3.6 PROTECTION AGAINST DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED BREAK OF PIPING

To ensure safe and reliable operation of the Byron and Braidwood Stations, the possibility of high or moderate energy line breaks have been considered in the design. Systems which were considered for high energy piping failure are listed in Table 3.6-2.

Piping failures are postulated to occur in high and moderate energy fluid systems at locations defined using the criteria in subsection 3.6.2.1. In addition to the loss of fluid from the failed system, and the direct results of the pipe failure (i.e., pipe whip, fluid impingement, pressurization, environmental effects, water spray, flooding), a functional failure of any single active component is assumed except in those cases where the piping failure is in a dual purpose, moderate energy safety system. In these cases, the single active failure is assumed in any system other than the system which initially failed. A loss of offsite power is assumed to occur if the piping failure results in loss of offsite power or reactor trip.

Standard Review Plans (SRP) 3.6.1 and 3.6.2 were used as the basis for this study. SRP 3.6.1 includes Branch Technical Position (BTP) APCSB 3-1. Appendix B of the BTP, the attachment to letters sent to applicants and licensees by A. Giambusso in December 1972, and Appendix C to the BTP, the July 12, 1973 letter to applicants, reactor vendors and architect-engineers from J. F. O'Leary, provide the basis for identification of high energy line breaks and evaluation of their consequences.

High energy lines can be identified through the engineering controlled equipment/component database(s). Breaks have been postulated at the locations required by Branch Technical Position APCSB 3-1 for the purpose of assessing pipe whip, jet impingement, and pressurization effects. Temperatures in areas were calculated assuming the break occurs in the limiting location in the area. Locations of mitigating features such as pipe restraints and impingement shields are shown in Section 3.6. Drawings showing the location of high energy lines have been provided to the NRC ASB reviewer. These drawings also indicate location of subcompartment walls and pipe tunnels.

The effects of high and moderate energy line breaks inside containment have been assessed as described in Sections 3.6 and 6.2. The effects of high energy line breaks in the turbine building have been evaluated with respect to potential impact on safety-related equipment located in adjoining auxiliary building rooms. The results of this evaluation are described in Section 3.11. Other non-safety related areas were not investigated because damage to or failure of equipment in these areas will not affect plant safety.

The possible effects associated with the postulated break of piping considered are structural loads due to pressurization, increases in pressure and temperature which could affect environmental qualification of equipment, and damage due to pipe whip and jet impingement.

The methods used for protection against each postulated high energy piping failure are:

a. Provision of pipe whip restraints for postulated breaks in plant areas containing safety-related equipment, such that the whipping pipe cannot impact any nearby equipment.

b. Provision of deflectors in the path of effluent discharging from postulated breaks that would otherwise (a) impinge on safety-related equipment to the extent that a loss of function may result, or (b) impinge on equipment whose failure, in turn, may propagate such that a loss of function of safety-related equipment may result.

Areas of system piping where no breaks are postulated are:

a. The main steam piping from the containment penetration fluid head outboard weld, to the upstream weld of the main steam pipe to the main steam isolation valve, including the main steam relief valve header and branch piping to the main steam power operated relief valve and main steam safety valves. This includes approximately 65 feet of piping (20 feet of header and 45 feet of relief piping) for each steam generator.

b. The main feedwater piping from the downstream weld of the main feedwater pipe to the main feedwater isolation valve, to the containment penetration fluid head outboard weld, including the main feedwater isolation valve bypass line from its branch off the main feedwater line to the upstream weld of the line to the normally closed feedwater backpurge isolation valve. This includes approximately 25 feet of piping for each steam generator.

The design of the plant is such that given the above, and applying the load combinations as described in Section 3.9, the function of essential systems and components will not be damaged to the extent that safe shutdown capability is lost.

3.6.1 Postulated Piping Failures in Fluid Systems Outside the Containment

The following is a summary of applicable definitions; criteria employed; potential sources and locations of piping failures; identification of systems and components essential to safe plant shutdown; limits of acceptable loss of function or damage and effect on safe shutdown; habitability of critical areas following postulated piping breaks; and the impact of the plant design on inservice surveillance and inspection.

3.6.1.1 Design Bases

3.6.1.1.1 Definitions

Throughout this section, the following definitions apply:

a. Essential Systems and Components

   Systems and components required to shut down the reactor and mitigate the consequences of a postulated piping failure.

b. Fluid Systems

   High and moderate energy fluid systems that are subject to the postulation of piping failures against which protection of essential systems and components is needed.

c. High-Energy Fluid Systems

   Systems which are either in operation or maintained pressurized during normal plant conditions and meet either or both of the following requirements are called high-energy fluid systems:

   1. maximum operating temperature exceeds 200°F

   2. maximum operating pressure exceeds 275 psig.

d. Moderate-Energy Fluid Systems

   Systems which are either in operation or maintained pressurized(above atmospheric pressure) during normal plant conditions and meet the following requirements are called moderate energy fluid systems:

   1. maximum operating temperature is 200°F or less, and

   2. maximum operating pressure is 275 psig or less.

e. Normal Plant Conditions

   Plant operating conditions normally experienced during reactors startup, operation at power, hot standby, or reactor cooldown to cold shutdown condition.

f. Upset Plant Conditions

Plant operating conditions during system transients that may occur with moderate frequency during plant service life and are anticipated operational occurrences, but not during system testing.

g. Postulated Piping Failures

Longitudinal and circumferential breaks in high-energy fluid system piping and through-wall leakage cracks in moderate-energy fluid system piping.

h. S_h and S_a

Allowable stresses at maximum (hot) temperature and allowable stress range for thermal expansion, respectively, as defined in Article NC-3600 of the ASME Code, Section III. As defined in article NC/ND-3611.2 of the ASME Code, the allowable stress range, S_a is given by the following formula:

$$S_a = f(1.25\,S_c + 0.25\,S_h)$$

The stress range reduction factor (f) is set at 1.0 for thermal expansion loading conditions of less than or equal to 7,000 equivalent full temperature cycles, and at incrementally smaller values for loading conditions of greater than 7,000 cycles, as provided in Table NC/ND-3611.2(c)-1. In lieu of the Code-defined values for f, f may be calculated by $5.875/(N)^{0.2}$ for ASME Class 2 and 3 and ANSI B31.1 piping and components, where N is the number of equivalent full temperature cycles.

i. S_m

Design stress intensity as defined in Article NB-3600 of ASME Code, Section III.

j. Terminal Ends

Extremities of piping runs that connect to structures, large components (e.g., vessels, pumps) or pipe anchors that act as rigid constraints to piping movement including rotational movement from static or dynamic loading. A branch connection to a main piping run is a terminal end of the branch run.

Intersections of runs of comparable size and stability are not considered terminal ends when the piping stress analysis model includes both the run and branch piping and the intersection is not rigidly constrained to the building structure.

k. Leakage Crack

A theoretical opening in the piping system, the consequences of which are evaluated on the basis of pressure and temperature differential conditions, flooding effects, and wetting of all unprotected components within the compartment.

3.6.1.1.2 Criteria

Regulatory Guide 1.46 and the NRC's letter from A. Giambusso, dated December 1972, have been met for designs inside and outside the containment, respectively. By virtue of the Construction Permit date for this plant, the above is the required minimum.

Subsequent criteria, including that in the NRC's letter from J. F. O'Leary, dated July 1973, and Branch Technical Positions APCSB 3-1 and MEB 3-1, have been employed to the extent possible and practical, given the stage of design/construction.

The required protection has been provided by optimization of the plant layout to minimize the number of areas affected by piping failures and to locate systems and components used for safe shutdown such that unacceptable damage would not occur. In cases where separation of systems or physical barriers provided by plant structure were not sufficient to provide protection, special protective features such as pipe whip restraints and jet impingement shields were employed.

3.6.1.1.3 Identification of Systems Important to Plant Safety

Systems important to plant safety are listed in Table 3.6-1. For a given postulated piping failure, additional systems may be required (e.g., safety injection is required for a LOCA). Refer to Subsection 3.6.1.3 for a more detailed discussion of systems and components important to plant safety.

3.6.1.2 Description of Design Approach

3.6.1.2.1 Potential Sources and Locations of Piping/Environmental Effects

Potential sources of piping failures that are within or could affect Safety Category I structures are listed by system in Table 3.6-2. High energy lines can be identified through the engineering controlled equipment/component database(s).

Locations, orientations, and size of piping failures within high/moderate energy piping systems are postulated per the criteria given in Subsection 3.6.2.1. The dynamic effects of these postulated failures are accommodated by the methodology described in Subsections 3.6.2.2 through 3.6.2.5.

Pressure rise analyses are addressed in Subsection 3.6.1.3 Item a. There are no credible secondary missiles formed from the postulated break of piping.

Control room habitability is addressed in Section 6.4.

3.6.1.2.2 Impact of Plant Design for Postulated Piping Failures on Inservice Inspection

There are three areas of design necessitated for protection from piping failures which may interfere with inservice inspection as dictated by the ASME Boiler and Pressure Vessel Code, Section XI. They are:

a. physical separation of high/moderate energy piping in tunnels or behind barriers,

b. pipe whip restraints which may surround piping welds to be examined, and

c. impingement barriers which may interfere with weld examination or personnel/equipment access.

Design measures employed so that proper inservice inspection can be conducted are, respectively:

a. Tunnels containing Section III piping have been made to allow personnel/equipment access as needed.

b. Pipe whip restraints are of a bolted design which may be either removed from around the pipe or moved axially along the pipe to allow access to any welds.

c. Impingement/separation barriers are designed to minimize inservice inspection interference to the extent that is practical.

3.6.1.3 Safety Evaluation

In the design of this plant, due consideration was given to the effects of postulated piping breaks with respect to the limits of acceptable damage/loss of function to assure that even with a coincident loss of a single active component the remaining structures, systems, and components would be adequate to safely shut down the plant. The following is a summary of the structural, mechanical, instrumentation, electrical, and HVAC items that are deemed essential and, therefore, designed to remain functional against (1) a high energy line break with resulting whip, impingement, compartment pressurization and temperature rise, wetting of compartment surfaces, and flooding, or (2) a moderate energy through-wall leakage crack with resulting wetting of compartment surfaces and flooding.

a. Structural

All Safety Category I structures, listed in Table 3.2-1, remain functional with the exception of certain concrete block and partition walls in the auxiliary building which have not been specifically designed for loads resulting from piping failure because the failure of the wall will not cause damage to the extent that safe shutdown capability is affected. In the event walls were predicted to be loaded by postulated flooding, pressurization or jet impingement, either the walls were shown to be capable of withstanding the load or the potential effects of failure of the wall on safe shutdown components was assessed.

Pressurization and temperature rise studies for postulated breaks in all subcompartments containing normally operating high energy piping are given in Section 6.2 and Attachment A3.6 for inside and outside the containment, respectively. Flooding inside and outside containment is addressed in Attachment D3.6.

b. Mechanical

Table 3.6-3 lists all the mechanical systems which may be used for safe shutdown following any postulated pipe break. Note that all are seismically designed and are comprised of two full capacity, independent, redundant trains. In addition, many of the safety functions can be accomplished by two or more systems, allowing a diversity in safe shutdown procedures. For example, reactor coolant pump seal integrity is maintained if either seal injection flow (chemical and volume control system) or the thermal barrier cooling (component cooling system) is maintained. As another example, chemical shimming may be accomplished via the chemical and volume control system or the safety injection system.

It should also be noted that the essential systems are a function of the postulated initiating event. For any given event, only certain portions of an essential system may be required to achieve safe shutdown, dependent upon the postulated conditions and coincident failures.

The plant design is such that, whenever possible, all potentially essential systems are protected against loss of function resulting from any potential break. This cannot be attained when essential systems have direct communication with the postulated break (e.g., auxiliary feedwater connection to main feedwater or safety injection connection to reactor coolant). In these cases, the hydraulic design of the essential system is such that the "escaping" flow is not large enough to degrade the essential system flow below minimum requirements.

Due to influences on reactivity, cooling capability, etc., break propagation is further limited as defined by Westinghouse (Reference 6) and shown in Table 3.6-4. In addition, containment leakage is always limited to an acceptable level as described in Section 3.8.

Operation of the secondary side isolation valves is critical to the safety of the plant. Therefore, the piping in the isolation valve room areas is designed well within the stress levels set for postulated breaks. In addition, the boundaries of this room, consisting of the containment and a wall at the start of the main steam tunnel, are placed as close to the isolation valves as practical, to minimize the extent of piping in the area. The piping penetrations are designed to withstand the loadings of piping breaks outside this area without transferring enough strain to the isolation valves to render them inoperable. Refer to Subsection 3.8.2 for a description of their designs.

An assessment of the impact of flooding inside and outside containment resulting from failure of high or moderate energy line is included in Attachment D3.6. No potential flooding event affects the ability to bring the plant to a safe shutdown condition.

c. Instrumentation

Appendix B of Reference 7 lists the instrumentation required to sense critical breaks and automatically initiate protective actions to bring the plant to a safe shutdown. In some cases, instrumentation is set to initiate protective measures only when multiple reading is indicated from a number of redundant sensors (e.g., a "2 out of 4" logic). In these situations, the break may be allowed to render a sensor or sensors inoperable, with the additional sensor assumed inoperable due to a single unrelated active failure, so long as the required number of sensors necessary to signal and initiate protective measures remain.

For example in a "2 out of 4" logic, one sensor may be rendered inoperable as a consequence of the break, and the required minimum of "2 out of 4" would remain, assuming a single active failure in one sensor.

d. Electrical

Safety-related electrical components are located, to the extent possible, in areas which will not be affected by high or moderate energy line breaks. In areas such as the containment, where some electrical equipment must be located near high energy systems, redundant components are well separated to prevent failure of both trains from a common initiating event.

An equipment environmental qualification program was conducted to ensure that safe shutdown capability exists after postulated accidents (including a single-ended pipe break of high energy lines in the safety valve house). A list of Class 1E electrical equipment required to function under postulated accident conditions has been developed. Environmental zones, shown in Table 3.11-2, were reviewed to verify that worst case conditions of temperature, pressure, humidity, radiation and potential flooding consequences have been established. Location and categorization of Class 1E electrical equipment with respect to environmental zones have been completed. Equipment operating times have been determined. Finally, qualification test reports were accumulated and reviewed to ensure that the requirements of NUREG-0588 and IEEE-323 were satisfied.

As a result of this program, any Class 1E equipment needed for safe shutdown, which can be affected by the postulated accident environments, shall be qualified to withstand worst case environmental effects.

3.6.1.3.1 Environmental Qualification

A program to document the environmental qualification of electrical equipment was completed for Byron/Braidwood Stations. This program established that the equipment required to safely shut down the plant will be operable under potentially adverse environmental conditions.

One of the potential causes of severe environmental conditions is a break or crack in a high or moderate energy line. This could cause an increase in pressure, temperature, or humidity or a flooding condition in the area of the break.

The basic design of the Byron/Braidwood stations includes features to mitigate the impact of line breaks on the ability to safely shut the plant down. Some of the features are:

a. Essential safety systems are redundant or backed up by other safety systems;

b. The effectiveness of the redundancy is protected by separation of redundant systems to the greatest extent possible;

c. Walls and compartments have been included to both protect equipment and to isolate breaks;

d. Large high energy lines such as main steam, feedwater, and auxiliary steam partially or completely enclosed in protective tunnels in the auxiliary building;

e. Efforts have been made to minimize the number of high energy lines in areas containing safety related equipment and to minimize the size and length of high energy lines. For example, Byron/Braidwood uses motor and diesel driven auxiliary feedwater pumps rather than turbine driven pumps, thereby eliminating the associated high energy steamlines.

The zones identified in Subsection A3.6.1.1 for high energy line breaks analysis are included in the environmental zones. Table 3.11-2 has been updated to include these environmental conditions. The subcompartment transient conditions calculated in the pressurization analysis are used for qualification of equipment in the subcompartment required to safely shut down the plant following the postulated break.

The large general areas containing high energy lines are not subject to pressurization but the temperature in the area may be affected. The general areas were examined to locate limiting high energy lines and a conservative affected area was defined. Large areas separated from breaks by doorways or other restrictive passages were not evaluated because of the restricted flow and the relatively large areas which dilute the break flow. Only two areas were identified which contain high energy lines.

The areas identified as 4A, 4B, 10A, and 10B are actually interconnected. All are affected by breaks at various locations in a 3-inch letdown line in the chemical and volume control system. Orifices in the system limit the flow to a maximum of 120 gpm. The portion of the break fluid which flashes to steam will rise to the upper portions of Zone 4A/4B and flow out through openings into the upper levels of the auxiliary building. The break flow duration will be limited because two main control board alarms (high flow and high letdown heat exchanger outlet temperature) will immediately sound. The break will be isolable with containment isolation valves. As a result of the limited flow from this break and the dilution area which is extremely large, the temperature of the air in these zones will not exceed the maximum temperatures predicted during operating transients and an additional accident environment is not necessary. If the break is in the upper portion of Zone 10A/10B, the potential exists for heating a restricted area with no natural ventilation. None of the equipment in this area is required for safe shutdown following a letdown line failure. This scenario is discussed further in the Byron/Braidwood equipment qualification report.

The other area investigated was Zone 14 at elevation 401 feet. This open area contains a two inch auxiliary steam line. Failure of this line would release steam into the general area. The only equipment required for plant shutdown which could be affected are the boric acid transfer pump motors. The pumps are not required to bring the plant to a hot standby condition. Cold shutdown can be achieved by using water from the refueling water storage tank to increase the reactor coolant boron concentration, eliminating the need for the boric acid transfer pumps. Under certain conditions, required boration may be achieved using only the charging system. Under other conditions, reactor coolant letdown may also be required. Since a total loss of capability to charge or let down the reactor coolant system would not result from an auxiliary steamline break, cold shutdown capability will not be lost. Flow into adjacent areas would eventually occur but the dilution would be so great that the temperature of the adjacent areas would remain effectively unchanged. Table 3.11-2 has been updated to include the environmental conditions discussed here.

Moderate energy line breaks do not impact the equipment qualification parameters. For lines with operating temperatures significantly above the normal area temperature, the crack flow rate and potential for heat transfer has been checked to ensure that sufficient HVAC capability exists to prevent failure of required safety-related equipment.

The Turbine Building contains no safety-related components or other components required for safe shutdown of the Unit. However, there are adjacent rooms in the Auxiliary Building that contain such equipment and that communicate with the Turbine Building through ventilation openings. Therefore, the equipment in those adjacent rooms must be protected from or shown to be able to withstand the effects of HELB in the Turbine Building. The HELB mitigation strategy for the Auxiliary Building rooms involves (1) keeping the Turbine Building environment out of the Auxiliary Building rooms by means of HELB backdraft dampers; (2) configuring the fire dampers to close only in the event of a fire (thereby keeping them open during the HELB to allow the room ventilation exhaust path to remain open); and (3) automatically restoring room cooling (by installing auto-restart capability for the room ventilation fans.)

The following subsections of UFSAR Section 3.6 describe the approach used to evaluate the effects of high energy line breaks, including Turbine Building HELB. The resultant environmental conditions in the adjacent Auxiliary Building rooms have been determined per Reference 18. Due to the limited magnitude and short duration of the transient, the environmental parameters within these zones would not be significantly more severe than the environment that would occur during normal plant operation.

3.6.2 Determination of Break Locations and Dynamic Effects Associated with the Postulated Break of Piping

Described herein are the design bases for locating breaks and cracks in piping inside and outside of containment, the procedures used to define the jet thrust reaction at the break location, the jet impingement loading criteria, and the dynamic response models and results.

Because of variations in requirements, techniques, and failure effects, high and moderate energy lines are addressed separately. Similarly, the pipe whip, subcompartment pressurization, and environmental analysis all have somewhat different approaches.

a. High Energy Line Analysis

Standard Review Plans 3.6.1 and 3.6.2 were followed in defining and identifying high energy lines. High energy lines are those larger than 1 inch diameter for which either:

1. The service temperature is greater than 200°F; or

2. The design pressure is greater than 275 psig.

Only a limited number of systems in the auxiliary building meet either of these criteria. The following systems have been identified as containing high energy lines in the auxiliary building:

Chemical and Volume Control	(CV)
Auxiliary Steam	(AS)
Steam Generator Blowdown	(SD)
Radioactive Waste Processing	(WX)
Boric Acid	(AB)
Main Steam	(MS)
Feedwater	(FW)
Auxiliary Feedwater	(AF)
Residual Heat Removal	(RH)
Safety Injection	(SI)

Systems which are normally not used or at reduced temperature and pressure are not necessarily required to be considered as high energy lines. A guideline has been established (Branch Technical Position MEB 3-1) that if the system is at high energy conditions less than 2% of the time, it may be considered a moderate energy line and its normal conditions applied to the line break analysis. On this basis, the last three systems (AF, RH, SI) are not considered as high energy systems. The Byron/Braidwood AF system is not used for normal startup as at some other plants. The only high energy line in the boric acid system is a steam supply line to the boric acid batching tank. This line is essentially a part of the auxiliary steam system and, as result, was not identified in Table 3.6-2.

Subcompartment pressurization is investigated for all lines with temperatures above 200°F. Lower temperatures lines do not have the potential for flashing to steam and thus will not increase the pressure of a subcompartment in the event of a break. Pressurization is of concern only in small subcompartments with relatively large high energy lines or subcompartments with limited pressure relief venting.

High energy lines below 200°F have only minor effects on the environmental conditions. The absence of steam and the ability to drain warm liquid from the break area limits the temperature rise from these breaks. The auxiliary building HVAC has sufficient capacity to accommodate these lower temperature breaks. Breaks of other high energy lines may influence the expected maximum temperature in some areas of the auxiliary building even if high pressures do not result. The auxiliary building contains several large areas with high energy lines that are not subject to pressurization but are investigated for environmental effects.

Certain postulated break locations in high energy piping systems are used to investigate the potential for damage due to pipe whip and jet impingement. The guidelines in Standard Review Plan 3.6.2 are used to determine the number and locations of the pipe breaks. Pipe restraints are added as required to prevent damage to structures and safety-related equipment.

The Turbine Building contains no safety-related components or other components required for safe shutdown of the Unit. However, there are adjacent rooms in the Auxiliary Building that contain such equipment and that communicate with the Turbine Building through ventilation openings. Therefore, the equipment in those adjacent rooms must be protected from or shown to be able to withstand the effects of HELB in the Turbine Building. Turbine Building HELBs were postulated in a manner that would produce the most challenging environmental conditions for the equipment in the adjacent Auxiliary Building rooms.

For the environmental analysis, numerous locations involving different Turbine Building elevations were considered to determine bounding conditions for the breaks. Break locations were chosen based on the resulting severity of the break and not on the potential to break (i.e., piping analysis results were not used to determine break locations). Per the UFSAR 15.1.5.2, the largest main steam (highest enthalpy) line break is 1.4 ft^2. This is based on the area of the integral flow restrictor in each of the four steam generators and flow losses between the steam generators and the Turbine Building and a Main Steam Isolation Valve to close (single failure). For liquid line breaks, the largest Feedwater line breaks and Heater Drain line breaks on different Turbine Building elevations were considered in the evaluation.

The pressures developed in the calculation are used as input for the qualification of the L-Line doors and dampers that separate the Turbine Building from the adjacent Auxiliary Building rooms. Additionally, the pressures internal to the rooms are used for qualifications of the divisional walls and doors between that separate them from each other.

The evaluations of flooding, pipe whip, and jet impingement effects for Turbine Building HELBs are discussed in Sections 3.6.2.b and 3.6.2.2.

b. Moderate Energy Line Breaks

Moderate energy lines are lines which operate at temperatures of 200°F or less and pressures of 275 psig or less. A break in a moderate energy line will not result in flashing of the liquid to steam and, as a result, has no potential for pressurization of areas. The relatively low temperature and reduced heat transfer effects of the liquid blowdown precludes significant temperature increases in the area of the break. The reduced break area applicable to these breaks and the absence of steam allows the auxiliary building HVAC to maintain temperatures within those specified in the environmental qualification program. The results of moderate energy line breaks are, therefore, confined to the physical effects of liquid discharge into the plant. Plant safety is affected only if equipment required to mitigate the break or to safely shut down the plant can be damaged by resultant flooding or water spray. Water spray was not found to affect plant safety because of the separation of redundant safe shutdown systems and components. Moderate energy line breaks do not result in pipe whip.

As an example, the auxiliary building basement at elevation 330 feet is designed to prevent loss of redundant trains of safety related equipment from the effects of a moderate energy line break. The basement is divided into two completely independent sections.

These sections are separated by a wall which has been designed to withstand the flooding. Each section contains redundant essential service water pumps which can supply both units. Therefore, flooding or spray from a break cannot affect the equipment in the other section of the basement and essential service water will be supplied to both units.

This separation is well documented in the Fire Protection Report. This report lists and locates equipment required for safe shutdown. When redundant safe shutdown systems are separated by fire walls or by more than 20 feet, spray from a crack in a moderate energy line would not impair the safe shutdown capability of the plant.

A moderate energy line break in the component cooling system was given special consideration because the component cooling system was not originally supplied with a Category I source of makeup water. A leak in this system could have theoretically drained the surge tanks resulting in damage to the component cooling pumps.

A significant leakage in the component cooling system is not expected. The system is a moderate energy, low pressure system and is not subject to severe loading. In the event the system is inoperable, the plant may be safely maintained in a hot shutdown condition until the component cooling system is restored.

If a crack is postulated in one of the large lines in the system, the level in the surge tank of the affected unit will drop. Demineralized water and primary water makeup is fed to the surge tank at preset level limits to maintain tank level in the normal range. Prior to reaching the pump trip setpoint, one or both trains of essential service water makeup MOVs will open to maintain the surge tank level and allow the component cooling water pumps to continue operation. Control Room annunciation is provided when essential service water makeup is fed to the component cooling water surge tank from either train. If the level reaches the low setpoint level, alarms will sound and the affected units component cooling pumps will be automatically tripped to prevent damage to the pumps.

If primary water, demineralized water or essential service water makeup is available, the component cooling pumps may be restarted and the unit operated normally while the leak is located and isolated. Otherwise, the reactor will be tripped because of the interruption of the component cooling to the reactor coolant pumps and the unit will be placed in a hot shutdown condition. Component cooling is not required to safely maintain the unit in hot shutdown mode. The component cooling system can be operated after a failure of the piping by maintaining sufficient surge tank makeup, and by closing the appropriate system valves to isolate the break location and maintain component cooling flow.

In the Turbine Building, numerous high energy lines are in the same area as the moderate energy lines. Because the environmental conditions from the high energy line breaks bound the environmental conditions from the moderate energy line breaks, the environmental impact analysis for Turbine Building HELBs bounds the effect of breaks in moderate energy lines.

Flooding in the Turbine Building would not adversely affect the equipment in the adjacent Auxiliary Building rooms. Numerous stairwells, grating areas, floor opening (e.g., pipe sleeves) and equipment hatches exist on all elevations of the Turbine Building. Therefore, water levels cannot develop any depth from which water could flow under doors into the adjacent Auxiliary Building rooms. Because the doors and dampers have been determined not to fail due to jet impingement, any leakage through these components would result in an inconsequential volume and level of water. Water that was not captured by the Turbine Building floor drain system would eventually reach the Turbine Building basement where flooding is bounded by a Circulating Water pipe break (UFSAR 10.4.5).

3.6.2.1 Criteria Used to Define Break and Crack Location and Configuration

3.6.2.1.1 Reactor Coolant Loop Piping

Pipe failure protection is provided in accordance with the requirements of 10 CFR 50, Appendix A, General Design Criterion 4 (GDC4). The original design postulated pipe break locations in the reactor coolant loop are described in Reference 1. In accordance with the provisions of GDC4 (as revised per 52 FR 41288, October 27, 1987), the dynamic effects associated with postulated pipe breaks can be eliminated from the structural design basis if it is demonstrated that the probability of pipe rupture is extremely low.

Through the application of leak-before-break technology, the dynamic effects from postulated breaks in the reactor coolant loop primary piping, accumulator line piping, and reactor coolant loop bypass piping can be eliminated from the structural design basis, based on the evaluation presented in References 10 and 12. For Byron Units 1 and 2, and Braidwood Units 1 and 2, based on the evaluation presented in Reference 17, following application of the Mechanical Stress Improvement Process (MSIP) on all eight reactor coolant inlet/outlet nozzles, the leak-before-break analysis margins for the critical locations as documented in Reference 10 are still bounding. Approval of the elimination of breaks in Units 1 and 2 primary loop piping, accumulator line piping, and reactor coolant loop bypass piping is given in References 11 and 13. To provide the high margins of safety required by GDC-4, the nonmechanistic pipe rupture design basis is maintained for containment design and ECCS analyses, and the postulated pipe ruptures are retained for electrical and mechanical equipment environmental qualification.

3.6.2.1.2 Piping Other Than Reactor Coolant Loop Piping

This section applies to all high and moderate energy piping outside the reactor coolant pressure boundary and to any reactor coolant pressure boundary piping not covered in Section 3.6.2.1.1.

3.6.2.1.2.1 High-Energy Fluid System Piping

3.6.2.1.2.1.1 Fluid System Piping not in the Containment Penetration Area

a. Breaks in ASME Section III Class 1 piping are postulated at the following locations in each piping run or branch run:

   1. at terminal ends of the run;

   2. at intermediate locations between terminal ends where the primary plus secondary stress intensity range (including the zero load set) as calculated by equation (10) and either equation (12) or (13) in Paragraph NB-3653 of ASME Section III exceeds 2.4 S_m for transients resulting from normal and upset plant conditions; and

   3. at any intermediate locations between terminal ends where the cumulative usage factor derived from the piping fatigue analysis under the loadings resulting from plant normal, upset, and testing conditions and an OBE event exceeds 0.1.

b. With the exception of those portions of piping identified in Subsection 3.6.2.1.2.1.2, breaks in ASME Section III Class 2 and 3 piping and seismically analyzed and supported ANSI B31.1 piping are postulated at the following locations in each piping run or branch run:

   1. At terminal ends of the run.

   2. At each location where the stresses under the loadings resulting from normal and upset plant conditions and an OBE event as calculated by equations (9) and (10) in Paragraph NC-3652 of ASME Section III exceed 0.8 ($1.2\ S_h + S_a$).

   3. As an alternate to (1) and (2), intermediate locations are assumed at each location of potential high stress or fatigue such as pipe fittings, valves, flanges and attachments.

c. Breaks in nonseismically qualified piping are postulated at the following locations in each piping run or branch run:

   1. At terminal ends of the run.

2. Intermediate locations are assumed at each location of potential high stress or fatigue such as pipe fittings, valves, flanges and attachments.

d. Leakage cracks in high energy ASME Section III Class 2 and 3 piping and seismically analyzed and supported ANSI B31.1 piping are postulated at locations where the stresses under the loadings resulting from normal and upset plant conditions and an OBE event as calculated by equations (9) and (10) in Paragraph NC-3652 of ASME Section III exceed 0.4 (1.2 S_h + S_a).

3.6.2.1.2.1.2 Fluid System Piping in Containment Penetration Areas

This section applies to the fluid system piping inside the isolation valve rooms, which includes the main steamlines and the feedwater lines, starting at the inside of the containment wall and extending to the first restraint outside the containment isolation valve.

3.6.2.1.2.1.2.1 Details of the Containment Penetration

Details of the containment penetrations are discussed in Subsections 3.8.1 and 3.8.2.

3.6.2.1.2.1.2.2 Break Criteria

Breaks are not postulated in the containment penetration area as defined above since the following design requirements are met:

a. The following design stress and fatigue limits are not exceeded for ASME Code Section III Class 2 piping and seismically qualified ANSI B31.1 piping:

1. The maximum stress ranges as calculated by the sum of Equations (9) and (10) in Paragraph NC-3652, ASME Code, Section III, under the loadings resulting from the normal and upset plant conditions (i.e., sustained loads, occasional loads, and thermal expansion) and an OBE event do not exceed 0.8 (1.2 S_h + S_a).

2. The maximum stress, as calculated by Equation (9) in Paragraph NC-3652 under the loadings resulting from internal pressure, dead weight, and a postulated piping failure of fluid systems piping beyond these portions of piping and excluding OBE, does not exceed 1.8 S_h. Primary loads include those which are deflection limited by whip restraints.

3. Following a piping failure outside the first pipe whip restraint, the formation of a plastic hinge is not permitted in the piping between the containment penetration and the first pipe whip restraint. Bending and torsion limiting restraints are installed, as necessary, at locations selected to optimize overall piping design, to prevent formation of a plastic hinge as just noted, to protect against the impairment of the leaktight integrity of the containment, to assure isolation valve operability and to meet the stress and fatigue limits in the containment penetration area.

b. Leakage cracks:

Per SRP 3.6.2, the break criteria of Subsection 3.6.2.1.2.1.2.2.a, paragraphs 1 and 2, also apply to the postulation of cracks in the penetration area in the region from the containment wall to and including the inboard or outboard isolation valves.

Leakage cracks in high energy ASME Section III Class 2 and 3 piping and seismically analyzed and supported ANSI B31.1 piping located in the containment penetration area, other than that piping described in the paragraph above, are postulated in accordance with Subsection 3.6.2.1.2.1.1. For the Main Feedwater and Main Steam lines, this includes the piping from the inboard weld of the FWIV/MSIV to the first restraint outside the isolation valve (i.e., in the MSIV room wall).

c. The number of circumferential and longitudinal piping welds and branch connections are minimized as far as practical.

d. The length of these portions of piping are reduced to the minimum length practical.

e. One hundred percent volumetric examination of full penetration process-piping butt welds, 6-inch nominal pipe size and greater, in the break exclusion area was performed as a baseline inspection before operation. During each inspection interval, process-piping welds in the break exclusion areas are subject to an examination program. In lieu of the requirements specified in NUREG 0800, EPRI Revised Risk-Informed Inservice Inspection Evaluation Procedure (Reference 14) and Extension of the EPRI Risk-Informed Inservice Inspection (RI-ISI) Methodology to Break Exclusion Region (BER) Programs (Reference 15) Topical Reports are used to establish the selection criteria and examination methods. The NRC approved the use of these alternate methods in Reference 16. The weld population subject to examination under the Risk-Informed BER program are non-exempted piping welds as determined in accordance with the rules of ASME Section XI, edition and addenda applicable to the existing inservice inspection program.

f. Access to process pipe welds within containment penetration sleeves is not provided since:

   1. There are no circumferential process pipe welds within containment penetration sleeves.

   2. Items a.2 and 3 of Subsection 3.6.2.1.2.1 cover break criteria for Class 1 piping, whereas, no Class 1 piping penetrates containment.

   3. There are no penetration sleeves to process pipe welds contained in piping covered in the augmented inservice inspection program. The containment penetrations for this piping are all Type I head fittings as shown in Figure 3.8-40.

3.6.2.1.2.2 Moderate-Energy Fluid System Piping

3.6.2.1.2.2.1 Moderate-Energy Fluid System Piping Outside Containment

a. Through-wall leakage cracks are postulated in Seismic Category I moderate-energy ASME Section III, Class 2 and 3 and seismically analyzed and supported ANSI B31.1 piping except where the maximum stress range is less than 0.4 $(1.2S_h + S_a)$. In unanalyzed moderate-energy ASME Section III Class 2 and 3 and ANSI B31.1 piping, this exception based on stress is not taken. The cracks are postulated individually at locations that result in the maximum effects from fluid spraying and flooding, with the consequent hazards or environmental conditions developed.

b. Through-wall leakage cracks instead of breaks are postulated in the piping of those fluid systems that qualify as high energy fluid systems for only short operational periods but qualify as moderate energy fluid systems for the major operational period.

   An operational period is considered "short" if the fraction of time that the system operates within the pressure-temperature conditions specified for high energy fluid systems is about 2 percent of the time that the system operates as a moderate energy fluid system.

3.6.2.1.2.2.2 Moderate-Energy Fluid System Piping Inside Containment

Through-wall leakage cracks are not postulated in moderate energy fluid systems inside containment because the flooding and water spray effects resulting from cracks is governed by the following:

a. Containment flooding is governed by a large loss of coolant accident which has been considered in the plant design.

b. Spray effects are considered in the equipment qualification program for safe shutdown equipment inside containment. "Chemical spray" qualification simulates containment spray.

3.6.2.1.2.3 Types of Breaks and Leakage Cracks in Fluid System Piping

3.6.2.1.2.3.1 Circumferential Pipe Breaks

Circumferential breaks are postulated in high-energy fluid system piping exceeding a nominal pipe size of 1 inch, at the locations specified in Subsection 3.6.2.1.2.1.

Where break locations are selected in piping without the benefit of stress calculations, breaks are postulated nonconcurrently at the piping welds to each fitting, valve, or welded attachment.

3.6.2.1.2.3.2 Longitudinal Pipe Breaks

The following longitudinal breaks are postulated in high-energy fluid system piping at the locations of the circumferential breaks specified in Subsection 3.6.2.1.2.3.1.

a. Longitudinal breaks in fluid systems piping and branch runs are postulated in nominal pipe size 4-inch and larger, where the maximum stress range exceeds 2.4 S_m for ASME Code, Section III, Class 1 piping and 0.8 (1.2 S_h + S_a) in ASME Code, Section III, Class 2 and 3 and seismically qualified ANSI B31.1 piping or where break locations are chosen per Subsection 3.6.2.1.2.1.1.

b. Longitudinal breaks are not postulated at:

   1. terminal ends; and

   2. locations chosen to meet the requirements of the minimum number of intermediate breaks as defined in Subsection 3.6.2.1.2.1.1 and Subsection 3.6.2.1.2.1.1 Item b.3.

c. Longitudinal breaks are assumed to result in an axial split without pipe severance. Splits are oriented (but not concurrently) at two diametrically-opposed points on the piping circumference such that the jet reaction causes out-of-plane bending of the piping configuration. Alternatively, a single split is assumed at the section of highest tensile stress as determined by detailed stress analysis.

d. If a postulated break location is at a nonaxisymmetric fitting (such as a tee or elbow), without the benefit of a detailed stress analysis, longitudinal breaks are postulated to occur:

1. Out of plane of an elbow oriented nonconcurrently at two diametrically-opposed points on the circumference in the middle of the elbow.

2. Out of plane of a tee oriented nonconcurrently at two diametrically-opposed points in the middle of the tee run section.

3.6.2.1.2.3.3 Through-Wall Leakage Cracks

The following through-wall leakage cracks are postulated in moderate energy fluid system piping at the locations specified in this position:

a. Cracks are postulated in fluid system piping and branch runs exceeding a nominal pipe size of 1 inch.

b. Fluid flow from a crack is based on a circular opening of area equal to that of a rectangle one-half pipe-diameter in length and one-half pipe wall thickness in width.

c. The flow from the crack is assumed to result in an environment that wets all unprotected components within the compartment, with consequent flooding in the compartment and communicating compartments. Flooding effects are determined on the basis of a conservatively estimated time period required to effect corrective actions. Evaluation of jet impingement effects is not considered for postulated through-wall leakage cracks.

3.6.2.1.2.4 Definitions

Definitions are given in Subsection 3.6.1.1.

3.6.2.2 Analytical Methods to Define Forcing Functions and Response Models

3.6.2.2.1 Reactor Coolant Loop Piping

3.6.2.2.1.1 Dynamic Analyses

Following is a summary of the methods used to determine the dynamic response of the reactor coolant loop associated with postulated pipe breaks in the loop piping. Although the dynamic effects of postulated pipe breaks in the reactor coolant loop primary piping, accumulator line piping, and reactor coolant loop bypass piping can be eliminated from the structural design basis (see Subsection 3.6.2.1.1), the design verification of certain structures and components may retain the original pipe break loadings. For these cases, the following subsections describe the methods used in the analysis.

3.6.2.2.1.2 Time Functions of Jet Thrust Force on Broken and Intact Loop Piping

In order to determine the thrust and reactive force loads to be applied to the reactor coolant loop during the postulated loss-of-coolant accident (LOCA), it is necessary to have a detailed description of the hydraulic transient. Hydraulic forcing functions are calculated for the broken and intact reactor coolant loops as a result of a postulated LOCA. These forces result from the transient flow and pressure histories in the reactor coolant system. The calculation is performed in two steps. The first step is to calculate the transient pressure, mass flow rates, and thermodynamic properties as a function of time. The second step uses the results obtained from the hydraulic analysis, along with input of areas and direction coordinates, and calculates the time history of forces at appropriate locations (e.g., elbows) in the reactor coolant loops.

The hydraulic model represents the behavior of the coolant fluid within the entire reactor coolant system. Key parameters calculated by the hydraulic model are pressure, mass flow rate, and density. These are supplied to the thrust calculation, together with plant layout information to determine the time-dependent loads exerted by the fluid on the loops. In evaluating the hydraulic forcing functions during a postulated LOCA, the pressure and momentum flux terms are dominant. The inertia and gravitational terms are taken into account in evaluation of the local fluid conditions in the hydraulic model.

The blowdown hydraulic analysis is required to provide the basic information concerning the dynamic behavior of the reactor core environment for the loop forces, reactor kinetics and core cooling analysis. This requires the ability to predict the flow, quality, and pressure of the fluid throughout the reactor system. The SATAN-IV Code (Reference 2) was developed with a capability to provide this information.

The SATAN-IV Code performs a comprehensive space-time dependent analysis of a LOCA and is designed to treat all phases of the blowdown. The stages are: (1) a subcooled stage where the rapidly changing pressure gradients in the subcooled fluid exert an influence upon the reactor coolant System and support structures, (2) a two phase depressurization stage, and (3) the saturated stage.

The code employs a one dimensional analysis in which the entire reactor coolant system is divided into control volumes. The fluid properties are considered uniform and thermodynamic equilibrium is assumed in each element. Pump characteristics, pump coastdown and cavitation, core and steam generator heat transfer including the W-3 DNB correlation in addition to the reactor kinetics are incorporated in the code.

The STHRUST computer program was developed to compute the transient (blowdown) hydraulic loads resulting from a LOCA.

The blowdown hydraulic loads on primary loop components are computed from the equation.

$$F = 144 A \left[(P - 14.7) + \left(\frac{\dot{m}^2}{144 \rho g A_m^2}\right) \right] \qquad (3.6\text{-}1)$$

The symbols and units are:

F	= Force, lb_f
A	= Aperture area, ft^2
P	= System pressure
M	= Mass flow rate, lb_m/sec
ρ	= Density, lb_m/ft^3
G	= Gravitational constant = 32.174 $ft\text{-}lb_m/lb_f - sec^2$
A_m	= Mass flow area, ft^2

In the model to compute forcing functions, the reactor coolant loop system is represented by a similar model as employed in the blowdown analysis. The entire loop layout is described in a global coordinate system. Each node is fully described by: (1) blowdown hydraulic information, and (2) the orientation of the streamlines of the force nodes in the system, which includes flow areas, and projection coefficients along the three axes of the global coordinate system. Each node is modeled as a separate control volume, with one or two flow apertures associated with it. Two apertures are used to simulate a change in flow direction and area. Each force is divided into its x, y, and z components using the projection coefficients. The force components are then summed over the total number of apertures in any one node to give a total x force, total y force, and total z force. These thrust forces serve as input to the piping/restraint dynamic analysis.

The STHRUST Code is described in Reference 3.

3.6.2.2.1.3 Dynamic Analysis of the Reactor Coolant Loop Piping Equipment Supports and Pipe Whip Restraints

The dynamic analysis of the reactor coolant loop piping for the LOCA loadings is described in Section 3.9.

3.6.2.2.2 Analytical Methods to Define Forcing Functions and Response Models for Piping Excluding Reactor Coolant Loop Piping

This section applies to all high energy piping outside the reactor coolant pressure boundary and to all reactor coolant pressure boundary piping, including the RCS bypass piping but excluding the reactor main coolant piping which connects the reactor vessel, the main coolant pumps, and the steam generators.

3.6.2.2.2.1 Determination of Pipe Thrust and Jet Loads

3.6.2.2.2.1.1 Circumferential Breaks

Circumferential breaks are assumed to result in pipe severance and separation amounting to at least a one-diameter lateral displacement of the broken piping sections unless physically limited by piping restraints, structural members, or piping stiffness. The dynamic force of the jet discharge at the break location is based on the effective cross-sectional flow area of the pipe and on a calculated fluid pressure as modified by an analytically determined thrust coefficient. Limited pipe displacement at the break location, line restriction flow limiters, positive pump controlled flow, and the absence of energy reservoirs are taken into account, as applicable, in the reduction of the jet discharge. Pipe whipping is 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.

3.6.2.2.2.1.2 Longitudinal Breaks

The dynamic force of the fluid jet discharge is based on a circular break area equal to the cross-sectional flow area of the pipe at the break location and on a calculated fluid pressure modified by an analytically determined thrust coefficient as determined for a circumferential break at the same location. Line restrictions, flow limiters, positive pump controlled flow, and the absence of energy reservoirs are taken into account, as applicable, in the reduction of jet discharge.

Piping movement is assumed to occur in the direction of the jet reaction unless limited by structural members, piping restraints, or piping stiffness.

3.6.2.2.2.1.3 Pipe Blowdown Force and Wave Force

The fluid discharge forces that result from either postulated circumferential or longitudinal breaks are calculated using a simplified one step forcing function methodology. This methodology is described in a Sargent & Lundy calculation procedure (Reference 5) and is based on the simplified methods described in ANSI 58.2 and in Reference 4.

When the simplified method discussed above leads to impractical whip restraint designs, then a more detailed computer solution which more accurately reflects the postulated pipe break event is used. The computer solution is based on the NRC's computer program, developed for calculating two-phase blowdown forces (Reference 9).

3.6.2.2.2.1.4 Evaluation of Jet Impingement Effects

The break locations defined for the pipe whip investigation were examined for jet impingement effects. The majority of locations had no effect on equipment required for safe shutdown. This was a result of the criteria used in design to maintain separation of redundant systems and the use of compartments to isolate high energy line break effects. Equipment which could be affected by jet impingement was analyzed and moved or protected if protection was required.

Jet impingement force calculations are required only if structures or components are located near postulated high energy line breaks and it cannot be demonstrated that failure of the structure or component will not adversely affect safe shutdown capability. The methodology used in the plant design when force calculations were found necessary is described in detail in Reference 5.

To confirm that the design approach for protection against jet impingement effects had been consistently applied throughout the design process, a thorough review of potential jet effects on safe shutdown components was completed in August 1984. A report (Reference 7) contains the results of this confirmatory review, and demonstrates that safe shutdown capability is not adversely affected by jet impingement. This effort utilized the most current information available as to the plant configuration and operating conditions. Recently, improved descriptions of steam and two-phase jet behavior were also incorporated into the review (Reference 8).

For Turbine Building HELBs, evaluations were performed in accordance with the methodologies described in the UFSAR to demonstrate that the L-line wall and components integral to the wall (doors and dampers) that separate the Turbine Building from the adjacent Auxiliary Building rooms can withstand the HELB jet forces.

The L-Line wall was determined to be not adversely affected by jet impingement due to the strength and thickness of the wall (a concrete re-enforced wall 42" in depth, and a safety related, Seismic Category I structure.) For doors and dampers, postulated jets were evaluated and found either (1) to not impact the doors or dampers, or (2) to result in forces that did not exceed the design pressures of the components, or (3) require shields to protect them from jet impingement.

The analysis utilized the guidance of Reference 8 to exclude targets greater than 10 pipe diameters from high energy lines. The use of Reference 8 was consistent with the NRC limitations on its use documented in Supplement 6 to the Byron Unit 1 Safety Evaluation Report (later made applicable to Byron Unit 2 and Braidwood Units 1 and 2.) For targets within 10 pipe diameters of high energy steam lines or high energy liquid lines that flash following the break, or that are near other high energy liquid lines, the evaluation utilized ANSI/ANS 58.2 to determine jet shapes and jet impingement loads. This is consistent with the methodology described in UFSAR Section 3.6.2 for determining jet loads.

3.6.2.2.2.2 Methods for the Dynamic Analysis of Pipe Whip

Pipe whip restraints provide clearance for thermal expansion during normal operation. If a break occurs, the restraints or anchors nearest the break are designed to prevent unlimited movement at the point of break (pipe whip). Two methods were used to analyze simplified models of the local region near the break and to calculate displacements of the pipe and restraint. These calculated displacements were then used to estimate strains in the pipe and the restraint.

An energy balance method was used to analyze carbon steel pipes since it was found possible to use a rigid-perfectly plastic moment-rotation law for pipes of this material with acceptable accuracy. The simplified models shown in Figure 3.6-15 were used to represent the local region near the break and to calculate the displacement of the pipe and the restraint when subjected to a suddenly applied constant force by the energy balance method. The restraint and structure resistances were assumed rigid perfectly plastic. Elastic effects increase the work done by the blowdown thrust. Since these effects are neglected in the rigid-plastic energy balance model, they were accounted for by increasing the gap between the pipe and the restraint by an empirical formula.

A finite difference model was used to analyze stainless steel pipes since it was found necessary to use a power law moment-curvature relationship for pipes of this material. The simplified models shown in Figure 3.6-16 were used to represent the local region near the break and to calculate the displacement in the restraint as well as the displacements and strains in the pipe.

3.6.2.2.2.2.1 <u>Stages of Motion - Energy Balance Method</u>

All references to points and lengths in this section can be found in Figure 3.6-15.

At the start of motion, the pipe is assumed fixed at point A. Physically, point A is an anchor, restraint, or elbow. In general, a hinge will form at some point B and outboard pipe segment BD will rotate as a rigid body until contact with the restraint is made at point C.

During the next stage of motion the hinge at B must move in order to satisfy the requirement that shear at a plastic hinge is zero. At the same time a hinge will form at the restraint (point C) if the plastic moment M_o is exceeded. Initially at contact, the force exerted on the pipe by the restraint is R, the restraint resistance. This force will remain constant as long as the restraint continues to deform.

If the structure resistance is $R_S < R$, at some point restraint deformation will stop while structure deformation (motion of point E) continues. The force on the pipe (and attached mass M) is the R_S. In any event, the moving hinge B will reach the fixed support at A before motion stops at C. In the final stage of motion hinges may exist at A and C until motion stops.

3.6.2.2.2.2.2 <u>First Stage of Motion</u>

The initial location of the hinge at B is determined by locating the point of zero shear and is given by:

$$L_z = 1.5\left[1 + \left(1 + \frac{8\ M_t F}{3\ m\ M_0}\right)^{1/2}\right]\frac{M_o}{F}$$

where:

M_t	= tip mass (lbm),
F	= blowdown force (lb),
m	= mass of pipe/inch,
M_o	= plastic moment of pipe (in.-lb), and
L_z	= location in inches (Figure 3.6-17)

3.6.2.2.2.2.3 Second Stage of Motion (Moving Hinge)

Case 1. No hinge at restraint for the case when M_s (structural mass) is not accounted for (Figure 3.6-17).

After integrating, with respect to time, the equations for conservation of linear and angular momentum are:

$$P_1 t = I_1 \omega - C_1 \quad (3.6\text{-}3)$$

$$P_2 t = I_2 \omega - C_2 \quad (3.6\text{-}4)$$

where:

C_1 and C_2 are constants and are determined at $t = 0$
t = time of motion from B to present location,
I_1 = $1/2\ m\ L^2 + M_s(L-L_2) + M_t L$,
I_2 = $(1/6)\ mL^2 + (3\ L_2-L) + M_t\ L_2 L$,
P_1 = $F - R$
P = $F\ L_2 - M_o$, and
ω = $\dot{\theta}$ (radians/second).

From Equations 3.6-3 and 3.6-4:

$$\omega = \frac{P_1\, t + C_1}{I_1} \quad (3.6\text{-}5)$$

$$t = \frac{C_1\, I_2 - C_2\, I_1}{P_2\, I_1 - P_1\, I_2} \quad (3.6\text{-}6)$$

Equations 3.6-5 and 3.6-6 describe the second stage of motion.

Case 2. Hinge at restraint for the case when M_s (structural mass) is not accounted for (Figure 3.6-17).

For conservation of linear and angular moment a of the segments:

$$\omega = C_3 / (L - L_2)^3 \quad (3.6\text{-}7)$$

$$P_2 t + C_5 = M_{12} C_3 / (L - L_2)^2 + M_{11}\omega \quad (3.6\text{-}8)$$

$$P_1 t + C_4 = I_3 C_3 / (L - L_2)^2 + M_{12}\omega \quad (3.6\text{-}9)$$

where:

V = velocity of restraint = $\omega\ (L - L_2)$

C_3, C_4 and C_5 are constants and are determined at t = 0

$I_3 = 1/2m(L+L_2) + M_t$,

$M_{11} = (1/3)mL_2^3 + M_tL_2^2$, and

$M_{12} = 1/2mL_2^2 + M_tL_2$.

From Equations (3.6-8) and (3.6-9):

$$t = \frac{C_3(M_{12}2 - M_{11}I_3)/(L - L_2)^2 - (C_5M_{12} - C_4M_{11})}{(P_2M_{12} - P_1M_{11})} \tag{3.6-10}$$

$$\omega = \frac{P_2t + C_5 - (C_3M_{12}/(L - L_2)^2)}{M_{11}} \tag{3.6-11}$$

Equations 3.6-7, 3.6-10, and 3.6-11 describe the second stage of motion for hinge at restraint.

3.6.2.2.2.2.4 Third Stage of Motion (Hinge at Support)

From summation of moment about two hinges (at support and restraint) one gets:

$$K_{11}\ddot{\theta}_1 + K_{12}\ddot{\theta}_2 = FL - RL_1 - M_o \tag{3.6-12}$$

$$K_{12}\ddot{\theta}_1 + K_{22}\ddot{\theta}_2 = FL_2 - M_o \tag{3.6-13}$$

where:

$K_{11} = (1/3)mL^3 + M_t L^2$

$K_{12} = (1/2)mL^2 (L-L_2/3) + M_tLL_2$, and

$K_{22} = (1/3)mL_2^3 + M\ L_2^2$.

Equations 3.6-12 and 3.6-13 describe motion in the third stage.

3.6.2.2.2.2.5 Gap Increase to Account for Elastic Effects

It has been found by comparison with finite difference results that the neglect of elastic effects in the energy balance method can be compensated for by increasing the gap by an amount given by the following empirical formula:

$$g = 0.0025 \left(\frac{L}{D}\right) \frac{2L - 1}{(3 - L_2)\bar{L}_2} \frac{M_o}{F} \qquad (3.6\text{-}14)$$

where:

$$\bar{L}_2 = \frac{FL_2}{M_o}\ ;\ \bar{L} = \frac{FL_1}{Mo}\ ;\ D = \text{Pipe diameter (in.)}.$$

Verification of the energy balance method by comparison with results obtained by finite difference calculations is documented in Tables 3.6-8 and 3.6-9 for a series of circumferential break models of the type shown in Figure 3.6-15 (item b). The tables compare restraint displacements given by the two methods. In all cases the bending strain in the pipe at the restraint as calculated by the finite difference program is less than half the strain at ultimate stress for this material.

3.6.2.2.2.2.6 Finite Difference Analysis

A finite difference formulation specialized to the case of a straight beam and neglecting axial inertia and large deflection effects is used for the analysis of pipe whip of stainless steel pipes. The dynamic analysis is performed by direct numerical time integration of the equations of motion.

The equations of motion are of the form:

$$h\ (p_k - m_k\ \ddot{y}_k) = -\ M_{k+1} + 2M_k - M_{k-1} \qquad (3.6\text{-}15)$$

where:

- h is the node spacing
- P_k is the externally applied lateral loads at node k
- m_k is the lumped mass at node k
- $\ddot{y}_k$ is the lateral deflection at node k

and

- M_k is the internal resisting moment in the beam at node k.

Power law moment-curvature relationship is assumed and the central difference approximation for the curvature,

$$1 / h^2(-Y_{k+1} + 2y_k - Y_{k-1})$$

is used.

A timewise central-difference scheme is used to solve the dynamic equations

$$y(t + \Delta t) = \Delta t^2 \ddot{y}(t) + 2y(t) - y(t - \Delta t) \quad (3.6\text{-}16)$$

and for the first time step

$$y(\Delta t) = \Delta t^2 \ddot{y}(0) \quad (3.6\text{-}17)$$

A time step equal to 1/10 the shortest period of vibration is used in the integration.

3.6.2.2.2.2.7 Elastic-Plastic Moment Curvature Law

The pipe is assumed to obey an elastic-strain hardening plastic moment-curvature law with isotropic strain hardening. The symbols used are defined as follows:

M	= Moment
$\overline{M}$	= current yield moment
E	= elastic modulus of material at temperature
I	= moment of inertia
Z	= EI
ϕ	= Curvature
ϕ_c	= M/Z = elastic curvature
$\Delta\phi_p$	= increment of plastic curvature
ϕ_p	= $\Sigma\lvert\Delta\phi\rvert$ = effective plastic curvature
ϕ_o	= $\Sigma\ \Delta\phi\rho$ = permanent set curvature

At the end of each integration step new values of ϕ are calculated at each node.

The known values of ϕ_p, ϕ_o, and $\overline{M}$ at the start of the step are used to calculated M, $\overline{M}$, and $\Delta\phi_p$ by the following procedure:

if $|\phi - \phi_o| < \overline{M}/Z$

$$M = Z\ (\phi - \phi_o)$$

and

$$\Delta\phi_p = 0$$

if $|\phi - \phi_o| > \overline{M}/Z$

$$M = \overline{M} = F(|\phi - \phi_o| + \phi_p)\ \text{sign}\ (\phi - \phi_o) \text{ and } \Delta\phi_p = \phi - \phi_o - \overline{M}/Z$$

where $F(\phi) = K(\phi)n.$

3.6.2.2.2.2.8 Power Law Moment Curvature Relationship

The following stress strain law is assumed in the plastic range:

$$\sigma = K(\varepsilon)^n \tag{3.6-18}$$

The corresponding moment-curvature law is

$$M = K(\phi)^n \tag{3.6-19}$$

where:

$$K = \frac{2\sqrt{\pi}}{3+n}(R_o^{3+n} - R_i^{3+n})\frac{\Gamma(1/2n+1)}{\Gamma(1/2n+3/2)}\bar{K} \tag{3.6-20}$$

or, to a good approximation:

$$K = \frac{4\bar{K}}{3+n}(1 - .291n - .076\,n^2)(R_o^{3+n} - R_i^{3+n}) \tag{3.6-21}$$

in which:

R_o = pipe outside radius
R_i = pipe inside radius

In the elastic range the moment-curvature law is:

$$M = EI\phi \tag{3.6-22}$$

The transition from elastic to plastic behavior on initial loading occurs at:

$$\phi = \frac{(EI)}{K}^{\frac{1}{n-1}} \tag{3.6-23}$$

3.6.2.2.2.2.9 Strain Rate Effects

The effect of strain rate in carbon steel is accounted for by using a rate dependent stress strain law of the form

$$\sigma(\varepsilon,\dot{\varepsilon}) = \left[1 + \frac{\dot{\varepsilon}}{(40.4)}\right]^{1/5} G(\varepsilon)$$

where G(ε) is the static stress-strain relationship. For stainless steels, the effect of strain rate is less pronounced so that a 10% increase in yield and ultimate strengths is used. The selection of material properties is discussed in Attachment B3.6.

3.6.2.2.2.2.10 Restraint Behavior

The analysis is capable of handling the bilinear or power law restraint behavior as shown in Figure 3.6-18. The behavior of the restraint is unidirectional. The restraint unloads elastically only to zero state, being left with a permanent set, and reloads along the same curve as shown in Figure 3.6-18.

3.6.2.2.2.3 Method of Dynamic Analysis of Unrestrained Pipes

The impact velocity and kinetic energy of unrestrained pipes is calculated on the basis of the assumption that the segments each side of the break act as rigid-plastic cantilever beams subject to piecewise constant blowdown forces. The hinge location is fixed either at the nearest restraint or at a point determined by the requirement that the shear at an interior plastic hinge is zero. The kinetic energy of an accelerating cantilever segment is equal to the difference between the work done by the blowdown force and that done on the plastic hinge. The impact velocity V is found from the expression for the kinetic energy:

$$KE = (1/2)\ M_{eg} V_I^2$$

where M_{eg} is the mass of the single degree of freedom dynamic model of the cantilever. The impacting mass is assumed equal to M_{eg}.

3.6.2.3 Dynamic Analysis Methods to Verify Integrity and Operability

3.6.2.3.1 Reactor Coolant Loop Pipe Whip Restraints and Jet Deflectors

As discussed in Subsection 3.6.2.1.1, the dynamic effects of postulated pipe breaks in the reactor coolant loop primary piping, accumulator line piping, and reactor coolant loop bypass piping can be eliminated from the structural design basis. Therefore, whip restraints or jet deflectors are not required.

3.6.2.3.2 Pipe Whip Restraints Inside Containment

This subsection applies to pipe whip restraints for all piping other than the reactor main coolant piping which connects the reactor vessel, the main coolant pumps, and the steam generators.

The methodology employed in the analysis of pipe whip is explained in detail in Subsection 3.6.2. Standard Review Plan

3.6.2 is followed. As discussed in the previous section, plant design features eliminate most pipe whip concerns.

Break locations have been defined for all high energy lines following the procedures in Standard Review Plan Section 3.6.2. Structural, piping, electrical and equipment target locations have been identified in the vicinity of the breaks and the potential for damage assessed. Restraints have been added where required to protect the plant structure or systems.

The main steam and feedwater systems are of significant concern due to the large size and high pressure.

In the remaining systems for which high energy line breaks must be postulated (CV, AS, SD, WX, AB systems), the lines in many cases are not highly stressed or do not have the potential of impacting safety systems.

3.6.2.3.2.1 General Description of Pipe Whip Restraints

Pipe whip restraints are designed and installed such that they do not offer thermal or seismic constraint/restraint to any piping. This is accomplished by providing adequate clearances and gaps to ensure that pipe whip restraints influence the piping only if a break should occur. Since all restraints are of an "unmovable" design and maximum piping temperatures are not in the creep range, the clearances and gaps established during installation will not change over the life of the plant. Therefore, there is no need for a procedure for ensuring that throughout the life of the plant, the restraints will not adversely affect the stresses in the pipes on which the restraints are installed.

Pipe whip restraints are provided to protect the plant against the effects of whipping during postulated pipe break. The design of pipe whip restraints is governed not only by the pipe break blowdown thrust, but also by functional requirements, deformation limitations, properties of whipping pipe and the capacity of the support structure. A pipe whip restraint consists of basically a ring around the pipe and components supporting the ring from the supporting structure. The diameter of the ring is established considering the pipe diameter, maximum thermal movement of pipe, thickness of insulation, and an additional 1/2 inch for installation tolerance. The restraint is designed for the impact force induced by the gap between the ring and the pipe.

This impact energy is usually too high for any elastic restraint system or support structure to absorb. Therefore energy absorbing measures designed by the energy balance approach (impact energy + external work = internal energy of pipe-restraint-structure system), are provided.

Pipe whip restraints on the Byron/Braidwood projects utilize a tension-compression system in which the legs of the restraints function as elements in a truss. The energy absorbing material is utilized only in taking compression loads in the restraint leg which is in compression under a given loading condition. The energy absorbing material (EAM) is not assumed to take any lateral load in the analysis of the restraints. However, during compression of the EAM in certain configurations, an angularity of load results. The effects of this angularity are considered to be minor.

3.6.2.3.2.2 Pipe Whip Restraint Components

Pipe whip restraints consist of the following components:

a. Energy Absorption Members - Members that under the influence of impacting pipes (pipe whip) absorb energy by significant plastic deformations (e.g., rods, and crushable honeycomb material).

b. Connecting Members - Those components which form a direct link between the pipe and the structure (e.g., ring and components other than energy absorption members).

c. Structural Attachments - Those fasteners which provide the method of securing the restraint connecting members to the structure (e.g., weld attachment).

d. Structural Components - Steel and concrete structures which ultimately carry the restraint load. Design criteria are specified in Section 3.8.

3.6.2.3.2.3 Design Loads

Restraint design loads, the reactions and the corresponding deflections are established using the criteria delineated in Subsection 3.6.2.2.2.2.

3.6.2.3.2.4 Allowable Stresses

The allowable stresses are as follows:

a. For energy absorption members - 0.95 Fy with 0.5 ε_u strain for steel in tension, where Fy is considered 15% higher than the Fy established according to the static test specified by ASTM and ε_u is the ultimate strain of steel at 0.16; and 6 ksi with 0.5 strain for crushable honeycomb in compression.

   The higher value for the allowable stress for energy absorbing tension steel members is comprised of the 10% dynamic increase factor in addition to a 5% increase factor for strain hardening effects.

This value is only 5% above the acceptable value (10%) which is given in Paragraph III.2.a of Standard Review Plan 3.6.2.

The energy balance method is used as the basis for pipe whip restraint analysis. The restraint resistance is assumed to be elastic-perfect plastic. In actuality, the material undergoes strain hardening much below 50% of the ultimate strain. The assumed 5% increase representing the strain hardening effect based on equivalent energy is a lower bound estimate and therefore conservative. Hence, the 5% increase in allowable stress above which is given in SRP Section 3.6.2 is acceptable.

The design of honeycomb material was based on energy absorption principles. The deflection is controlled by the design energy. The honeycomb material thickness is designed such that the strain under this deflection is less than approximately 50% of the ultimate strain and lies within the horizontal portion of the stress strain curve of the material. This ensures that the honeycomb material will not experience a deflection in excess of that defined by the horizontal portion of the load deflection curve.

Test specimens were taken from each lot of honeycomb material and precrushed to determine its actual dynamic crush strength and dynamic strain. The dynamic crush strength is maintained at ± 7% for at least 95% of the minimum usable strain. To ensure that energy absorption requirements are met, an adjusted cross-sectional area is determined based on the actual dynamic crush strength and dynamic strain.

b. For connecting member - 1.6 times the AISC allowable stress but not to exceed 0.95 Fcr where Fcr is Fy for bending and 0.55 Fy for shear, except for compression members, the allowable stress is 0.9 times the buckling stress Fbu as follows:

Fbu = 5/3 x Fa x DIF

where: 5/3 = Lower bound factor of safety in AISC for compression stress

Fa = AISC allowable compression stress

DIF = Dynamic increase factor = 1.1

c. For structural attachments and structural components - allowable stresses are the same as item b.

3.6.2.3.2.5 Design Criteria

The unique features in the design of pipe whip restraint components relative to the structural steel design are geared to the loads used and the allowable stresses. These are as follows:

a. Energy absorption members are designed for the reaction and the corresponding deflection established according to the pipe size and material and the blowdown force using the criteria delineated in Subsection 3.6.2.2.2.2.

b. Connecting members are designed for 1.25 times the reaction to ensure that the deflection required occurs in the energy absorption members instead of the connecting members.

c. The structural components and structural attachments are designed for 1.8 times the reaction. The 1.8 factor is the maximum dynamic load factor for 7% damping given in ASCE, Structural Design of Nuclear Plant Facilities, Volume 1-B, 1975, Page 1508.

3.6.2.3.2.6 Materials

The materials used are as follows:

a. For energy absorption members - ASTM A-193 Grade B7 for tension rods; and crushable honeycomb made of stainless steel for compression.

b. For other components - ASTM A-588, ASTM A572 Grade 50, and ASTM A36. Charpy tests are performed on materials subjected to impact loads and lamination tests are performed on members subjected to through thickness tension.

3.6.2.3.2.7 Jet Impingement Shields

The results of the HELB analysis of the as-built condition of piping outside containment have indicated that jet impingement shields are not required at Byron/Braidwood with the exception of shields for a small number of dampers in the boundary wall between the Turbine Building and the adjacent Auxiliary Building rooms that provide protection from Turbine Building HELBs.

3.6.2.3.3 Criteria for Protection Against Postulated Pipe Breaks in Reactor Coolant System Piping

A loss of reactor coolant accident is assumed to occur for a branch line break down to the restraint of the second normally open automatic isolation valve (Case II in Figure 3.6-23) on outgoing lines (Note: It is assumed that motion of the unsupported line containing the isolation valves could cause failure of the operators of both valves to function) and down to and including the second check valve (Case III in Figure 3.6-23) on incoming lines normally with flow. A pipe break beyond the restraint or second check valve will not result in an uncontrolled loss of reactor coolant if either of the two valves in the line close. Accordingly, both of the automatic isolation valves are suitably protected and restrained as close to the valves as possible so that a pipe break beyond the restraint will not jeopardize the integrity and operability of the valves. Further, periodic testing capability of the valves to perform their intended function is essential. This criterion takes credit for only one of the two valves performing its intended function. For normally closed isolation or incoming check valves (Cases I and IV in Figure 3.6-23) a loss of reactor coolant accident is assumed to occur for pipe breaks on the reactor side of the valve.

Branch lines connected to the reactor coolant system are defined as "large" for the purpose of this criteria if they have an inside diameter greater than 4 inches up to the largest connecting line, generally the pressurizer surge line. A break of these lines results in a rapid blowdown from the reactor coolant system and protection is basically provided by the accumulators and the low head safety injection pumps (residual heat removal pumps).

Branch lines connected to the reactor coolant system are defined as "small" if they have an inside diameter equal to or less than 4 inches. This size is such that emergency core cooling system analyses using realistic assumptions show that no clad damage is expected for a break area of up to 12.5 in^2 corresponding to 4-inch inside diameter piping.

Engineered safety features are provided for core cooling and boration, pressure reduction, and activity confinement in the event of a loss of reactor coolant or steam or feedwater line break accident to ensure that the public is protected in accordance with 10 CFR 100 guidelines for accidents analyzed using TID-14844 or Regulatory Guide 1.183 for accidents using AST. These safety systems have been designed to provide protection for a reactor coolant system pipe break of a size up to and including a double ended break of the reactor coolant system main loop.

In order to assure the continued integrity of the vital components and the engineered safety systems, consideration is given to the consequential effects of the pipe break itself to the extent that:

a. The minimum performance capabilities of the engineered safety systems are not reduced below that required to protect against the postulated break.

b. The containment leaktightness is not decreased below the design value if the break leads to a loss of reactor coolant. (Note: The containment is here defined as the containment structure liner and penetrations and the steam generator shell, the steam generator steam side instrumentation connections, the steam, feedwater, blowdown, and steam generator drain pipes within the containment structure.)

3.6.2.3.3.1 Large Reactor Coolant System Piping

a. Propagation of damage resulting from a break of the main reactor coolant loop is permitted to occur but must not exceed the design basis for calculating containment and subcompartment pressure, loop hydraulic force, reactor internals reactor loads, primary equipment support loads, or ECCS performance.

b. Large branch line piping, as defined in Subsection 3.6.2.3.3, is restrained to meet the following criteria in addition to items a and b of Subsection 3.6.2.3.3.

    1. Propagation of the break is permitted to occur only within the limits of Table 3.6-4.

    2. Where restraints on the lines are necessary in order to prevent impact on and subsequent damage to the neighboring equipment or piping, restraint type and spacing are chosen such that a plastic hinge of the pipe at the two support points closest to the break is not formed.

3.6.2.3.3.2 Small Branch Lines

In the unlikely event that one of the small pressurized lines, as defined in Subsection 3.6.2.3.3, should fail and initiate a loss-of-coolant accident, the piping is restrained or arranged to meet the limits of Table 3.6-4 in addition to items a through b in Subsection 3.6.2.3.3.1.

3.6.2.3.3.3 Protective Provisions for Vital Equipment

In addition to pipe restraints, barriers and layout are used to provide protection from pipe whip, blowdown jet, and reactive forces.

Some of the barriers utilized for protection against pipe whip are the following. The secondary shield wall serves as a barrier between the reactor coolant loops and the containment liner. In addition, the refueling cavity walls, the operating floor, and the secondary shield wall, enclose each reactor coolant loop into a separate compartment, thereby preventing an accident which may occur in one loop from affecting another loop or the containment liner. The portion of the steam and feedwater lines within the containment have been routed behind barriers which separate these lines from all reactor cooling piping. The barriers described above will withstand loadings caused by jet forces and pipe whip impact forces.

Other than for the emergency core cooling system lines, which must circulate cooling water to the vessel, the engineered safety features are located outside the secondary shield wall. The emergency core cooling system lines which penetrate the secondary shield wall are routed around and outside the secondary shield wall to penetrate the secondary shield wall in the vicinity of the loop to which they are attached.

It has been demonstrated by Westinghouse Nuclear Energy System tests that lines hitting equal or larger size lines of same schedule will not cause failure of the line being hit e.g., a 1-inch line, should it fail, will not cause subsequent failure of a 1-inch or larger size line. The reverse, however, is assumed to be probable i.e., a 4-inch line, should it fail and whip as a result of the fluid discharged through the line, could break smaller size lines such as neighboring 3-inch or 2-inch lines. In this case, the total break area is less than 12.5 in^2.

Alternately, if the layout is such that whipping of the two free sections cannot reach equipment or other pipes for which protection is required, plastic hinge formation is allowed. As another alternative, barriers are erected to prevent the whipping pipe from impacting on equipment or piping requiring protection. Finally, tests and/or analyses are performed to demonstrate that the whipping pipe will not cause damage in excess of acceptable limits.

Whipping in bending of a broken stainless steel pipe section as used in the reactor coolant system does not cause this section to become a missile. This design basis has been demonstrated by Westinghouse Nuclear Energy Systems bending tests on large and small diameter, heavy and thin walled stainless steel pipes.

The methods described below are used in the Westinghouse design and verification of adequacy of primary reactor coolant loop components and supports. It is emphasized that these methods are used only to determine jet impingement loads on components and supports and are not used for design and checking of walls, barriers, cable trays, etc. Although the dynamic effects of postulated pipe breaks in the reactor coolant loop primary piping, accumulator line piping, and reactor coolant loop bypass piping can be eliminated from the structural design basis (see Subsection 3.6.2.1.1), the design verification of certain components and supports may retain the original jet impingement loadings. For these cases, the following subsection describes the methods used in the analysis.

The design-basis postulated pipe break locations for the reactor coolant loop piping are determined using the criteria given in Subsection 3.6.2. These design basis breaks are used here as the break locations for consideration of jet impingement effects on primary equipment and supports.

The dynamic analysis, as discussed in Subsection 3.6.2.2.1.3, is used to determine maximum piping displacements at each design-basis break location. These maximum piping displacements are used to compute the effective break flow area at each location. This area and break orientation are then used to determine the jet flow pattern and to identify any primary components and supports which are potential targets for jet impingement.

The jet thrust at the point of the break is based on the fluid pressure and temperature conditions occurring during normal (100%) steady-state operating conditions of the plant. At the point of the break, the jet force is equal and opposite to the jet thrust. The force of the jet is conservatively assumed to be constant throughout the jet flow distance. The subcooled jet is assumed to expand uniformly at a half-angle of 10° from which the area of the jet at the target and the fraction of the jet intercepted by the target structure can be readily determined.

The shape of the target affects the amount of momentum change in the jet and thus affects the impingement force on the target. The target shape factor is used to account for target shapes which do not deflect the flow 90° away from the jet axis.

The method used to compute the jet impingement load on a target is one of the following:

a. The dynamic effect of jet impingement on the target structure is evaluated by applying a step load whose magnitude is given by

$$F_j = K_o \; P_o \; A_{mB} \; RS$$

where:

F_j	=	jet impingement load on target
K_o	=	dimensionless jet thrust coefficient based on initial fluid conditions in broken loop
P_o	=	initial system pressure
A_{mB}	=	calculated maximum break flow area
R	=	fraction of jet intercepted by target
S	=	target shape factor.

Discharge flow areas for limited flow area circumferential breaks are obtained from reactor coolant loop analyses performed to determine the axial and lateral displacements of the broken ends as a function of time. A_{mB} is the maximum break flow area occurring during the transient, and is calculated as the total surface area through which the fluid must pass to emerge from the broken pipe. Using geometrical formulations, this surface area is determined to be a function of the pipe separation (axial and transverse) and the dimensions of the pipe (inside and outside diameter).

If a simplified static analysis is performed instead of a dynamic analysis, the above jet load (F_j) is multiplied by a dynamic load factor. For an equivalent static analysis of the target structure, the jet impingement force is multiplied by a dynamic load factor of 2.0. This factor assumes the target can be represented as essentially a one degree of freedom system and the impingement force is conservatively applied as a step load.

The calculation of the dimensionless jet thrust coefficient and break flow area is discussed in Subsection 3.6.2.5.

b. The dynamic effect of jet impingement is evaluated by applying the following time-dependent load to the target structure.

$$F_j = K\ P\ A_{mB}\ RS$$

where the system pressure P is a function of time; the jet thrust coefficient K is evaluated as a function of system pressure and enthalpy; and the break flow area A_{mB} is a function of time.

3.6.2.3.3.4 Pipe Restraints and Locations

Reactor coolant loop pipe restraints are discussed in Subsection 3.6.2.3.1.

3.6.2.3.3.5 Design Loading Combinations

As described in Section 3.9, the forces associated with the break of reactor piping systems are considered in combination with normal operating loads and earthquake loads for the design of supports and restraints in order to assure continued integrity of vital components and engineered safety features. Although the dynamic effects of postulated pipe breaks in the reactor coolant loop primary piping, accumulator line piping, and reactor coolant loop bypass piping can be eliminated from the structural design basis (see Subsection 3.6.2.1.1), the design verification of certain structures and components may retain the original pipe break loadings.

The stress limits for reactor coolant piping and supports are discussed in Section 3.9.

3.6.2.4 Guard Pipe Assembly Design Criteria

Guard pipe assemblies were utilized in the design of the Byron and Braidwood Stations for the recirculation sump piping and the fuel transfer tube. The guard pipes on these moderate energy lines are used to ensure containment integrity.

The guard pipe for the recirculation sump piping extends from the recirculation sump to the sump suction valve protection chamber. A seal ring exists between the guard pipe and the recirculation sump piping which serves as the containment boundary. The seal rings are subjected to Appendix J leakage testing as part of the containment integrated leak rate test. The section of guard pipe and seal ring that serve as the containment boundary are classified as ASME Section III, Class MC. The sump suction valve protection chamber and the section of guard pipe that extends beyond the containment boundary are classified as ASME Section III, Class 2.

The guard pipe for the fuel transfer tube extends along the length of the fuel transfer tube from the inside of containment, through the containment wall, to the outside of containment. The portion of the guard pipe from the containment liner of the 3'-6" wall, across the bellows towards the inside of containment, including the end flange of the tube on the inside of containment, then back towards the containment liner, serves as the containment boundary. This section of guard pipe is classified as ASME Section III, Class MC and is subjected to Appendix J leakage testing as part of the local leak rate testing program. The remainder of the guard pipe is maintained as ASME Section III, Class MC, but is not subject to hydrostatic testing or code stamping.

3.6.2.5 Dynamic Analysis Applicable to Postulated High Energy Pipe Break

3.6.2.5.1 Reactor Coolant Loops

a. The dynamic effects of postulated pipe breaks in the reactor coolant loop primary piping, accumulator line piping, and reactor coolant loop bypass piping can be eliminated from the structural design basis (see Subsection 3.6.2.1.1). The RHR line and pressurizer surge line connections remain as postulated break locations. These two locations are not eliminated by the reactor coolant loop or the accumulator line piping and reactor coolant loop bypass piping LBB analysis.

b. Design loading combinations and applicable criteria for ASME Class 1 components and supports are provided in Subsection 3.6.2.3.3.5. Pipe break loads include not only the jet thrust forces acting on the piping but also jet impingement loads on the primary equipment and supports.

c. The interface between Sargent & Lundy and Westinghouse concerning the design of the primary equipment supports and the interaction with the primary coolant loop is described in Subsection 3.9.3.4.4.1.

3.6.2.5.2 Postulated Breaks in Piping Other than Reactor Coolant Loop

The following material pertains to dynamic analyses completed for piping systems other than the reactor main coolant piping which connects the reactor vessel, the main coolant pumps, and the steam generators.

3.6.2.5.2.1 Implementation of Criteria for Defining Pipe Break Locations and Configurations

The locations and number of design basis breaks, including postulated break orientations, for the high energy piping systems are shown in Figures 3.6-25 through 3.6-99.

The above information was derived from the implementation of the criteria delineated in Subsection 3.6.2.1.

Stress levels and usage factors (usage factors for Class 1 piping only) for the postulated break locations are shown in Tables 3.6-11 and 3.6-12.

For Turbine Building HELBs, the selection of pipe break locations and configuration are described in UFSAR Sections 3.6.2.a for the environmental analysis, and 3.6.2.2 for the evaluation of pipe whip and jet impingement effects.

3.6.2.5.2.2 Implementation of Criteria Dealing with Special Features

Special protective devices in the form of pipe whip restraints and impingement shields are designed in accordance with Subsection 3.6.2.3.

Inservice inspection is discussed in Subsection 3.6.1.2.2.

3.6.2.5.2.3 Acceptability of Analyses Results

The postulation of break and crack locations for high and moderate energy piping systems and the analyses of the resulting jet thrust, impingement and pipe whip effects has conservatively identified areas where restraints, impingement shields, or other protective measures are needed and has yielded the conservative design of the required protective devices.

Results of jet thrust and pipe whip dynamic effects are given in Tables 3.6-13 and 3.6-14.

3.6.2.5.2.4 Design Adequacy of Systems, Components, and Component Supports

For each of the postulated breaks, the equipment and systems necessary to mitigate the consequences of the break and to safely shut down the plant (i.e., all essential systems and components) have been identified (Subsection 3.6.1). The equipment and systems are protected against the consequences of each of the postulated breaks to ensure that their design-intended functions will not be impaired to unacceptable levels as a result of a pipe break or crack.

When it became necessary to restrict the motion of a pipe which would result from a postulated break, pipe whip restraints were added to the applicable piping systems, or structural barriers or walls were designed to prevent the whipping of the pipe.

Design adequacy of the pipe whip restraints is demonstrated in Tables 3.6-13 and 3.6-14. Data in the tables was obtained through use of the criteria delineated in Subsection 3.6.2.1 through 3.6.2.3 inclusive.

The design adequacy of structural barriers, walls, and components is discussed in Section 3.8.

For Turbine Building HELBs, pipe whip as a result of a HELB is not a concern. There are no safety related components in the Turbine Building that are required for safe shutdown of the Unit that can be impacted by pipe movement (including jet thrust.) Additionally, if a pipe were to damage another high- or moderate-energy line, the pressure in the Turbine Building from the first break would have caused the dampers protecting the adjacent auxiliary building rooms to isolate. Therefore, a second break would not increase the environmental conditions in the rooms containing the safety-related equipment.

There are high- and moderate- energy piping subsystems in the vicinity of the L-Line wall separating the Turbine Building from the Auxiliary Building and the dampers and doors integral to L-Line wall. L-Line wall is a concrete re-enforced wall 42" in depth (a safety related, Seismic Category I structure). Although a pipe hitting the wall could cause surface damage to the concrete, the strength and thickness of the wall would prevent structural failure of the wall. For the dampers and doors integral to L-Line wall, the evaluation has determined that the doors and dampers would not be adversely impacted by pipe whip.

3.6.2.5.2.5 Implementation of the Criteria Related to Protective Assembly Design

Guard pipes or protective assembly designs were utilized in the design of the Byron and Braidwood Stations only for the containment penetrations for the fuel transfer tube and the recirculation sump piping. The guard pipes on these moderate energy lines are used to ensure containment integrity.

3.6.3 References

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