5-MSS-117. A number of main steam break pipe whip cases can be expected to impact and fail various hangers for the steam drum and riser system. However, gross failure of the steam drum and riser support system is not predicted. Some main steam breaks can also cause failure of the steam drum level instrumentation piping.

4.1.5 Jet Impingement Results for Main Steam and Feedwater Breaks

Jets from breaks in the feedwater piping will fail the 1.5-MSS-117 RPV level instrumentation line, a 4" core spray line, and the electrical conduit to MO-7053.

Jets from 12" main steam piping breaks will cause failure of cable trays SB06, SB07, the 4" core spray line and steam drum level instrumentation lines 1.5-MSS-111 and 112.

4.1.6 Pipe Whip Results for Other Systems in the Recirculation Pump Room

Breaks were considered in a number of lines within the Recirculation Pump Room including piping as small as the 1.5" NPS instrumentation lines. Mainly, targets similar to those for larger lines are impacted by these smaller pipe break cases. Additional targets which are failed by these other line breaks are: lines 5-RCS-131, 3-LPS-103, and 2-CRD-111. In addition, failures of other targets such as the 4" core spray, cable trays, reactor vessel level indicators, and steam drum level indicators can be expected due to failure of these miscellaneous lines. It appears, however, that solutions required for the larger recirculation, main steam, and feedwater breaks will eliminate most, if not all, of the problems due to these "other" breaks. For specific details on breaks and targets refer to Appendix A, pages A.1-11 through A.1-16.

4.1.7 Jet Impingement Results for Other Breaks in the Recirculation Pump Room

Jets from breaks in the RDS and ECS systems will cause failure in the 1.5-MSS-111 and 112 instrumentation lines. Jets from breaks in the 4" core spray piping will cause failures in cable trays TF14 and TF15, and SB07 and SB06. Jets from a break in the shutdown cooling system will cause failure of the 4" core spray piping. Again, however, solutions for larger breaks will eliminate must of the effects of these "other" breaks. For details on these breaks refer to Appendix A, pages A.2-12 and A.2-13.

4.2 Tunnel Room Results

Although the Tunnel Room analysis results are not as conclusive as for the Recirculation Pump Room, problem areas have been identified as discussed below.

4.2.1 Tunnel Room Pipe Whip Results

There is a high probability that postulated breaks in the main steam and feedwater lines will cause partial or complete failure of the Tunnel Room pipe supports (MS-6, MS-7, RF-11, RF-12, and RF-13). Excessive deformation of these restraints will result in potentially unacceptable deformation of the penetration bellows.

It is anticipated that a considerably more sophisticated analysis of the individual restraints will show that a gross restraint failure will not occur or that strengthening of the restraints to preclude failure is possible. Therefore, prevention of pipe whip damage to other piping inside the Tunnel Room would not be extremely difficult. See Appendix A1, pages A1.1-1 through A1.1-6 for a summary of pipe whip breaks within the Tunnel Room.

4.2.2 Tunnel Room Jet Impingement Results

A number of potential problems due to jet impingement have been identified in the Tunnel Room. Jets from postulated breaks adjacent to the containment penetrations for the main steam and feedwater piping can cause pressurization of the containment penetration. This pressure will be in excess of the design pressure of the bellows and could cause bellows failure, resulting in loss of containment integrity.

The possibility of a jet hitting the containment shell is very remote, however, in the interest of safety, the containment shell was analyzed and found adequate to withstand jet impingement loads for main steam and feedwater breaks. A number of piping targets in the Steam Tunnel can be shown to fail under the impingement of jets from main steam and feedwater breaks. Included in this list of targets that will fail are the 6" main core spray and fire protection system and the 4" backup enclosure spray and redundant core spray supply piping. The electrical conduit to the MSIV can also be expected to fail under impingement from jets. Refer to Appendix A1, pages A1.2-1 through A1.2-11 for details of breaks within the Steam Tunnel.

4.3 Emergency Condenser Area Results

A few problems were found in the Emergency Condenser Area. The emergency condenser tank can be potentially penetrated by impact from the 2-LPS-101 CB1 pipe whip. Failure of a 1" LPS nitrogen line due to pipe whip impact from a 3" LPS line break and failure of the 6" ECS line due to an impact from the 12" RDS line has also been predicted. Jets from breaks in the RDS system in the Emergency Condenser Area will cause failure of the 4" ECS line, the bellows on the emergency condenser vent line, and electrical conduits to the RDS valves. The results of the break analysis in the Emergency Condenser Area are summarized in Appendix A2.

4.4 Results for Control Rod Drive Room

Control rod drives in the southwest quadrant of the reactor can be disabled due to pipe whip from break 3-LPS-102-CB2. No jet impingement problems were discovered in this room since the high energy lines are all below the 4" NPS cut off used for jet impingement considerations.

4.5 Results for Control Rod Drive Accumulator Area

A number of instances have been found where breaks in the 2" CRD piping will impact and cause failure of 3/4" CRD piping. In addition, for certain breaks, some accumulators may be affected by the pipe whip impact and may become inoperable. See Appendix A3 for a sumary of results in this area.

4.6 Results for Clean Up Demineralizer Pump Room

Pipe whip from breaks in the 3" RCS piping will impact and fail 4" core spray piping within the Cleanup Demineralizer Pump Room. Note that in this one instance a smaller line can be expected to cause failure of a larger line because it is heavier wall pipe and has a larger section modulus than the target pipe. No jet impingement effects have been determined in this area since the high energy piping is below the 4" NPS cutoff size used for jet impingement analysis.

4.7 Results for CRD Pump Room

No problems due to high energy line breaks in the CRD Pump Room were determined.

4.8 Results for Reactor Vessel Cavity

Jet impingement from the 14" recirculation piping breaks in the Reactor Vessel Cavity will cause failure of the 4" core spray line as it enters the reactor vessel. Also, jets from the 14" recirculation piping in this area will cause failure of the 1.5-MSS-117 RPV vent line. Failure of the 2" reactor level instrumentation line at penetration N22 is also expected. CRD piping below the RPV will fail due to slot breaks at the RPV inlet nozzles. See Appendix A3 for a summary of breaks in the Reactor Vessel Cavity.

TABLE 4-1

SUMMARY OF RESULTS FOR TARGETS IN THE RECIRCULATION PUMP ROOM

Target	Target Fails Due to Break No.(s):	Target Probably Fails Due to Break No.(s):	Possible Failure of Target Due to Break No.(s):
CSS STRAINER	24-MRS-122-CB1 24-MRS-121-CB1 24-MRS-121-SB1 24-MRS-122-SB1	None	2-CRD-111-CB1
RECIRCULATION ROOM WALLS	None	None	None
CABLE TRAY SB-6	4-CSS-101-SB3 14-MRS-104-SB3 12-MSS-105-CB3 12-MSS-105-SB5 12-MSS-105-SB6 12-MSS-105-CB6	None	None
CABLE TRAY SB-7	14-MRS-103-CB1 17-MRS-112-SB2 3-RCS-108-CB1 4-CSS-101-SB2 12-MSS-105-SB5 12-MSS-105-SB6 12-MSS-105-CB6 12-MSS-105-CB3	14-MRS-106-CB1	14-MRS-105-CB1 14-MRS-105-TB2 14-MRS-103-TB2
CABLE TRAY SB-11	20-MRS-121-CB1 14-MRS-103-CB1 17-MRS-111-SB3 3-RCS-108-CB1	14-MRS-106-CB1	14-MRS-105-CB1 14-MRS-105-TB2 14-MRS-103-TB2
CABLE TRAY SB-12	14-MRS-103-CB1 20-MRS-121-SB2 3-RCS-108-CB1	14-MRS-106-CB1	14-MRS-105-CB1 14-MRS-105-TB2 14-MRS-103-TB2

TABLE 4-1 (Continued)

SUMMARY OF RESULTS FOR TARGETS IN THE RECIRCULATION PUMP ROOM

Target	Target Fails Due to Break No.(s):	Target Probably Fails Due to Break No.(s):	Possible Failure of Target Due to Break No.(s):
CORE SPRAY PIPING 4"-CSS-101	14-MRS-104-CB1 14-MRS-104-TB2 14-MRS-103-CB1 14-MRS-103-SB4 14-MRS-102-CB1 17-MRS-111-SB2 17-MRS-112-SB1 17-MRS-113-SB3 12-MSS-105-CB6 12-MSS-105-CB5 12-MSS-105-SB7 12-MSS-105-SB8 10-FWS-201-CB2 10-FWS-201-SB3 10-FWS-201-SB6 10-FWS-201-SB7 8-SCS-102-SB1 8-SCS-101-TB2	14-MRS-106-CB1 14-MRS-102-CB1 14-MRS-102-TB2 14-MRS-101-CB1 14-MRS-101-TB2	14-MRS-105-CB1 14-MRS-105-TB2 14-MRS-103-TB2 14-MRS-103-SB2 14-MRS-104-SB2 14-MRS-105-SB4 14-MRS-104-SB4 17-MRS-113-SB1 17-MRS-113-SB2 17-MRS-113-SB4 20-MRS-122-SB2
CABLE TRAY SB-10	20-MRS-121-CB1 20-MRS-121-SB1	None	None
CABLE TRAY TF-14	20-MRS-122-CB1 14-MRS-104-CB1 14-MRS-104-TB2 17-MRS-113-SB4 17-MRS-114-SB2 4-CSS-101-SB1	14-MRS-102-CB1 14-MRS-101-CB1	None
CABLE TRAY TF-13	20-MRS-122-CB1 20-MRS-122-SB3	None	None

TABLE 4-1 (Continued)

SUMMARY OF RESULTS FOR TARGETS IN THE RECIRCULATION PUMP ROOM

Target	Target Fails Due to Break No.(s):	Target Probably Fails Due to Break No.(s):	Possible Failure of Target Due to Break No.(s):
INST. PIPING 1.5-MSS-117	14-MRS-104-TB2 14-MRS-101-CB1 14-MRS-101-SB1 14-MRS-102-SB1 14-MRS-106-SB1 14-MRS-106-SB2 14-MRS-106-SB5 14-MRS-106-SB6 8-FWS-103-CB1 8-FWS-103-SB1	14-MRS-104-CB1 14-MRS-103-CB1 14-MRS-103-TB2 14-MRS-102-SB2	14-MRS-101-TB1 14-MRS-102-CB1
FEEDWATER PIPING 10-FWS-201	14-MRS-104-CB1 14-MRS-103-CB1 17-MRS-111-SB6 17-MRS-111-SB7 17-MRS-112-SB4 17-MRS-113-SB5	None	None
FEEDWATER PIPING 10-FWS-101	14-MRS-106-TB1 17-MRS-111-SB4 17-MRS-111-SB5	None	None
FEEDWATER PIPING 8-FWS-102	None	None	None
FEEDWATER PIPING 8-FWS-103	14-MRS-102-SB5 14-MRS-102-TB1	None	None
MAIN STEAM 12-MSS-105	None	None	None

TABLE 4-1 (Continued)

SUMMARY OF RESULTS FOR TARGETS IN THE RECIRCULATION PUMP ROOM

Target	Target Fails Due to Break No.(s):	Target Probably Fails Due to Break No.(s):	Possible Failure of Target Due to Break No.(s):
STEEL @ EL. 597'	14-MRS-104-CB1 14-MRS-103-CB1 17-MRS-114-CB1 20-MRS-121-CB1 20-MRS-122-CB1	14-MRS-106-CB1 14-MRS-102-CB1 14-MRS-101-CB1 8-SCS-101-TB2	14-MRS-104-TB2 14-MRS-103-TB2 14-MRS-105-CB1 14-MRS-105-TB2
CABLE TRAY TF-15	14-MRS-104-CB1 14-MRS-104-TB2 20-MRS-122-SB4 17-MRS-113-SB4 4-CSS-101-SB1	14-MRS-102-CB1 14-MRS-101-CB1	None
STEEL @ EL. 619'	14-MRS-102-TB2 14-MRS-101-TB2	None	None
INST. PIPING 2-MSS-132, 133, 122, 123	14-MRS-102-TB2 14-MRS-102-CB1 14-MRS-102-SB3 14-MRS-102-SB4 14-MRS-105-SB2 14-MRS-105-SB1 14-MRS-105-SB4	14-MRS-101-TB2 14-MRS-101-CB1	None
1.5-MSS-111 1.5-MSS-112 (STEAM DRUM LEVEL)	17-MRS-111-SB1 17-MRS-114-SB1 12-RDS-101-SB5 12-RDS-101-CB6 4-ECS-104-SB1 8-MSS-101-TB1 14-MRS-105-SB6 14-MRS-103-SB8	None	None

TABLE 4-1 (continued)

SUMMARY OF RESULTS FOR TARGETS IN THE RECIRCULATION PUMP ROOM

Target	Target Fails Due to Break No.(s):	Target Probably Fails Due to Break No.(s):	Possible Failure of Target Due to Break No.(s):
STEAM DRUM INST. PIPING (Continued)	4-ECS-103-SB1 8-MSS-104-TB1	None	None
INSTRUMENT TUBING TO LSRE09 (C&G,D&H)	14-MRS-103-SB1 14-MRS-104-SB1 14-MRS-101-CB1 14-MRS-101-TB2	None	None
INSTRUMENT TUBING TO LSRE09(A-H)	20-MRS-122-SB1	None	None
2-MSS-124	14-MRS-105-SB3 14-MRS-106-SB3	None	None
ELECTRICAL CONDUIT TO MO-7053 and MO-7063	14-MRS-103-SB3 1.5-MSS-111-CB1 1.5-MSS-112-CB1 10-FWS-201-SB2	None	None
LEVEL INDICATOR LE RE09B	4-CSS-101-TB1	None	None
LEVEL INDICATORS LE RE09C AND RE09D	6-SCS-101-TB1	None	None

TABLE 4-1 (Continued)

SUMMARY OF RESULTS FOR TARGETS IN THE RECIRCULATION PUMP ROOM

Target	Target Fails Due to Break No.(s):	Target Probably Fails Due to Break No.(s):	Possible Failure of Target Due to Break No.(s):
5-MRS-131	6-SCS-102-CB3	None	None
3-LPS-103	4-MRS-141-CB1	None	None
2-CRD-111	4-MRS-141-CB1	None	None
4-ECS-104	10-FWS-201-SB2	None	None
Steam Drum Hanger Supports	12-RDS-101-CB1	None	None
Emergency Condenser Drain and Overflow Line	None	None	24-MRS-121-SB1 24-MRS-121-CB1 24-MRS-122-CB1 20-MRS-121-TB2 17-MRS-114-CB1 17-MRS-111-SB4 17-MRS-111-SB5 17-MRS-112-SB3 14-MRS-101-TB1 14-MRS-102-TB1 14-MRS-102-SB2 14-MRS-102-SB5 14-MRS-103-SB8 14-MRS-104-TB1 14-MRS-105-TB1 14-MRS-105-SB6 14-MRS-106-TB1 14-MRS-106-SB2 14-MRS-106-SB6 12-RDS-101-CB1 12-RDS-101-CB6

TABLE 4-1 (Continued)

SUMMARY OF RESULTS FOR TARGETS IN THE RECIRCULATION PUMP ROOM

Target	Target Fails Due to Break No.(s):	Target Probably Fails Due to Break No.(s):	Possible Failure of Target Due to Break No.(s):
Emergency Condenser Drain and Overflow Line (Continued)			10-FWS-201-SB2 8-MSS-101-TB1 8-MSS-102-TB1 8-MSS-103-TB1 8-MSS-104-TB1 2-CRD-111-CB1

TABLE 4-2

SUMMARY OF RESULTS FOR TARGETS IN THE STEAM TUNNEL

Target	Target Fails Due to Break No.(s)	Target Probably Fails Due to Break No.(s)	Possible Failure of Target Due to Break No.(s)
Feedwater Containment Penetration Bellows	10-FWS-201-SB4 10-FWS-201-CB4 10-FWS-201-SB5 10-FWS-201-CB5	10-FWS-201-CB2	None
Feedwater Pipe Restraints RF-10,11,12,13	None	10-FWS-201-CB2 10-FWS-201-CB3	10-FWS-201-SB4 10-FWS-201-SB5
Main Steam Containment Penetration Bellows	12-MSS-205-SB4 12-MSS-205-CB1 12-MSS-205-CB2	12-MSS-205-SB1 12-MSS-205-SB2	12-MSS-105-CB4 12-MSS-105-CB2 12-MSS-105-CB3
Main Steam Pipe Restraints MS-6,7	None	12-MSS-105-CB3 12-MSS-205-SB1 12-MSS-205-SB2	12-MSS-105-SB4 12-MSS-105-CB2
2" CRD Supply Line	12-MSS-105-SB4 10-FWS-201-SB4 10-FWS-201-SB5	None	12-MSS-205-SB1 12-MSS-205-SB2
6" Main Core Spray & Fire Protection System	12-MSS-205-SB2 12-MSS-105-SB4	None	None

TABLE 4-2 (Continued)

SUMMARY OF RESULTS FOR TARGETS IN THE STEAM TUNNEL

Target	Target Fails Due to Break No.(s)	Target Probably Fails Due to Break No.(s)	Possible Failure of Target Due to Break No.(s)
4" Backup Enclosure Spray and Redundant Core Spray Supply	12-MSS-105-SB4 12-MSS-105-CB4 12-MSS-205-CB1 10-FWS-201-SB4 10-FWS-201-SB5	None	12-MSS-105-CB5 12-MSS-205-CB2 10-FWS-201-CB5
Electrical Conduit	12-MSS-105-SB4 12-MSS-105-CB4 12-MSS-105-CB5 10-FWS-201-SB4 10-FWS-201-SB5	12-MSS-205-CB2	12-MSS-205-CB1
4" Service Water Supply & Return	12-MSS-105-CB4 12-MSS-105-CB5 12-MSS-205-CB1	None	None
6" Cooling Water Supply & Return	None	None	12-MSS-105-CB5
2" Demineralized Water Line	10-FWS-201-SB4 10-FWS-201-SB5 10-FWS-201-CB4 10-FWS-201-CB5	None	12-MSS-105-CB5
Cable Trays SB02, SB03	12-MSS-105-CB4 12-MSS-205-CB1 12-MSS-205-CB2	None	None

TABLE 4-3

SUMMARY OF RESULTS FOR TARGETS IN THE EMERGENCY CONDENSER AREA

Target	Target Fails Due to Break No.(s)	Target Probably Fails Due to Break No.(s)	Possible Failure of Target Due to Break No.(s)
Emergency Condenser Shell	2-LPS-101-CB1	None	None
1" LPS Nitrogen Line	3-LPS-102-CB2	None	None
6-ECS-101	12-RDS-101-CB5 12-RDS-101-SB3	None	None
4-ECS-104 4-ECS-103	12-RDS-101-SB1 12-RDS-101-SB3	None	None
Emergency Condenser Vent Stack Bellows	12-RDS-101-SB2	None	None
Electrical Conduit to RDS Valves	12-RDS-101-SB4	None	None

TABLE 4-4

SUMMARY OF RESULTS FOR TARGETS IN THE CONTROL ROD DRIVE CRD ACCUMULATOR AND CRD PUMP ROOMS

Target	Target Fails Due to Break No.(s)	Target Probably Fails Due to Break No.(s)	Target Likely Fails Due to Break No.(s)
Southwest Quadrant of CRD's (CRD Room)	None	3-LPS-102-CB2	None
CRD Accumulators E1 & E2	None	2-CRD-111-CB2 2-CRD-205-CB1 2-CRD-101-CB1	None
CRD Accumulators C5 & C6	None	2-CRD-111-CB3 2-CRD-102-CB1	None
CRD Accumulators B1 & B2	None	2-CRD-205-CB2 2-CRD-111-CB4 (B 1 only)	None

TABLE 4-5

SUMMARY OF RESULTS FOR TARGETS
IN THE CLEAN UP DEMINERALIZER PUMP ROOM

Target	Target Fails Due to Break No.(s)	Target Probably Fails Due to Break No.(s)	Possible Failure of Target Due to Break No.(s)
4" Core Spray Piping	None	3-RCS-101-CB1 3-RCS-101-CB2	None

TABLE 4-6

SUMMARY OF RESULTS FOR TARGETS IN THE REACTOR CAVITY

Target	Target Fails Due to Break No.(s)	Target Probably Fails Due to Break No.(s)	Possible Failure of Target Due to Break No.(s)
4-CSS-101	14-MRS-105-SB8 14-MRS-106-SB7	None	None
1.5-MSS-117 (RPV Vent Line)	14-MRS-105-SB8 14-MRS-106-SB7 14-MRS-104-SB5 14-MRS-103-SB6 4-RDC-101-SB1	None	None
2" RPV Level Instrumentation Line at Penetration N22	14-MRS-101-SB2 14-MRS-102-SB6	None	None
CRD Piping Below RPV	Slot Breaks at 20" RPV inlet Nozzles	None	None

5.0 CONCLUSIONS

Based on the results in Section 4.0, some general conclusions concerning postulated breaks inside the containment at Big Rock Point can be drawn:

1. Using the approaches described herein, several postulated break locations result in the disabling of safety related piping, equipment, or cable trays in the Recirculation Pump Room.

2. The walls of the Recirculation Pump Room are structurally adequate to withstand pipe and jet impact for breaks inside and outside the room. Cracking, spalling, and scabbing of the concrete walls will occur locally, but will not effect the gross structural integrity of the walls.

3. Pipe whip inside the Steam Tunnel area may cause failure of the containment penetration and penetration bellows due to the effect of the pipe whip reaction.

4. The containment vessel is adequate to withstand the effects of jet impingement due to postulated high energy line breaks in the Steam Tunnel and Emergency Condenser Area.

5. Jet impingement inside the Steam Tunnel can cause failure of other safety related piping routed through the Steam Tunnel.

6. There is a potential failure of the emergency condenser stack bellows, which is technically a part of the containment boundary, due to high energy line breaks in the Emergency Condenser Area.

7. In the Reactor Vessel Cavity, jets from the 14" and 20" recirculation piping can cause failure of safety related piping routed into the reactor vessel.

6.0 POTENTIAL SOLUTIONS TO PROBLEMS IDENTIFIED

A number of potential solutions have been identified for the problems discovered in this study. These potential solutions are listed below by area within the containment. Note that several different solutions to the same problem have been listed in some cases:

1. Recirculation Pump Room

   - Reroute the entire core spray system within the Recirculation Pump Room.
   - Add redundant core spray piping
   - Install pipe whip restraints on recirculation system piping
   - Use ISI plus leak detection on recirculation, main steam, and feed water piping to allow operator action prior to potential breaks.
   - Use pipe whip restraints on the main steam and feedwater piping
   - Install pipe whip restraints on the shutdown cooling system line
   - Install jet barriers on 4" core spray piping
   - Remove and relocate safety related cables from effected cable trays

- Move RPV level indicators to a safe area in the Recirculation Pump Room
- Install jet deflectors around breaks and recirculation piping to protect RPV level instrumentation piping from jet impingement effects
- Protect feedwater piping from breaks in the recirculation system with jet shields around the feedwater piping or around the break in the recirculation piping
- Move the core spray suction strainer to a safer location in the Recirculation Pump Room
- Install protective barriers around the core spray suction strainer
- Install pipe whip restraints on the RDS piping to protect the steam drum level instrumentation
- Install jet barriers in the steam drum area to protect steam drum level instrumentation
- Reroute the electrical conduit to MO-7053 to protect it from jet effects

2. Potential Solutions for the Steam Tunnel Area
    - Strengthen the pipe restraints within the steam tunnel area to withstand pipe break loads
    - Use ISI plus leak detection on main steam and feedwater lines to allow operator action prior to potential breaks

- Perform nonlinear time-history analysis for pipe whip effects, to determine if replacement or strengthening of pipe restraints are needed
- Add jet deflectors on containment penetration inlets to protect them from over pressurization due to jets
- Install jet deflectors around target piping
- Install jet barriers around break locations in main steam and feedwater piping to protect other piping targets from jet impingement

3. Potential Solutions for the Emergency Condenser Room
   - Perform more detailed analysis for the emergency condenser shell to show that it survives impact from a 2" LPS line
   - Add pipe whip restraints to 2" LPS line to protect the emergency condenser shell
   - Install a jet shield around the emergency condenser vent stack bellows
   - Place a jet deflector around break locations in the 12" RDS lines to protect the emergency condenser vent stack bellows
   - Install a check valve in the Emergency Condenser Drain and Overflow Line to prevent venting to the outside atmosphere caused by line breaks in the Recirculation Pump Room

4. Potential Solutions for the Control Rod Drive Room
   - Install a protective barrier around CRD bundles to protect them from pipe whip from a 3" LPS line break
   - Install a pipe whip restraint on the 3" LPS line
   - Demonstrate the predicted damage is acceptable
5. Potential Solution for the Control Rod Drive Accumulator Room
   - Install protective barriers in front of the accumulators to protect them from pipe whip in the 2" CRD lines
   - Install pipe whip restraints on 2" CRD piping in the room
   - Demonstrate the predicted damage is acceptable
6. Potential Solutions for the Cleanup Demineralizer Pump Room
   - Install pipe whip restraints on 3" RCS piping to protect 4" core spray piping
   - Install a protective barrier in front of 4" core spray piping
   - Add redundant core spray piping
7. Potential solutions for the Reactor Cavity
   - Use ISI plus leak detection at the reactor vessel inlet nozzles to allow operator action prior to potential breaks at these points
   - Install jet shields on 4" core spray piping

- Install jet shields on 1.5-MSS-117 piping to protect it from jets from recirculation piping breaks
- Install jet deflectors to protect CRD system piping below the reactor vessel from jets
- Install a jet barrier around the 2" instrument line to penetration N22.

It is anticipated that the above list will provide satisfactory solutions to satisfy all NRC criteria concerning safe shut-down of the plant following a postulated loss of coolant accident inside containment. Again, it should be noted that more than one potential solution for a particular problem has been listed above. The above list was provided to give an indication of types of solutions that are available and that need to be considered in more detail.

7.0 RECOMMENDATIONS

The purpose of this report is to document the effects of breaks inside the Containment. Solutions to these problems are possible, as evidenced from the list of solutions given in Section 6.0 of this report. During the course of this study, certain key items for solution of the pipe break problem have come to light and these are discussed below.

It is recommended that Consumers Power give serious consideration to the initiation of a leak detection plus ISI program on the large piping systems in the Recirculation Pump Room and in the Steam Tunnel. Use of ISI plus leak detection would provide indications for early operator actions which would midicate or eliminate a number of problems caused by breaks in the main steam, feedwater, and recirculation system piping.

It is also recommended that consideration be given to movement of safety related equipment out of the Recirculation Pump Room wherever possible. This includes relocation of core spray system piping and safety related cables in cable trays. In other areas of the plant, it is suggested that structural modifications should be undertaken to eliminate problems with pipe whip or jet impingement only when absolutely necessary. Since most of these problem areas are small, the amount of actual modifications to the plant is expected to be minor. In addition, because most of the piping outside of the Recirculation Pump Room and Steam Tunnel is small piping, structural problems associated with designing jet impingement barriers or pipe whip restraints are not significant.

8.0 REFERENCES

1. Design Basis for Protection of Nuclear Power Plants Against Effects of Postulated Pipe Rupture, ANSI-176 (ANS-58.2).

2. A.S.C.E. Structural Analysis and Design of Nuclear Facilities, ASCE, 1976.

3. Newmark, N.M. and Richart, F.E., Impact Tests of Reinforced Concrete Beams, NDRC Report No. A125, A213, A304, 1941-1946.

4. Disque, Robert O., Applied Plastic Design In Steel, Van Nostrand Reinhold Co., 1971.

5. Telecon from W. V. Weber to R. Marusich, 8/2/79, "Weekly CPCo Phone Conversation."

6. Beedle, L. S. Plastic Design of Steel Frames, Wiley, New York, 1958.

7. AISC, Manual of Steel Construction, 7th Ed.

8. NUTECH Communication Record, telecon between W. Beckius and R. Petrokas, Sept. 13, 1979.

9. Design Handbook In Accordance with the Strength Design Method of ACI 318-71. (American Concrete Institute)

10. "Preliminary Pipe Break Analysis for the Big Rock Point Recirculation Room," NUTECH Report CPC-01-053, Revision A.

11. Letter to KMC, Inc. from CPCo. "Assessment of Postulated Pipe Breaks Inside Containment for SEP Plants (Topic III-5.A)" plus attachments, dated July 20, 1978.

12. Letter from Consumers Power Company to NUTECH, MARU 48-79, September 5, 1979.

13. Letter from Consumers Power Company to NUTECH, MARU 41-79, "Big Rock Point - HELB Equipment List Review (Revision to July 18, 1979 Memo)," August 23, 1979.

14. Consumers Power Company (CPCo) Project Instruction Number One, "Project Plan for Evaluation of Pipe Break Inside Containment", Revision 1, CPC-01-002.

15. Biggs, John M., "Introduction to Structural Dynamics", McGraw Hill, 1964.

16. "Piping Materials Specification for the Consumers Power Company", by Bechtel Corporation, Spec. No. 3259 M-53, Rev. 5.

17. ASA B31.1-1955, American Standard Code for Pressure Piping.

18. Szilard, Rudolph, Theory and Analysis of Plates, 1974 by Prentice-Hall.

19. Roark & Young, Formulas for Stress and Strain, Fifth Edition, McGraw Hill, date 1975.

20. Meeting minutes (issued by NUTECH) for the October 2, 1979, NUTECH/Consumers Power Meeting.

21. NUTECH Drawings:

    0110-M-0201, Revision 0
    0110-M-0202, Revision 0
    0110-M-0204, Revision 0

22. Blodgett, O. W., "Design of Welded Structures, James F. Lincoln Arc Welding Foundation, 1976".

23. ASME Boiler and Pressure Vessel Code, 1977 Edition.

24. Seely and Smith, "Advanced Mechanics of Materials," Wiley, 2nd Edition/August, 1967.

25. Bechtel Drawing No. 0740940126, Revision C, "Big Rock Point Plant, Main Steam and Reactor Feedwater Plans," November 29, 1979, NUTECH File No. 104.0201.0019.

26. Bechtel Drawing No. 0740940127, Revision C, "Big Rock Point Plant, Main steam and Reactor Feedwater Sections," November 29, 1976, NUTECH File No. 104.0201.0019.

27. CPCO Drawing No. CPC-0740941004, Revision E, "Big Rock Point Plant, Reactor Depressurizing System, Emergency Core Cooling System Modification Plan," September 28, 1977, NUTECH File No. 104.0201.0019.

28. CPCO Drawing No. CPC-0740941005, Revision E., "Big Rock Point Plant, Reactor Depressurizing System, Emergency Core cooling System Modification Section

and Details," September 28, 1977, NUTECH File No. 104.0201.0019.

29. CPCO Drawing No. CPC-0740941006, Revision E, "Big Rock Point Plant, Reactor Depressurizing System, Emergency Core Cooling System Modification Elevation Looking North," September 28, 1977, NUTECH File No. 104.0201.0019.

30. Flow of Fluids Through Valves, Fittings, and Pipe, Technical Paper No. 410, Crane Co., 1976.

31. Idel'Chik, I.E., Handbook of Hydraulic Resistance, Coefficients of Local Resistance and of Friction, AEC-TR-6630, 1966.

32. NUTECH Communication Record, Telecon between W. V. Weber and R. Marusich, October 17, 1979, "Feedwater Line Pressure-Big Rock Point".

33. Crane Co. Catalogue VC-1300, Steel Valves.

34. Tube Turns Welding Fittings, Flanges, Catalog 411, Tube Turns Division of Chemetron Corporation, Louisville, Kentucky, 1977.

35. Sharma, R., "Big Rock Point Feedwater Line Pressure Calculation." Revision 0, Nov. 1979. NUTECH File No. 104.0201.0040

36. NUTECH Drawing 0110-M-0200, Revision 0. Pipe Break Evaluation Tunnel Room, Sheet 1, Nov-1-79.

37. CPCO Dwg. CPC-0740G40217, Rev. A, Penetration Attachment Details Big Rock Point Plant, Date Oct. 65.

38. Wichman, K. R., Hopper, A. G., and Mershon, J. L., "Local Stresses in Spherical and Cylindrical Shells due to External Loadings", Welding Research Council Bulletin 107, August 1965.

39. Bechtel Drawing No. C-123, Revision 2, "Big Rock Point Plant, Reactor Building Misc Steel Details Sheet 2", NUTECH File No. 104.0201.0014.

40. Bechtel Drawing No. M-126, Revision C, "Big Rock Point Plant, Main Steam and Feed Water Plans", NUTECH File No. 104.0201.0019.

41. ITT Grinnel Catalogue PH79, "Pipe Hangers".

42. Tube-Turns Drawing No. 80.0934-A2.0, "Tube-Turns Bellows Expansion Joint for Bechtel Corp.", NUTECH File No. 104.0201.0046.

43. Timoshenko and Young, "Elements of Strength of Materials", D. Van Nostrand Company, 5th Edition.

44. General Electric Design Report 22A4613, "Pipe Whip Restraint for Postulated Effects on Major Lines, BWR6MKIII".

45. Fisher Controls Bulletin 51.2:HS, "Designs HS, HSC & HSV Control Valve Bodies", July 1970.