# US-APWR

# Methodology of Pipe Break Hazard Analysis

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# Abstract

This report sets down the protection design standard for pipe rupture protection in US-APWR, specifies the piping to be postulated pipe rupture, positions of postulated pipe ruptures, pipe rupture types, phenomena to be considered as affected by pipe ruptures and the calculation method for loads to evaluate strengths, and describes the policy to design structural strengths and the policy to evaluate strengths which enable the equipment, piping, electric instrumentation and structures to maintain their functions.

Pipe rupture protection design is implemented to conform to 10 Code of Federal Regulations ("CFR") Part50, Appendix-A, General Design Criteria ("GDC") 4. Evaluation requirements and design policy are shown specifically in this standard based on the concept of deep-layered protection at nuclear plant.

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# List of Acronyms

The following list defines the acronyms used in this document.

| | |
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| ASME | American Society of Mechanical Engineers |
| CFR | Code of Federal Regulations |
| GDC | General Design Criteria |
| LBB | leak before break |
| LOCA | loss-of-coolant accident |
| MHI | Mitsubishi Heavy Industries, Ltd. |
| NRC | U.S. Nuclear Regulatory Commission |
| OBE | operating-basis earthquake |
| RCL | Reactor Coolant Loop |

## 1.0 INTRODUCTION

Appendix A of 10 CFR 50, GDC 4 (Reference 1), requires that structures, systems, and components (SSCs) be designed to accommodate the effects of and to be compatible with the environmental conditions associated with the normal operation, maintenance, testing, and postulated accidents, including the LOCA. This section deals with the protection against the dynamic effects of postulated pipe break accidents, specifically in the localized regions of the pipe break, including pipe whip, jet impingement, subcompartment pressurization, and fluid system decompression in the ruptured pipe. In addition, the environmental effects, spray wetting, and flooding are also addressed in this section.

The criteria used to evaluate pipe failure protection are generally consistent with the NRC guidelines including those in NUREG-0800, SRP 3.6.1, 3.6.2, and 3.6.3 (References 2, 3, and 4), and applicable Branch Technical Position (BTP) 3-4 and BTP 3-3 (References 5 and 6).

## 2.0 BASIC POLICY IN PROTECTIVE DESIGN

In order to maintain the safety of plant when pipe rupture is postulated, the following items shall basically be met in the design of plant including the arrangement and pipe design.

### 2.1 Maintaining functions

Following design shall be implemented against the direct or indirect effects by pipe ruptures.

a. Engineering safety facilities and related facilities required in cooling the core shall not impair their functions.

b. Reactor shutdown system (Note) shall not impair its function.

(Note) System designed to be equipped with the function to shift to low-temperature shutdown from high-temperature shutdown and maintain the shutdown condition by inserting negative reactivity into reactor from output operation condition to put the reactor in less than criticality.

c. Range shall not be impaired; range designed to become a pressure barrier and also form a pressure barrier against the diffusion of radioactive substances in the loss-of- coolant accident (piping and valve forming the reactor containment vessel and containment vessel boundary).

d. Central control room shall not impair its function and interior comfort.

e. Containment integrity is maintained.

### 2.2 Prevention of expansion of accidents

The following design shall be implemented to prevent accidents from expanding.

a. Primary coolant pipe, etc. must not provide cause to rupture the main feedwater pipe or secondary pipe.

b. Ruptures of secondary pipes for main steam and main feedwater must not provide cause to rupture the pipes in the primary system such as primary coolant pipe.

c. Rupture of a certain pipe must not provide cause to rupture the reactor coolant pressure boundary or the function of main steam or main feedwater system.

d. In the primary cooling system and the main steam and main feedwater system, ruptures of a certain loop pipe must not affect any other loop.

## 2.3 Design Basis

Essential systems are evaluated for conformance to the following design bases and susceptibility to pipe failure effects.

A. The selection of the failure type is based on whether the system is high or moderate-energy during normal operating conditions of the system as defined in item B, below. High-energy fluid systems are defined to be those systems or portion of systems that, during normal plant conditions, are either in operation or are maintained pressurized under conditions where either or both of the following are met:

a. Maximum operating temperature exceeds 200°F

b. Maximum operating pressure exceeds 275 psig

Moderate-energy fluid systems are defined to be those systems or portion of systems that, during normal plant conditions are either in operation or maintained pressurized (above atmospheric pressure) under conditions where both of the following are met:

a. Maximum operating temperature is 200°F or less.

b. Maximum operating pressure is 275 psig or less.

Piping systems are classified as moderate-energy systems when they operate as high-energy piping for only short periods in performing their system function but, for the major portion of their operational period, qualify as moderate–energy fluid systems. An operational period is considered short if the total fraction of time that the system operates within the pressure-temperature conditions specified for high-energy fluid systems is less than 2% of the total time that the system operates as a moderate-energy fluid system.

Table 1 identifies systems which contain high- and moderate-energy lines.

B. The pressure-temperature condition in the fluid when the postulated piping failure occurs determines the magnitudes of the fluid reaction forces. The technical basis used to determine the state of the fluid is as follows:

1. For piping sections that are operating at a pressure greater than atmosphere, the thermodynamic state is assumed to be the one associated with normal full power operation.

2. For the piping sections that are pressurized during normal plant operating modes other than the design power generation, such as during hot standby, start up, shut down, and refueling, the thermodynamic state is assumed as operating mode that gives the worst fluid reaction forces. For high energy lines as defined in item A above, if the piping sections are pressurized to the high

energy level only for 2% of the total operating time, such piping sections are considered as moderate energy and not evaluated for high energy pipe failure.

3. High-stress-based postulated pipe rupture locations are determined based on calculated stresses due to Level A service loading (normal loads) and Level B service loading (normal plus operational transients) without contribution of seismic loads since operating basis earthquake is eliminated from the explicit design considerations. However, postulated pipe rupture locations based on fatigue effects will include seismic cyclic effects.

C. For longitudinal and circumferential pipe breaks, evaluations are performed for dynamic effects, such as pipe whip, jet impingement, and subcompartment pressurization, as well as those of environmental conditions, flooding, and spray wetting. For leakage cracks, evaluations for environmental condition, flooding and spray wetting are performed. Additionally, when leak before break ("LBB") criteria are successfully applied, evaluation of dynamic effects is not required.

D. Circumferential and longitudinal breaks of the main steam and feedwater lines are not postulated in the break exclusion zones. However, the effects of flooding, spray wetting, and subcompartment pressurization are evaluated for a postulated 1.0 sq. ft. break for the main steam and feedwater lines at a location that has the greatest effect on essential equipment.

E. Each postulated piping failure event (pipe break or crack) is considered as a single initial event during normal plant operation. For systems not analyzed for seismic considerations, it is assumed that a SSE event will cause pressure boundary failure at any location.

F. Offsite power is assumed to be unavailable if a trip of the turbine-generator system or reactor protection system is a direct consequence of the postulated piping failure. Also, offsite power is assumed unavailable during and following seismic events.

G. A single active component failure is assumed in systems used to mitigate consequences of the postulated piping failure and to shut down the reactor, except as noted in item H below. The single active component failure is assumed to occur in addition to the postulated piping failure and any direct consequences of the piping failure, such as unit trip and loss of offsite power.

H. Where the postulated piping failure is assumed to occur in one of two or more redundant trains of a dual-purpose moderate-energy essential system (e.g., one required to operate during normal plant conditions as well as to shut down the reactor and mitigate the consequences of the postulated piping failure), single active failures of components in the other train or trains of that system or other systems necessary to mitigate the consequences of the piping failure and shut down the reactor need not be assumed, provided the systems are designed to seismic Category I standards, are powered from both offsite and onsite sources, and are constructed, operated, and inspected to quality assurance, testing, and ISI standards appropriate for nuclear safety systems.

I. All available systems, including those actuated by operator actions, may be employed to mitigate the consequences of a postulated piping failure. In judging the availability of systems, consideration of the postulated failure and its direct consequences, such as unit trip and loss of offsite power, are assumed together with an assumed single active component failure and its direct consequences. The feasibility of carrying out operator actions is judged on the basis of ample time and adequate access to equipment being available for the proposed actions. For breaks in non-seismic piping systems, only seismically-qualified systems are assumed to be available to mitigate the consequences of the failure since a seismic event may have caused the pipe break.

J. Rapid motion of the pipe whip resulting from postulated pipe break is assumed to occur in the plane determined by the piping geometry. The direction of the movement is in the direction of jet reaction force.

If a thrust force causes a whipping pipe to impact a flat surface normal to its direction of travel, the direction of the initial pipe movement is assumed to rest against that surface, without any pipe whip in other directions.

Pipe whip restraints are provided when the whipping pipe could impair the capability of any essential system or component to perform its intended function. Pipe whip restraints are located within the length of location of plastic hinge formation when permissible. If it is not possible to locate the whip restraint within the length of plastic hinge, the consequences of pipe whipping and jet impingement effect are further investigated.

K. The pipe break reaction force and jet impingement force calculation considers the fluid internal energy considering any line restrictions (that is, flow limiter) between the pressure source and break location and the absence of energy reservoirs, as applicable.

L. Jet loads resulting from postulated pipe break in a high pressure steam system (pressure greater than 870 psia) or sub-cooled water which would flash at the break, are evaluated as follows:

1. Any directly impacted component within 10 pipe diameters is assumed to fail, unless the components is required for safe shutdown and accident mitigation capability in which case the jet loads are computed and evaluated based on the criteria given in Section 7.0.

2. Based on NUREG CR-2913 (Reference 8), components beyond 10 pipe diameter range are properly evaluated based on the computed jet impingement force.

M. By definition, a non-essential system is not required for safe shutdown of the nuclear plant following a postulated pipe rupture accident scenario and as such, it is not required to be evaluated for pipe rupture protection. However, if a non essential system or a portion of it, which is affected by a specific piping failure event that could potentially affect an essential system or component, then it is evaluated for pipe rupture protection per the rules of this section.

N. The environmental effects of a postulated piping failure do not preclude habitability of the MCR or access to surrounding areas important to the safe control of reactor operations needed to cope with the consequences of the piping failure.

The capability of all essential components to perform their intended safety functions is maintained.

## 2.4 Safety Evaluation

### 2.4.1 General

Safety evaluations assess safety-related systems and components for the adequacy of their intended protective actions and measures in the event of postulated pipe failures, including those required to mitigate the consequences of the failure. Protective measures include separation, barriers, and restraints as discussed below.

### 2.4.2 Basic Protection Measures

#### 2.4.2.1 Separation

Separation by distance, compartments or enclosures is used as much as practicable to protect redundant safety-related systems and trains. Deliberate separation protects against the dynamic effects of postulated pipe failures of the systems and components. Redundant safety systems and components are arranged to prevent the loss of the safety function as a result of a postulated pipe failure.

A multi-step process is used to develop the placement of safety-related systems and components which consider the following means for separation.

- Wherever practical, locate safety-related systems away from high-energy piping
- Locate redundant safety systems in separate compartments
- If necessary, enclose specific components required to function as a result of a postulated pipe failure
- Design drainage routing and flood control to maintain adequate separation from equipment required to function as a result of a postulated pipe failure

Each of the four safety trains are separated into four quadrants around the outside of the PCCV. Each train is isolated by physical barriers as well as isolating the radiological control area from the non-radiological control area of the R/B. The concrete walls are designed to prevent events on one safety train from impacting another train. The segregation also includes segregation of fluid containing SSCs of a train from the electrical SSCs of the same train to the extent practical. In general, cable trays are routed at higher elevations than piping. Chases are provided between the cable trays and piping to maintain the electrical/mechanical separation if required. Physically, individual train equipment within the four quadrants is located to provide the maximum separation between the same equipment of the other three trains within the confines of the R/B footprint. This separation minimizes the probability of an event affecting more than one of the safety trains at a given time. Where components must cross between isolating barriers, the penetrations are located above flood levels to the extent possible. In addition, penetration seals maintain compartment to compartment separation.

#### 2.4.2.2 Barriers and Shields

Where physical separation is not sufficient to protect safety-related systems and components from postulated pipe failures, structural elements such as walls, floors, columns, and foundations are designed to serve as protective barriers and shields whenever possible. Other barriers, deflectors or shields are provided where additional protection is required. The barriers, including compartments as applicable, are designed to withstand loading generated by postulated jet forces and pipe whip impact forces in combination with loadings associated with seismic Category I requirements, within the respective design load limits for the structures. Refer to Section 6.0 for additional discussion on the design of barriers, deflectors and shields.

Portions of the containment internal structure provide a series of protective barriers. The reactor coolant loops ("RCLs") are shielded from the containment liner by the secondary shield wall. Redundancy of each loop of the reactor coolant system is also maintained by barriers formed by the secondary shield wall, refueling cavity walls, and operating deck. The combination of physical separation and robust barriers also protects the steam and feedwater lines against possible adverse interactions with the RCL.

#### 2.4.2.3 Piping Restraints

Piping restraints are provided for postulated pipe ruptures where unrestrained movement of either end of the ruptured pipe could adversely impact SSCs, which are required to mitigate the effects of the pipe failure. Refer to Section 6.0 for methods of analysis of pipe whip restraints.

### 2.4.3 Specific Protection Measures

#### 2.4.3.1 Subcompartment Pressurization

Analyses of postulated pipe breaks of high-energy piping is performed to determine the subcompartment's pressurization response. Locations of postulated pipe breaks are determined in accordance with Section 3.0.

High-energy piping and piping evaluated for LBB requirements are identified in Appendix 1. The subcompartments inside the PCCV are designed to accommodate the pressurization loads from the breaks in lines that are not qualified for LBB.

The CVCS makeup piping is classified as high energy due to its design pressure, but does not cause pressurization because it operates at ambient temperature.

The reactor vessel (RV) annulus (volume between the RV and biological shield wall below elevation 46 ft, 11 in.) is evaluated for asymmetric compartment pressurization, and the RV is evaluated for asymmetric pressurization. These pressures are assumed to develop based on a postulated pipe break in the largest RCS line that is not qualified for LBB.

The potential for pressurization from high-energy lines in the R/B is limited, and the localized effects are considered where applicable. The pressurization loads for the elevation 65'-0" PCCV penetration room containing the break exclusion zone are based on an assumed non-mechanistic longitudinal break with a one square foot break from either main steam or feedwater line.

#### 2.4.3.2 MCR Habitability

MCR habitability is evaluated for adverse effects resulting from postulated pipe breaks and cracks within the R/B. The remote shutdown workstation is not subject to postulated pipe ruptures.

There are no high-energy lines near the MCR. The closest high-energy lines to the MCR are in the main steam pipe room and are part of the break exclusion areas. The MCR is separated from the isolation valve compartment by two structural floors. The area between the two floors is used for heating, ventilation, and air conditioning components associated with the MCR. The floors separating the HVAC compartment room from the main steam isolation valve compartment are thick, reinforced concrete floors. Refer to Section 3.0 for discussion applicable to PCCV penetrations in the main steam pipe room.

The main steam pipe room is evaluated using criteria for the evaluation of a one square foot longitudinal break in a break exclusion area. This location is evaluated for the effects of flooding, spray wetting, and subcompartment pressurization resulting from a postulated one square foot break of either a main steam or feedwater line. The MCR is not affected by any of the effects of a postulated break of this piping.

## 3.0 CRITERIA USED TO DEFINE BREAK AND CRACK LOCATION AND CONFIGURATION

The following subsections establish the criteria used for selecting the locations and configuration of the postulated breaks and cracks, except for piping that satisfies the requirements for LBB.

### 3.1 High-Energy Fluid Systems Piping

The designer is to identify each piping run it considers in order to postulate the break locations pursuant to Subsection 3.1.2. In complex systems such as those containing arrangements of headers and parallel piping running between headers, the designer is to identify and include all such piping within a designated run in order to postulate the number of breaks pursuant to these criteria.

#### 3.1.1 High-Energy Fluid System Piping in PCCV Penetration Area

Breaks and cracks need not be postulated in the portions of piping from containment wall to and including the inboard or outboard isolation valves. This portion of piping meets the following criteria.

All piping in the PCCV penetration area defined above is ASME Code, Section III, Class 2 (Reference 9). For ASME Code, Section III, Class 2 piping the following design criteria are met.

(1) The design criteria of the ASME Code, Section III (Reference 10), Subarticle NE 1120, is satisfied for the PCCV penetration.

(2) The maximum stress ranges as calculated by the sum of Equations 9 and 10 in Paragraph NC-3653 of ASME Code, Section III (Reference 9), considering those loads and conditions thereof for which Level A and Level B stress limits have been specified in the system's design specification, does not exceed 0.8(1.8 Sh + SA). The Sh and SA are 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.

(3) The maximum stress in this piping as calculated by Equation 9, of paragraph NC 3653 of ASME Code, Section III (Reference 9) does not exceed the smaller of 2.25 Sh or 1.8 Sy, when subjected to the combined loading of internal pressure, dead weight and postulated pipe rupture beyond this portion of piping, except that following a failure outside containment, the pipe between the outboard isolation valve and the first restraint may be permitted higher stresses provided a plastic hinge is not formed, operability of the valves with such stresses is ensured in accordance with the criteria specified in SRP Section 3.9.3, the piping between the outboard isolation valve and the restraint is constructed in accordance with the Power Piping Code ANSI B31.1 and the piping should either be of seamless construction with full radiography of all circumferential welds or all longitudinal and circumferential welds should be fully radiographed.

Primary loads include those which are deflection-limited by whip restraints.

(4) The number of circumferential and longitudinal piping welds and branch connections are minimized.

(5) Welded attachments, for pipe supports or other purposes, to this portion of piping are avoided. Where welded attachments are necessary, the welds are 100% volumetrically examinable and detailed stress analyses are performed to demonstrate compliance with the limits of Subsection 3.1.2.

(6) 100% volumetric examination in accordance with IWA-2400 of ASME Code, Section XI (Reference 11) of all piping welds is performed.

(7) Anchors or five way restraints do not prevent the access required to conduct inservice examination specified in ASME Code, Section XI (Reference 11). ISI completed during each inspection interval provides examination of circumferential and longitudinal welds within the boundary of this portion of piping.

(8) The length of these portions of piping is to be reduced to the minimum length practical.

Application to Main Steam Pipe Room

No breaks are postulated in the main steam supply system (MSS) and feedwater system (FWS) piping from the PCCV penetration outboard weld to the wall of main steam pipe room (Figure 1) provided the following actions are taken:

• The pipe is routed straight to lower the stresses.

• Five–way restraint (free only in axial direction) is installed in the main steam pipe room wall penetration.

• Essential equipment is protected from the environmental, flooding, and subcompartment pressurization effects of an assumed non-mechanistic longitudinal break. Each assumed non-mechanistic break has a cross sectional area of one square foot and postulated to occur at a location that has the greatest effect on essential equipment.

### 3.1.2 Postulation of Pipe Breaks in Areas Other than PCCV Penetrations

The locations for postulated breaks in high-energy piping are dependent on the classification, quality group, and design standards used for the piping system. The break locations for high-energy piping are described in the following sections. These locations are postulated based on “as-designed” analyses using the design configuration. As a result of piping reanalysis, due to differences between the design configuration and the as-built configuration, the high stress and usage factor location may be shifted. The intermediate break (if any) locations need not be changed unless one of the following conditions exists:

a. The dynamic effects from the new (as-built) intermediate break locations are not mitigated by the original pipe whip restraint and jet shields.

b. There is significant change in pipe design parameters such as pipe size, wall thickness, or pressure rating.

For structures that separate a high-energy line from an essential component, the separating structure is designed to withstand the consequences of the pipe break in the high-energy line, which produces the greatest effect at the structure, irrespective of the fact that the following criteria might not need such a break location to be postulated.

ASME Code, Section III, Division 1 – Class 1 Piping

Pipe breaks are postulated to occur at the following locations in piping and branch runs designed and constructed to the requirements for Class 1 piping in the ASME Code, Section III (Reference 12).

• At terminal ends of the piping, including the following:

– The extremity of the piping connected to structures, components, or anchors that act as essentially rigid restraints to piping translation and rotational motion due to static or dynamic loading.

– Branch intersection points are considered a terminal end for the branch line unless the following are met: the branch and the main piping systems are modeled in the same static, dynamic, and thermal analyses, and shown to have significant effect on the main line behavior (that is, the branch line can not be decoupled from the main run).

– In a piping run that is maintained pressurized during normal plant conditions for only a portion of the run, the terminal end, for the purpose of defining break locations, is the piping connection to the first normally closed valve.

• At the intermediate locations where the following conditions are satisfied:

– Intermediate locations where the maximum stress range as calculated by Equation 10 of Paragraph NB-3653 of the ASME Code, Section III and either Equation 12 or Equation 13 of Paragraph NB-3653.6 of the ASME Code, Section III exceeds 2.4 Sm (where Sm is design stress intensity) (Reference 12).

– Intermediate locations where the cumulative usage factor as determined by the ASME Code, exceeds 0.1.

ASME Code, Section III, Division 1 – Class 2 and Class 3 Piping

Pipe breaks are postulated to occur at the following locations in piping and branch runs designed and constructed to the requirements for Class 2 and 3 piping in the ASME Code, Section III, Division 1 (Reference 9).

• At terminal ends of the piping, using the same definition for terminal ends as for Class 1 pipe.

• At intermediate locations selected by one of the following criteria:

– At each fitting (e.g., elbow, tee, cross, flange, and non-standard fitting), welded attachment, and valve.

– At one location at each extreme of piping run adjacent to protective structure for piping that contains no fittings, welded attachments, or valves.

– At each location where stresses calculated by the sum of Equation 9 and 10 in NC/ND-3653 of ASME Code, Section III, exceed 0.8 times the sum of the stress limits given in NC/ND-3653 (Reference 9).

Non-ASME Class Piping

Breaks in seismically analyzed non-ASME Class piping are postulated according to the same criteria as for ASME Class 2 and 3 piping above.

Separation and interaction requirements between seismically analyzed and non seismically analyzed piping are met.

### 3.1.3 Postulation of Leakage Cracks in Areas Other than PCCV Penetrations

Leakage cracks in high energy piping are postulated as follows:

• For ASME Code, Section III (Reference 12), Division 1, Class 1 piping, at axial locations where the calculated stress range by Equation 10 in NB-3653 exceeds 1.2 Sm.

• For ASME Code, Section III (Reference 9), Division 1, Class 2 and 3 piping, at axial locations where calculated stress by the sum of Equations 9 and 10 in NC/ND-3653 exceeds 0.4 times the sum of the stress limits given in NC/ND-3653.

• For seismically analyzed non-ASME Class piping at the locations defined in the same way as ASME Code, Section III (Reference 9), Class 3 piping.

• For non-ASME Class piping, which has not been evaluated to obtain stress information, leakage cracks are postulated at axial locations that produce the most severe environmental effects.

## 3.2 Moderate-Energy Fluid System Piping Break Locations

Leakage cracks are not postulated in moderate-energy fluid system piping located in an area where a break in the high-energy fluid system is postulated, provided that such a crack does not result in environmental conditions more severe than the high-energy break. If the effects of breaks of moderate-energy fluid system piping are more severe than those of high-energy fluid system piping, then the provision of this Subsection 3.2.2 is applied.

Through-wall leakage cracks instead of breaks may be postulated in the piping of those fluid systems that qualify as high-energy fluid systems for about 2% of the operational period but qualify as moderate-energy fluid systems for the major operational period.

### 3.2.1 Moderate-Energy Fluid System Piping in PCCV Penetration Areas

Leakage cracks are not postulated in those portion of the piping from PCCV wall to and including the inboard and outboard isolation valves provided that the PCCV penetration meets the requirements of ASME Code, Section III (Reference 10), Subarticle NE 1120 and the piping is designed so that the maximum stress range based on the sum of Equations (9) and (10) in Subarticle NC/ND-3653 of the ASME Code, Section III (Reference 9) does not exceed 0.4 times the sum of the stress limits given in NC/ND-3653.

### 3.2.2 Moderate-Energy Fluid System Piping in Areas Other than PCCV Penetrations

Leakage cracks are postulated in the following piping systems located adjacent to SSCs important to safety.

• For ASME Code, Section III, Class 1 piping, where the stress range calculated by Eq. (10) in NB-3653 is less than 1.2 S(m)

• For ASME Code, Section III (Reference 9), Class 2 and 3 and non-safety class piping, at axial locations where calculated stress by the sum of Equations 9 and 10 in NC/ND-3653 exceed 0.4 times the sum of the stress limits given in NC/ND 3653.

• For non-safety class piping, which has not been evaluated to obtain stress information, leakage cracks are postulated at axial locations that produce the most severe environmental effects.

## 3.3 Types of Break/Cracks Postulated

### 3.3.1 Circumferential Pipe Breaks

Circumferential breaks are postulated in high-energy fluid system piping and branch runs exceeding a nominal pipe size of 1 inch at locations identified by the criteria in Subsection 3.1.2

No breaks are postulated in piping having a nominal diameter less than 1 inch, including instrument lines that are designed in accordance with RG 1.11 (Reference 13).

If the maximum stress range exceeds the limits specified in Subsection 3.1.2 and the circumferential stress range is greater than 1.5 times the axial stress range, no circumferential break is postulated; only a longitudinal break (Subsection 3.3.2) is postulated.

Where break locations are selected without the benefit of stress calculations, breaks are postulated at the piping welds to each fitting, valve, or welded attachment. The line restrictions, flow limiters, positive pump-controlled flow and the absence of energy reservoirs may be taken into account, as applicable.

Following a circumferential break, the two ends of the broken pipe are assumed to move clear of each other unless physically limited by piping restraints, structural members, or pipe stiffness. The effective cross sectional (inside diameter) flow area of the pipe is used in the jet discharge evaluation. Pipe whipping is assumed to occur in the plane defined by the piping geometry and configuration and to initiate pipe movement in the direction of the jet reaction.

### 3.3.2 Longitudinal Pipe Breaks

Longitudinal breaks are postulated in high-energy fluid system piping and branch runs in nominal pipe sizes 4 inches and larger. Longitudinal breaks are postulated in high energy fluid system piping at locations of circumferential breaks as described in Subsection 3.3.1.

If the maximum stress range exceeds the limits specified in Subsection 3.1.2 and the axial stress range is greater than 1.5 times the circumferential stress range, no longitudinal break is postulated, only a circumferential break (Subsection 3.3.1) is postulated.

Longitudinal breaks need not be postulated at terminal ends.

Longitudinal breaks in the form of axial split without pipe severance are postulated in the center of the piping at two diametrically opposed points (but not concurrently) located so that the reaction force is perpendicular to the plane of piping configuration and produces out-of-plane bending. Alternatively, a single split is assumed at the section of highest tensile stress as determined by detailed stress analysis (e.g., finite element analysis).

For longitudinal breaks, the dynamic force of the fluid jet discharge is based on a circular or elliptical (2D x 1/2D) break area equal to the effective cross-sectional flow area of the pipe at the break location and on a calculated fluid pressure modified by an analytically or experimentally determined thrust coefficient as determined for a circumferential break at the same location, where D is the effective inner diameter of the pipe. Line restrictions, flow limiters, positive pump-controlled flow, and the absence of energy reservoirs may be 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 pipe stiffness as demonstrated by inelastic limit analysis.

### 3.3.3 Leakage Cracks

Leakage cracks are postulated in high-energy fluid system piping at locations identified in Subsection 3.1.3. Leakage cracks are also postulated in moderate-energy fluid system piping at locations identified in Subsection 3.2.2, except where excluded by the criterion in Subsection 3.2.2.

Leakage cracks are not postulated in 1-inch nominal diameter and smaller piping.

Leakage cracks are postulated in those circumferential directions that result in the most severe environmental, spray wetting, and flooding consequences.

Fluid flow from leakage cracks is based on a circular orifice with a cross-sectional area equal to that of a rectangle one-half the pipe inside diameter in length and one-half the pipe wall thickness in width. The flow from the crack opening is assumed to result in an environment that wets all unprotected components within the compartment, with consequent flooding in the compartment and communicating compartments based on conservatively estimated time period to effect corrective actions.

## 4.0 GUARD PIPE ASSEMBLY DESIGN CRITERIA

Piping penetrations are an integral part of the PCCV pressure boundary. The annular space of the US-APWR consists of multiple compartments encircling the PCCV. These compartments segregate the PCCV electrical and mechanical penetrations into their own isolated compartments; specifically, electrical penetration rooms and mechanical penetration rooms. By virtue of the plant configuration, as piping crosses from inside to outside the PCCV, it emerges into piping penetration compartments. These compartments are designed to address postulated piping failures and the effect there of, as such, guard pipe assemblies are not required.

## 5.0 ANALYTIC METHODS TO DEFINE FORCING FUNCTIONS AND RESPONSE MODELS

The rupture of a pressurized pipe causes the flow characteristics of the system to change, creating reaction forces that can dynamically excite the piping system. To determine the forcing function for breaks postulated based on the criteria in Section 3.0, the fluid conditions at the upstream source and at the break exit determine the analytical approach. For most applications, one of the following situations exists.

• Superheated or saturated steam

• Saturated or sub-cooled water

• Cold water (non-flashing)

The analytical methods used for the calculation of the jet thrust for the above described situations are based on SRP 3.6.2 (Reference 3) and ANSI/ANS 58.2-1988 (Reference 14).

The time dependent forcing function is effected by the thrust pulse resulting from the sudden pressure drop at the initial moment of pipe rupture, the thrust transient resulting from wave propagation and reflection, and the blowdown thrust resulting from the buildup of the discharge flow rate, which may reach a steady state if there is fluid energy reservoir having sufficient capacity to develop a steady jet for a significant interval.

Alternatively, a steady state jet thrust function may be used as outlined in Section 5.1.

A rise time of one millisecond is used for the initial pulse.

The loading condition of a pipe run or branch, prior to the postulated rupture, in terms of internal pressure, temperature, and inertial effects are used in the evaluation for postulated breaks. For piping pressurized during operation at power, the initial condition is the greater of the contained energy at hot standby or at 102% power.

### 5.1 Steady State Jet Force

The steady state jet force can be represented by:

$F_j = C_T P A$ (Reference 14)

where

$F_j$ = Jet Force

$C_T$ = Thrust Factor

$P$ = Pipe Internal Pressure Before Break

A = Break Plane Area

The thrust factor CT is established as a function of fluid state as follows:

(a) Sub-Cooled Water

$$C_T = 2.0-0.861\ h^{*2} \qquad (0 \le h^* \le 0.75)$$

$$= 3.22 - 3.0\ h^* + 0.97\ h^{*2} \qquad (0.75 \le h^* \le 1.0)$$

where

$h^* = (h_0 - 180)/(h_{sat} - 180)$

$h_0$ = Sub-Cooled water enthalpy (BTU/lbm)

$h_{sat}$ = Saturated water enthalpy at pressure P (BTU/lbm)

$C_T$ value varies based on the pressure and enthalpy. In case of saturated water, the minimum value of 1.26 comes closer to maximum value of 2.0 as enthalpy (temperature) decreases. In case of $h_0$ = 180 BTU/lbm (Temperature $T_0$ < 212°F) or lower, condition for sub-cooled, non flashing water value of 2.0 is used.

(b) Saturated water-saturated steam:

Use $C_T$ =1.26

The above approach is a conservative method for calculating the thrust factor. Then, pipe pressure drop and diaphragm effects may be considered and the detailed analysis and experiment data may be applied.

Schematics of jets discharging from a pipe break are shown in Appendix 2.

## 5.2 Time Dependent Break Forcing Function

Time dependent break forcing is applied to RCL piping from postulated pipe breaks in branch lines not included in the LBB. LBB criteria are used to demonstrate that there are no postulated pipe ruptures in the large diameter RCL piping.

A detailed description of the hydraulic transient caused by a postulated pipe rupture is developed for application to the RCL. The thrust and reactive forces resulting from a postulated branch pipe rupture connecting to the RCL are applied in calculating the hydraulic forcing functions for the intact RCL. The RCL forces result from the transient flow and pressure histories in the RCS. A two-step calculation first determines the transient pressure, mass flow rates, and thermodynamic properties as a function of time. The final step calculates the time history of forces at appropriate RCL locations (such as elbows) using the results obtained from the hydraulic analysis, and input of area and directional coordinates.

Hydraulic modeling of the entire RCS results in calculating the pressure, mass flow rate, and density. Time-dependent loads exerted by the fluid on the loops are then determined by applying the pressure, mass flow rate, density to the thrust calculation and plant layout information. Pressure and momentum flux terms become dominant for hydraulic forcing functions during a postulated loss-of-coolant accident ("LOCA"). Local fluid conditions in the hydraulic model utilize the inertia and gravitational terms.

The reactor core environment is dynamically analyzed using a blowdown hydraulic analysis to determine the loop forces. A blow-down hydraulic analysis computer code is used to calculate RCS hydraulic transients from predicted flow, quality and pressure of the fluid throughout the system.

The equation for determining blowdown hydraulic loads on primary loop components is:

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

where

| | | |
|---|---|---|
| F | = | Forces (lbs) |
| A | = | Area of aperture (ft$^2$ ) |
| P | = | Pressure of system (psia) |
| $\dot{m}$ | = | Mass flow rate (lbm/s) |
| $\rho$ | = | Density (lbm/ft$^3$) |
| g | = | Pull force constant (gravitational speed) = 32.174 ft-lbm/lb -s$^2$ |
| $A_m$ | = | Mass flow area (ft$^2$) |

The RCL is modeled similarly to the model used in blowdown analysis for the purpose of computing forcing functions. A global coordinate system is developed for the entire loop layout, where each mode is then described by blowdown hydraulic information and the streamline force node orientation in the system. The flow areas and projection coefficients are described along the three axes of the global coordinate system. Each node is described by one or two flow apertures as a separate control volume. Forces are broken down orthogonally into x, y, and z components. The summation of the total number of apertures results in orthogonal thrust forces Fx, Fy, and Fz. These thrust forces are applied as input in dynamic analyses of piping and restraints.

## 6.0 DYNAMIC ANALYSIS METHODS TO VERIFY INTEGRITY AND OPERABILITY

Time dependent and steady state thrust reaction loads caused by saturated or superheated steam, saturated or sub-cooled water, and cold water (non-flashing) fluid from a ruptured pipe are used in the analyses of dynamic effects of pipe breaks.

### 6.1 Jet Impingement Loading on Safety-Related Components

Structural integrity of safety-related SSCs against jet impingement load caused by pipe break is evaluated based on steady state jet force from Section 5.0.

Jet impingement loading is a suddenly applied constant load which can have significant energy content. These loads are generally treated as statically applied loads.

The methods used to evaluate the jet effects resulting from the postulated breaks in high energy piping are described in Appendices C and D of ANSI/ANS 58.2 (Reference 14). Appendix 2 depicts jet characteristics for the three fluid states. The short term response evaluates the jet impingement load considering a dynamic load factor of 2 and snubber supports to be active. No dynamic load factor is used and the snubbers are considered inactive for the long-term response.

### 6.2 Dynamic Analysis for Piping Systems

#### 6.2.1 RCL Piping

Loads generated by postulated breaks from branch lines are applied to determine structural response of RCL piping.

#### 6.2.2 Piping Other Than RCL Piping

In evaluating the dynamic effects of breaks in high-energy-fluid system piping other than RCL piping, possible break locations and break configurations are first established based on Section 3.0 and the effects of pipe whipping are then evaluated based on Section 6.5.

If the above evaluation determines that no safety-related SSCs are damaged, then dynamic analysis is not necessary. If the above evaluation determines that the structural integrity of safety-related SSCs is impaired, pipe whip restraints are incorporated in the high energy-fluid system piping of concern and dynamic analysis is conducted for the system including the piping and the pipe whip restraints.

In general, a gap is provided between a pipe whip restraint and pipe so as not to restrict thermal movement in the pipe. In the event of a pipe-break accident, the pipe accelerates in the gap due to the jet force and collides with the pipe whip restraint. The dynamic effects of this pipe and pipe whip restraint are usually evaluated by the energy balance method.

Conservatively assuming a fixed jet force at maximum load as described in Section 5.0, the maximum displacement of the pipe and pipe whip restraint can be given by the following equation based on the energy balance method.

[work done on system] = [energy absorbed by pipe + energy absorbed by restraint] (1)

Generally, in Equation (1), energy absorbed by the system is conservatively ignored so that the maximum displacement of the pipe and pipe whip restraint is given by the following equation.

work done on system = energy absorbed by restraint (2)

See Subsection 6.4.1 for the design methodology for pipe whip restraints.

When making a more detailed evaluation to analyze the dynamic effects associated with pipe rupture events on the broken pipe, a non-linear elastic-plastic analysis is performed. In this model, restraints specifically designed to prevent pipe whip are included, i.e. pipe whip restraints. The normal supports that act during plant operational loads, including seismic events to maintain the integrity of the unbroken pipe, are not considered unless they are capable of withstanding pipe rupture loads based on a broken pipe analysis.

The five-way restraint is installed for main steam piping and feedwater piping outside of the PCCV to prevent a load from being applied to the CV isolation valve due to a postulated pipe break outside of break exclusion zone.

In other cases, the subject valve is installed sufficiently away from a postulated break location to prevent dynamic effects. Furthermore, the pipe stress in the vicinity of the valve is validated as very small by using a static force displacement methodology for the pipe displacement at the break location.

### 6.2.3 Closure of the Feedwater Check Valve

This loading has a short duration of approximately 0.5 seconds and arises from rapidly traveling pressure waves in piping systems connected to the broken piping system. The closure of the feedwater check valve due to a postulated pipe rupture upstream of the valve can increase the magnitude of these loads.

For piping systems with closing check valves, the magnitude of the loadings depends on the valve closure time, with shorter closing times generally causing higher loadings.

The maximum internal pressure and the kinetic energy of the valve disc at the time of closure are used to assure the pressure boundary integrity of the piping. The RELAP-5 code (Reference 15) can be used to calculate the pressure and kinetic energy in this loading situation.

## 6.3 Subcompartment Pressure Forces

Subcompartment pressure forces are considered in the evaluation of structures and components. The code GOTHIC (Reference 16) may be used to calculate the pressure transients in the building subcompartments. The subcompartment pressure forces are determined by integrating the pressure transient over the surface of the structure or component. Jet impingement forces, when applicable, are considered additive to subcompartment pressure forces.

### 6.4 Pipe Whip Restraints, Barriers and Shields

This section provides analytical methods used to verify integrity and operability of the safety-related SSCs needed to safely shutdown the plant, that are nearby the postulated pipe breaks. The analytical methods apply to the following structures:

• Whip restraint

• Jet impingement barriers and shields

#### 6.4.1 Pipe Whip Restraints

The analytical methods for the design of the pipe whip restraints are described in this subsection.

When pipe whip restraints are required to satisfy protection requirements, the following guidelines are followed to select the type of restraint.

To satisfy varying requirements of available space, allowable building structure reaction, permissible pipe deflection, and equipment operability, the restraint may be a combination of an energy absorbing element and a restraining structure suitable for the geometry required to transfer the load from the whipping pipe to the main building structure or a relatively rigid steel frame to restrain the whipping pipe.

A typical rupture restraint is shown in Figure 2. The restraint structure is typically a structural steel frame or truss and the energy absorbing element is one of the following:

• U-Bar (One-Dimensional Restraint):

– This is a U-shaped rod or flat plate, usually of carbon steel, looped around the pipe but not in contact with the pipe to allow unimpeded pipe movement during normal operation and a seismic event. At rupture, the pipe converges with the U-Bar(s), which absorbs the kinetic energy of the pipe by yielding plastically.

• Structural Steel (Two-Dimensional Restraint):

– This is a structural steel frame assembly enveloping the pipe but not in contact with the pipe that allows unimpeded pipe motion during normal operation and a seismic event. At rupture, pipe converges with the structural steel frame and the frame, which deflects plastically, absorbing the kinetic energy of the pipe.

Pipe whip restraints used to protect SSCs are designed as seismic Category I.

Loads to be evaluated in combination with pipe break forces are Level A or B service loads and are not combined with seismic loads. Seismic loads are independently considered to confirm the structural integrity of the pipe whip restraint if the restraint becomes in contact with the pipe during the seismic event. In the evaluation of structures, loads producing primary stresses are used.

#### 6.4.1.1 Location of Pipe Whip Restraints and Analytical Methods

A. To determine the pipe hinge location, the plastic moment of the pipe is determined in the following manner.

$$MP = 1.1\ ZP \times SY$$

where

ZP = Plastic section modulus of pipe

SY = Yield stress at pipe operating temperature

1.1 = 10% factor to account for strain hardening

Pipe whip restraints are located as close to the axis of the reaction thrust force break as practicable, but within the length of location of plastic hinge. When it is not possible to locate the whip restraint within the length of plastic hinge, the consequences of the whipping pipe and the jet impingement effect are further investigated.

B. Pipe whip restraints are installed with sufficient annular clearance between them and the process pipe. This provides sufficient clearance for insulation and thermal and seismic movement of the pipe during normal plant operation.

If restraint also functions as a seismic support, the restraint is included in the piping analysis.

C. Restraints generally must not impede the access required to carry out the ISI of pipe welds. If the position of any restraint impedes the access to the pipe welds, part of the restraint can be removed to assure the accessibility.

#### 6.4.1.2 Analysis and Design of Pipe Whip Restraint

The analysis and design of the pipe whip restraints for the effects of postulated pipe rupture conform to the following criteria.

A. Pipe whip restraints are designed based on the principle of energy absorption by considering the behavior of material’s elasticity/plasticity and strain hardening.

B. Coefficient of rebound 1.1 is applied to jet thrust forces.

C. Energy absorption by the broken pipe is assumed to be zero, except in the case of calculating to check the formation of a plastic hinge. The developed thrust force is assumed to be applied to move a broken pipe directly, and is not reduced by the forces required to bend the pipes.

D. In the elasticity/plasticity design, the kinetic energy of the pipe is absorbed by the restraint by yielding plastically. The strain in the restraint is limited as shown below.

$$e = 0.5\varepsilon_u$$

where

e = Allowable strain used in the design

$\varepsilon_u$ = Ultimate homogeneous tensile strain.

### 6.4.2 Jet Impingement Barriers and Shields

Barriers or shields are provided to protect essential equipment, including instrumentation, from the effects of jet forces resulting from postulated pipe breaks. Generally, protection provided by walls, floors, and columns is sufficient to meet protection requirements.

### 6.4.3 Pipe Whip Impact on Structures

The evaluation of structures that are impacted by whipping pipes is described below.

Following a postulated pipe rupture, pipe whip into surrounding structures will occur, if the pipe is not sufficiently restrained. The level of energy in the whipping pipe may be determined by calculating work quantities using simplified methods. The external work is calculated by multiplying the break force acting on the whipping pipe by the distance (from its initial position, before the pipe break, to the final position when the pipe impacts the structure) traveled by that break force.

As the impact occurs on concrete targets, the section of the pipe near the impact area is rapidly decelerated and crushed. The magnitude and the duration of the impact loading are determined by characteristics of both the whipping pipe and the concrete barrier. In the evaluation of the target, both local and overall response is considered. The evaluation procedures are as described in References 17, 18, 19, and 20. For impact into concrete, the concrete ductility ratio is calculated for this impact, and it is assumed to be within the limits. The evaluation of the response of steel targets relies on empirical formulae established from test data. Various formulae and their range of application are described in Reference 18.

If the whipping pipe impacts another pipe, the evaluation criteria are provided below.

- A whipping pipe is not considered capable of damaging an impacted pipe of equal or greater diameter and thickness. It is considered capable of (a) rupturing impacted pipes of smaller nominal pipe sizes, and (b) developing through-wall leakage cracks in pipe of equal or greater diameter having a lesser wall thickness (Reference 14), except where analytical or experimental, or both, data for the expected range of impact energies demonstrate the capability to withstand the impact without rupture. Effects on environment and shutdown logics associated with the failure of the impacted pipe are considered.

# 7.0 IMPLEMENTATION OF CRITERIA DEALING WITH SPECIAL FEATURES

Special features such as pipe whip restraints, barriers, and shields are discussed in Section 6.4.

## 8.0 REFERENCES


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3 Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants. NUREG-0800, SRP 3.6.2, Rev.2, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

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18 Roemer, R.E. et al., Evaluation of Pipe Whip Impact on Concrete Barriers-A Simplified Approach. Proceeding of Second ASCE Conference on Civil Engineering and Nuclear Power, Volume IV (Impactive and Impulsive Loads), 1980.

19 Enis, R.O. et. al., A Design Guide for Evaluation of Barriers for Impact from Whipping Pipes. Proceeding of Second ASCE Conference on Civil Engineering and Nuclear Power, Volume IV (Impactive and Impulsive Loads), 1980.

20 Report of the ASCE Committee on Impactive and Impulsive Loads. Second ASCE Conference on Civil Engineering and Nuclear Power, Volume V, 1980.

### Table 1 High and Moderate Energy Fluid Systems

| System | High-Energy(1) | Moderate-Energy(1) |
|---|---|---|
| Reactor Coolant System (RCS) | X | - |
| Chemical and Volume Control System (CVCS) | X | - |
| Safety Injection System (SIS) | X | - |
| Residual Heat Removal System (RHRS) (2) | - | X |
| Emergency Feedwater System (EFWS) (2) | - | X |
| Feedwater System (FWS) | X | - |
| Main Steam Supply System (MSS) | X | - |
| Containment Spray System (CSS) | - | X |
| Component Cooling Water System | - | X |
| Spent Fuel Pit Cooling and Purification System (SFPCS) | - | X |
| Essential Service Water System (ESWS) | - | X |
| Gaseous Waste Management System (GWMS) | - | X |
| Liquid Waste Management System (LWMS) | - | X |
| Solid Waste Management System (SWMS) | - | X |
| Sampling System (SS) | X | - |
| Steam Generator Blowdown System (SGBDS) | X | - |
| Refueling Water Storage System (RWS) | - | X |
| Primary Makeup Water System (PMWS) | - | X |
| Auxiliary Steam Supply System (ASSS) | X | - |
| Instrument Air System (IAS) | - | X |
| Fire Service System (FSS) | - | X |
| Station Service Air System (SSAS) | - | X |
| Chilled Water System (VCWS) | - | X |

Notes

1. High-energy piping includes those systems or portions of systems in which the maximum normal operating temperature exceeds 200°F or the maximum normal operating pressure exceeds 275 psig.

   Piping systems or portions of systems pressurized above atmospheric pressure during normal plant conditions and not identified as high-energy are considered as moderate-energy.

   Piping systems that exceed 200°F or 275 psig for two percent or less of the time during which the system is in operation are considered moderate-energy.

2. The RHRS and EFWS lines are classified as moderate-energy based on the 2 percent rule. These lines experience high-energy conditions for less than 2 percent of the system operation time. The portions of the RHR system from the connections to the RCS to the first closed valve in each line are high-energy.

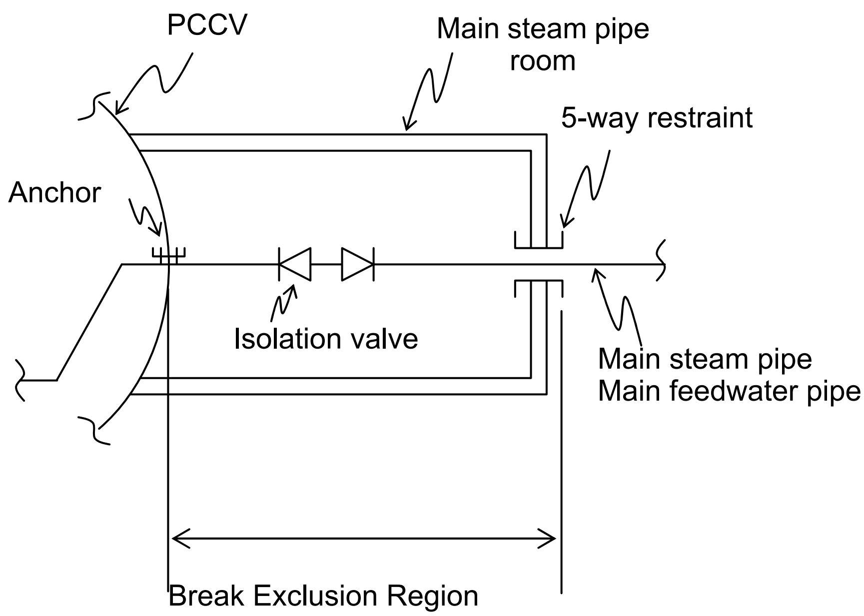
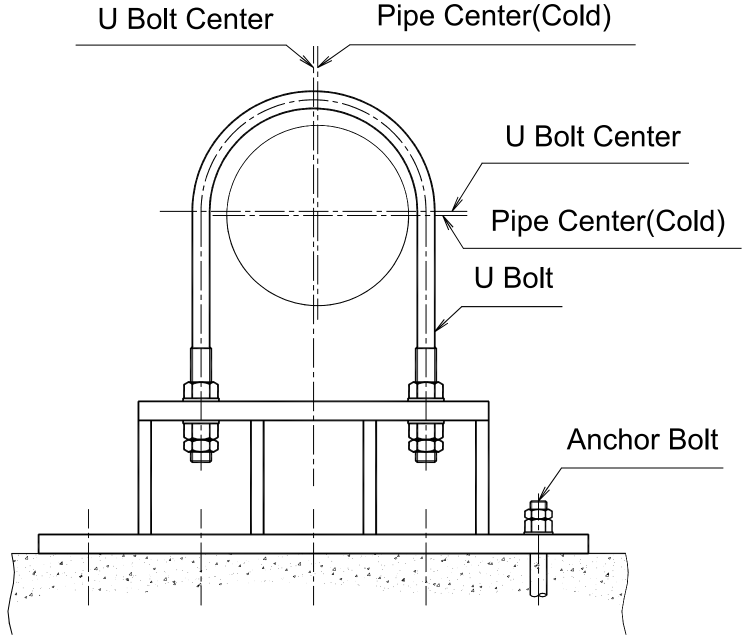
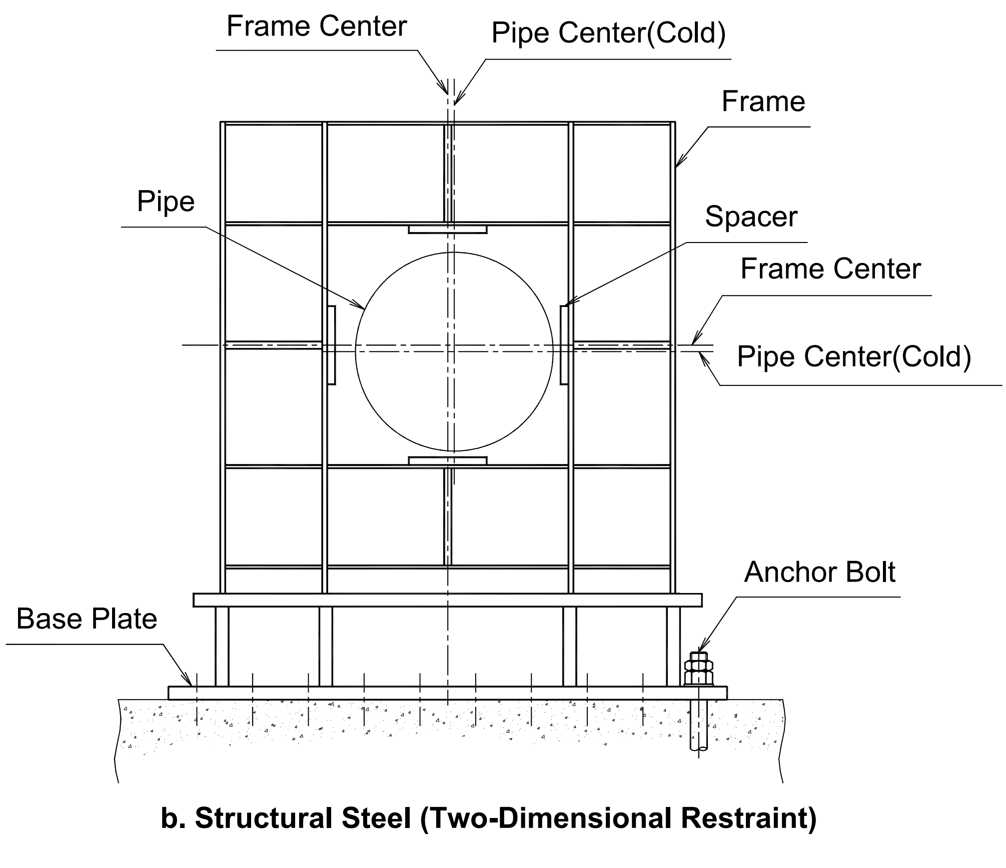



**Figure 1 Break Exclusion Region- Main Steam Pipe Room**




**a. U-Bar (One-Dimensional Restraint)**




**b. Structural Steel (Two-Dimensional Restraint)**

**Figure 2 Typical Rupture Restraints**

# Appendix 1 High Energy and Moderate Energy Piping in the Prestressed Concrete Containment Vessel and Reactor Building

## 1 INTRODUCTION

This appendix identifies high-energy piping in the prestressed concrete containment vessel (PCCV) and reactor building (R/B) with a diameter greater than 1 inch. Piping selected for leak-before-break (LBB) criteria are also identified in these figures. These figures identify piping in the break exclusion zones outside containment. One inch piping and smaller are not included in these figures. Instrumentation and instrument lines are not included.

High-energy piping includes those systems or portion of systems that, during normal plant operating conditions, are either in operation or maintained pressurized at operating temperature that exceed 200°F or the maximum operating pressure 275 psig. Piping systems or portion of systems pressurized above atmospheric pressure during normal plant conditions and not identified as high-energy are considered moderate energy. Piping systems that exceed 200°F or 275 psig for 2% or less of the time during which the system is in operation are considered moderate energy. Breaks in high-energy piping greater than 1 inch are postulated based on the criteria provided in Section 3.0. Breaks are not postulated in high-energy piping system meeting the LBB criteria.

LEGEND:

| | | | | Candidate LBB Piping

High Energy Break Exclusion Zone Piping
(diameter is greater than 1 inch)

Other High Energy Piping in PCCV and R/B
(diameter is greater than 1 inch)

△ Boundary

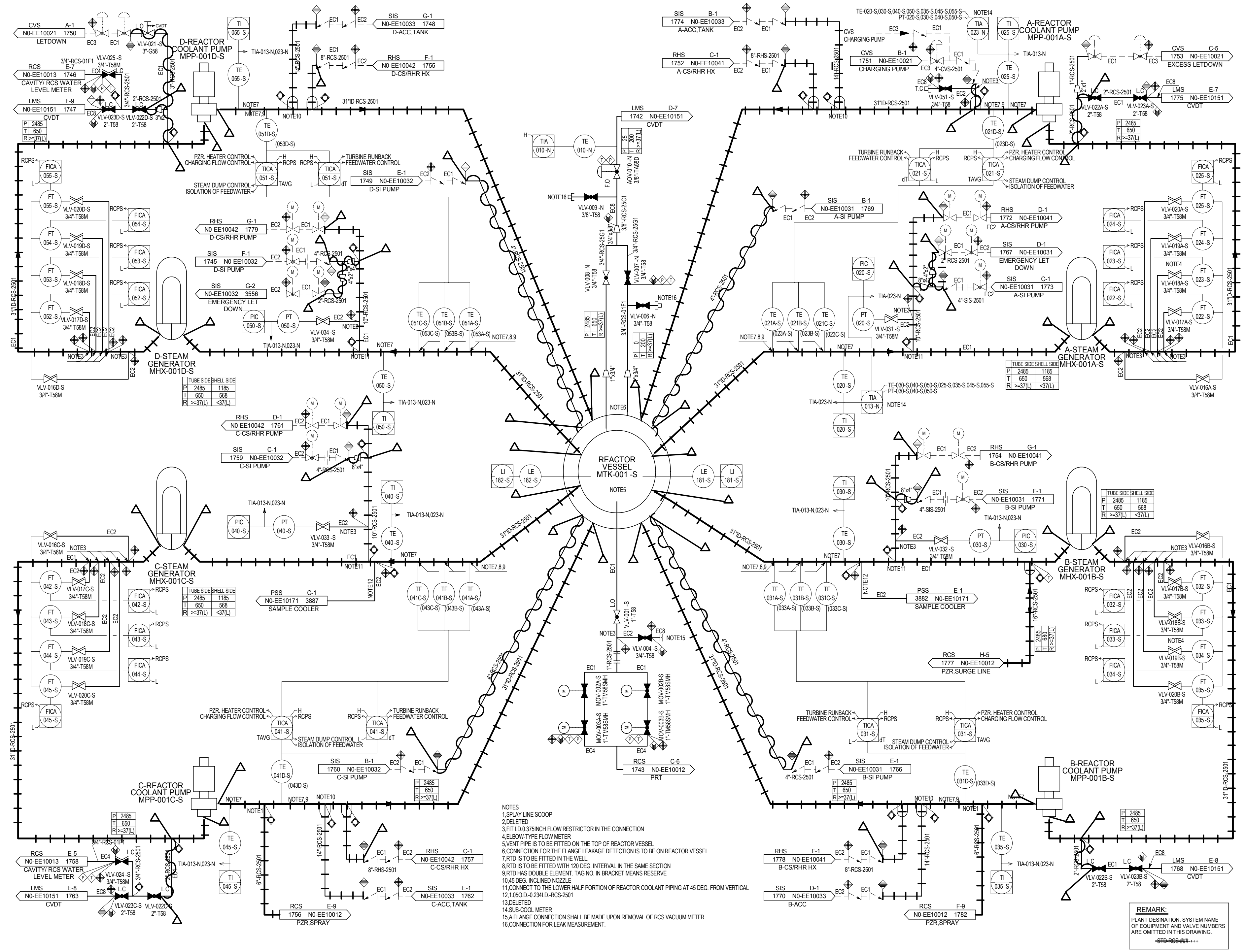


Figure A1-1 Reactor Coolant System Flow Diagram (1/2)

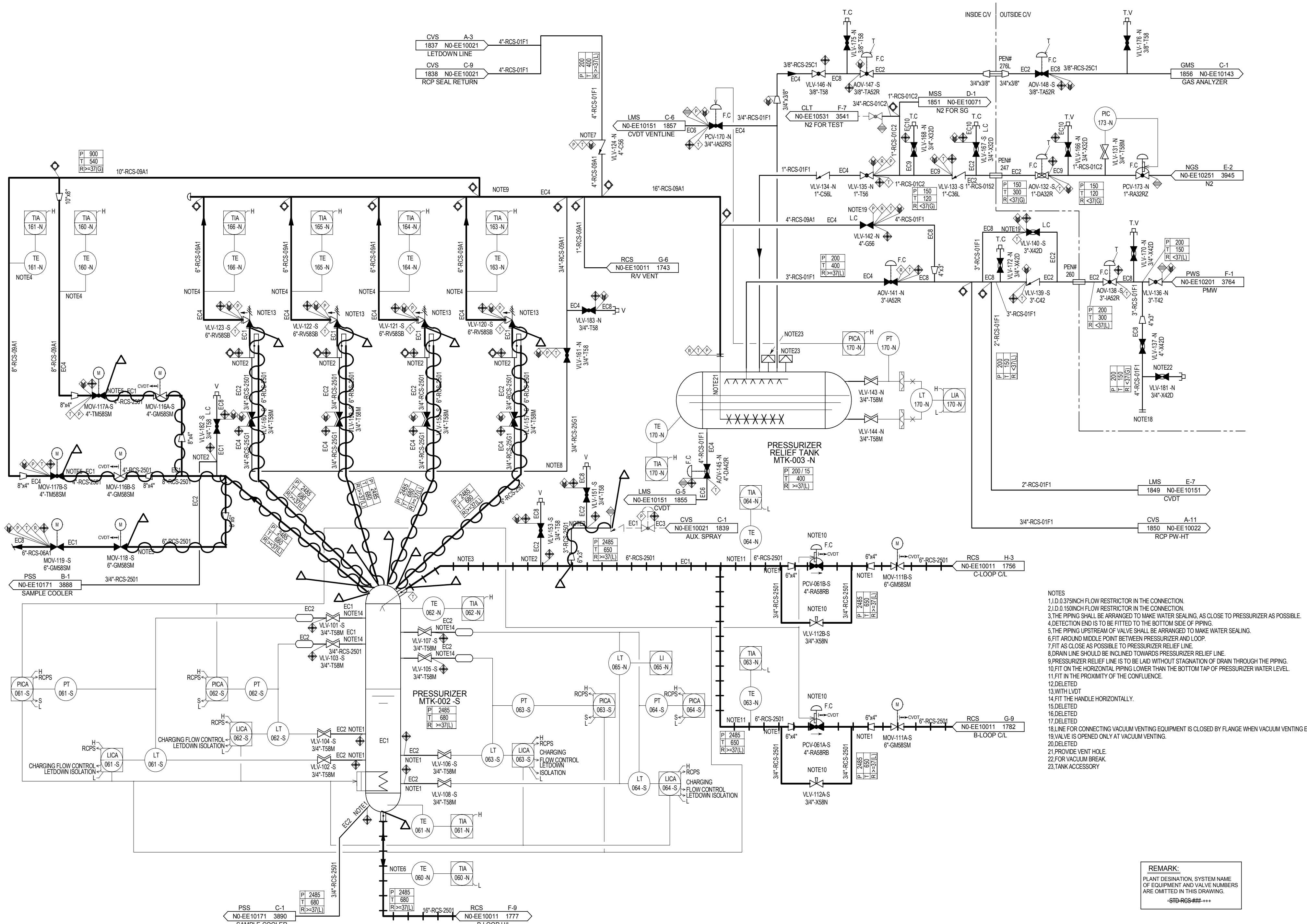



Figure A1-2 Reactor Coolant System Flow Diagram (2/2)

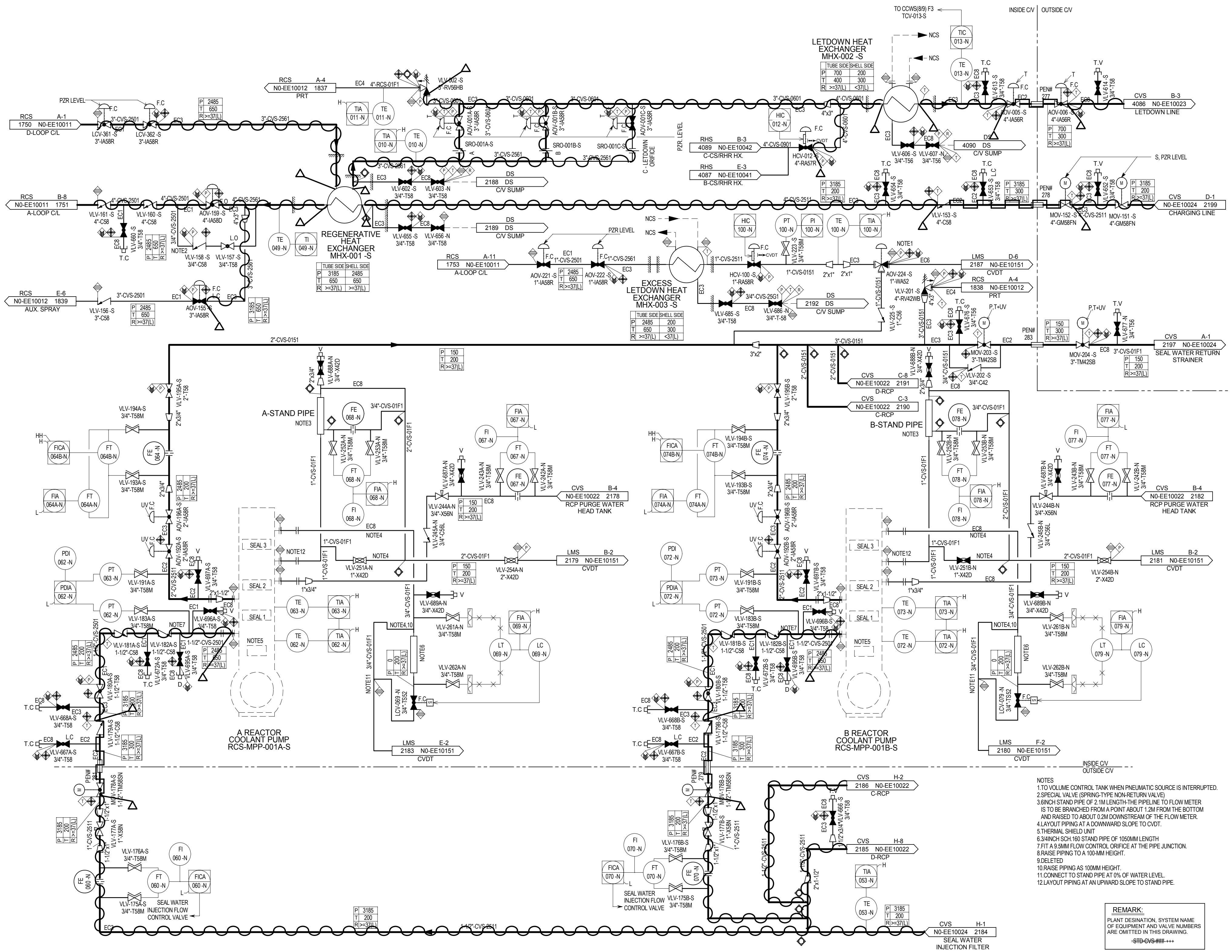



**Figure A1-3 Chemical and Volume Control System Flow Diagram (1/4)**

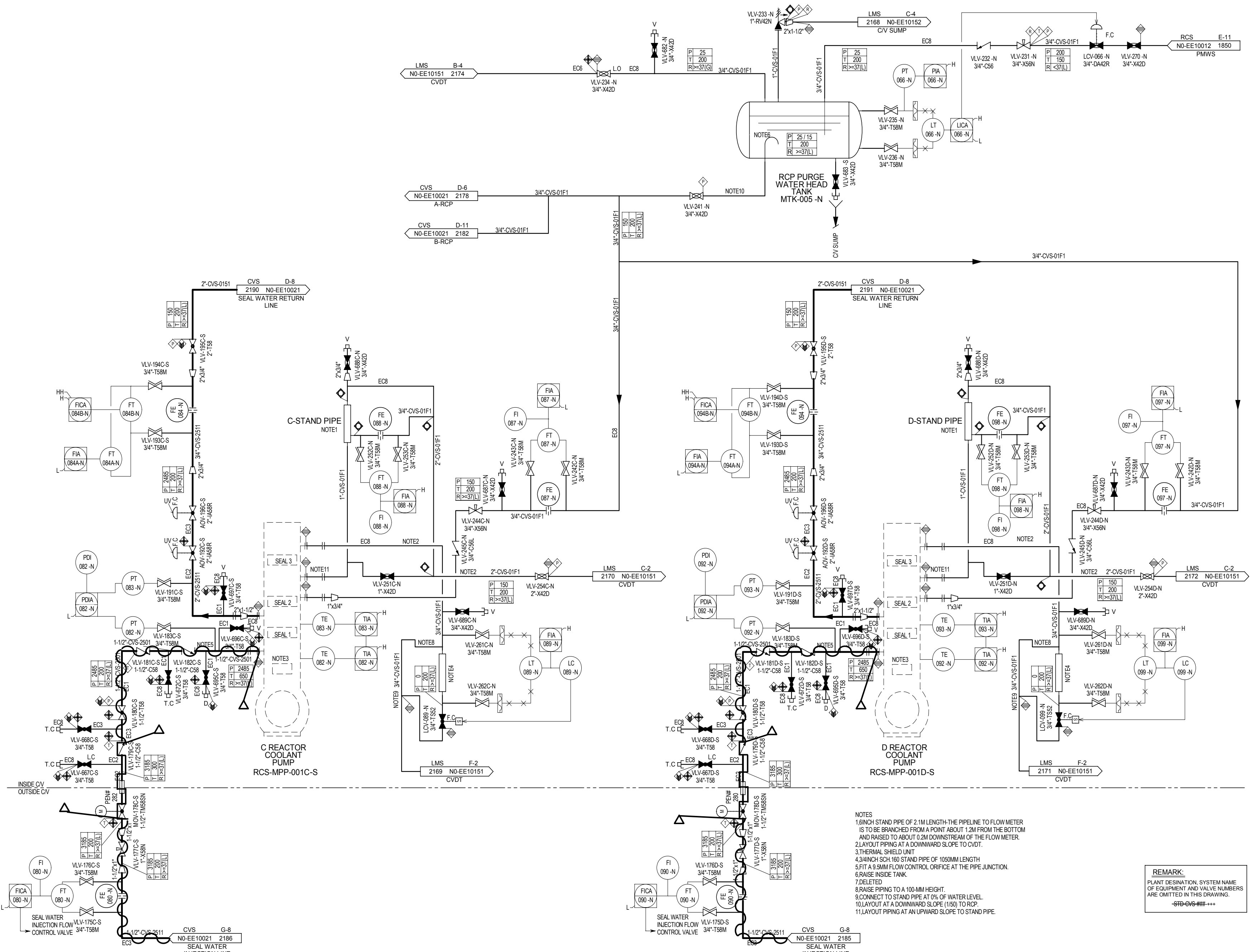



Figure A1-4 Chemical and Volume Control System Flow Diagram (2/4)

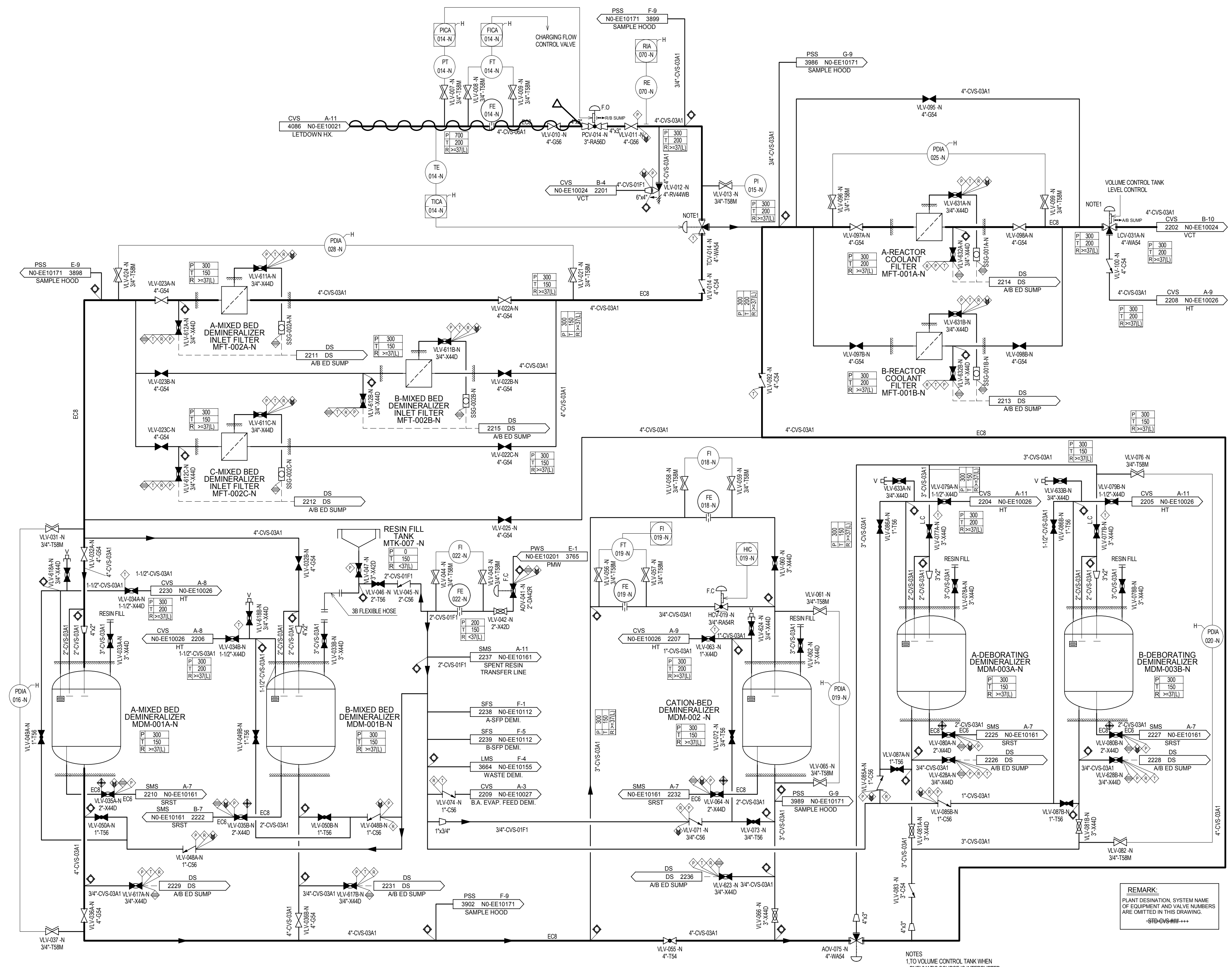



**Figure A1-5 Chemical and Volume Control System Flow Diagram (3/4)**

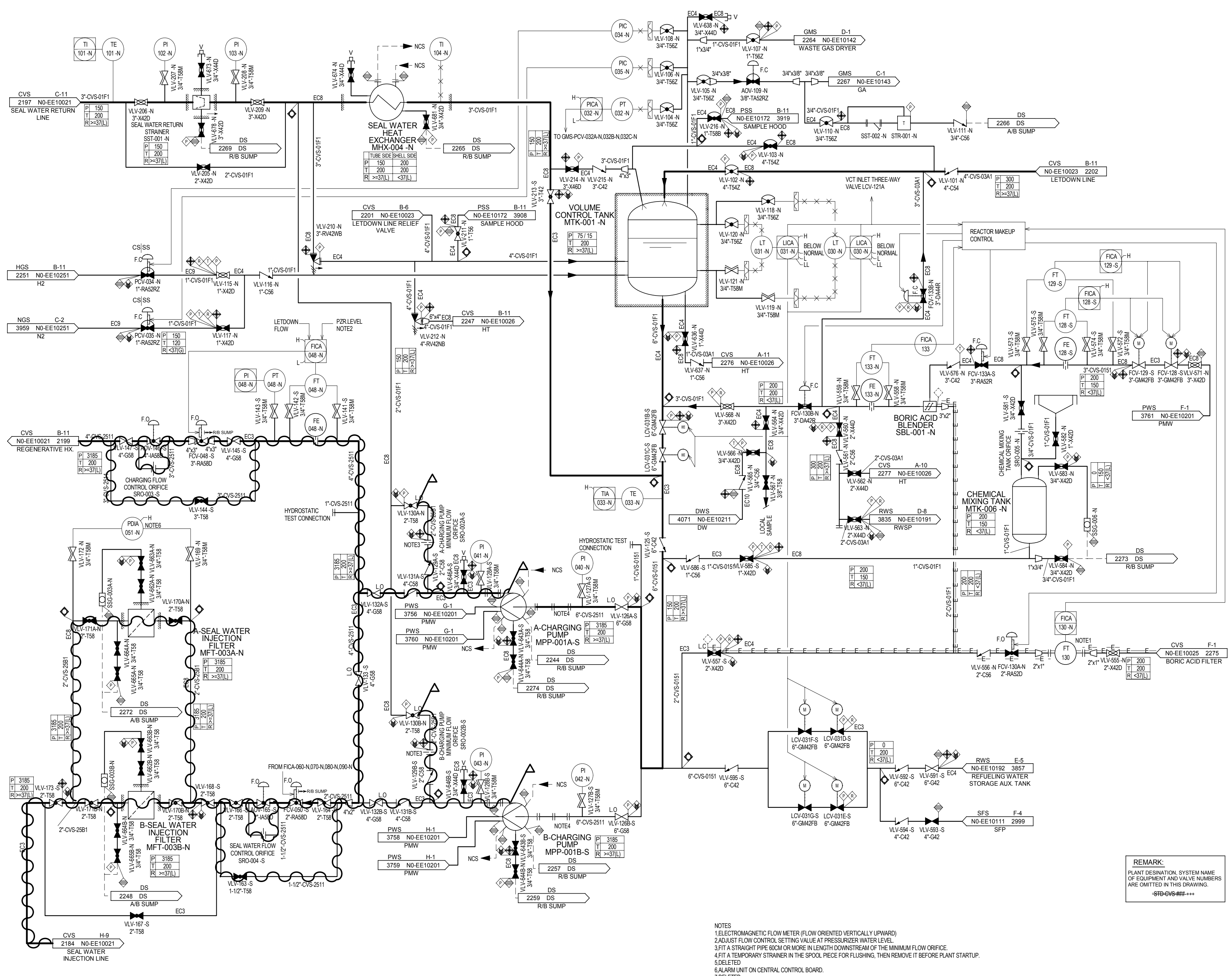



**Figure A1-6 Chemical and Volume Control System Flow Diagram (4/4)**

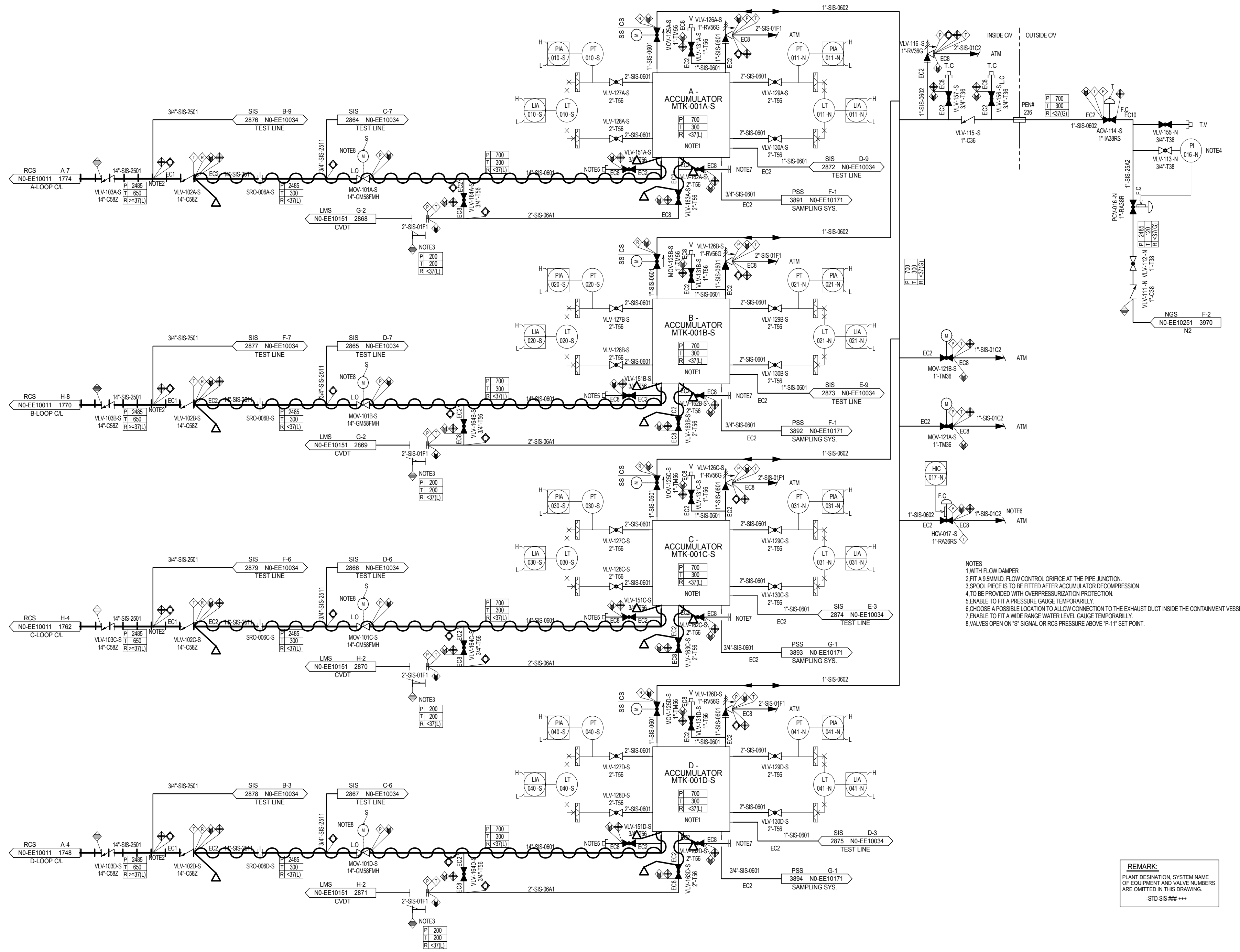


Figure A1-7 Safety Injection System Flow Diagram

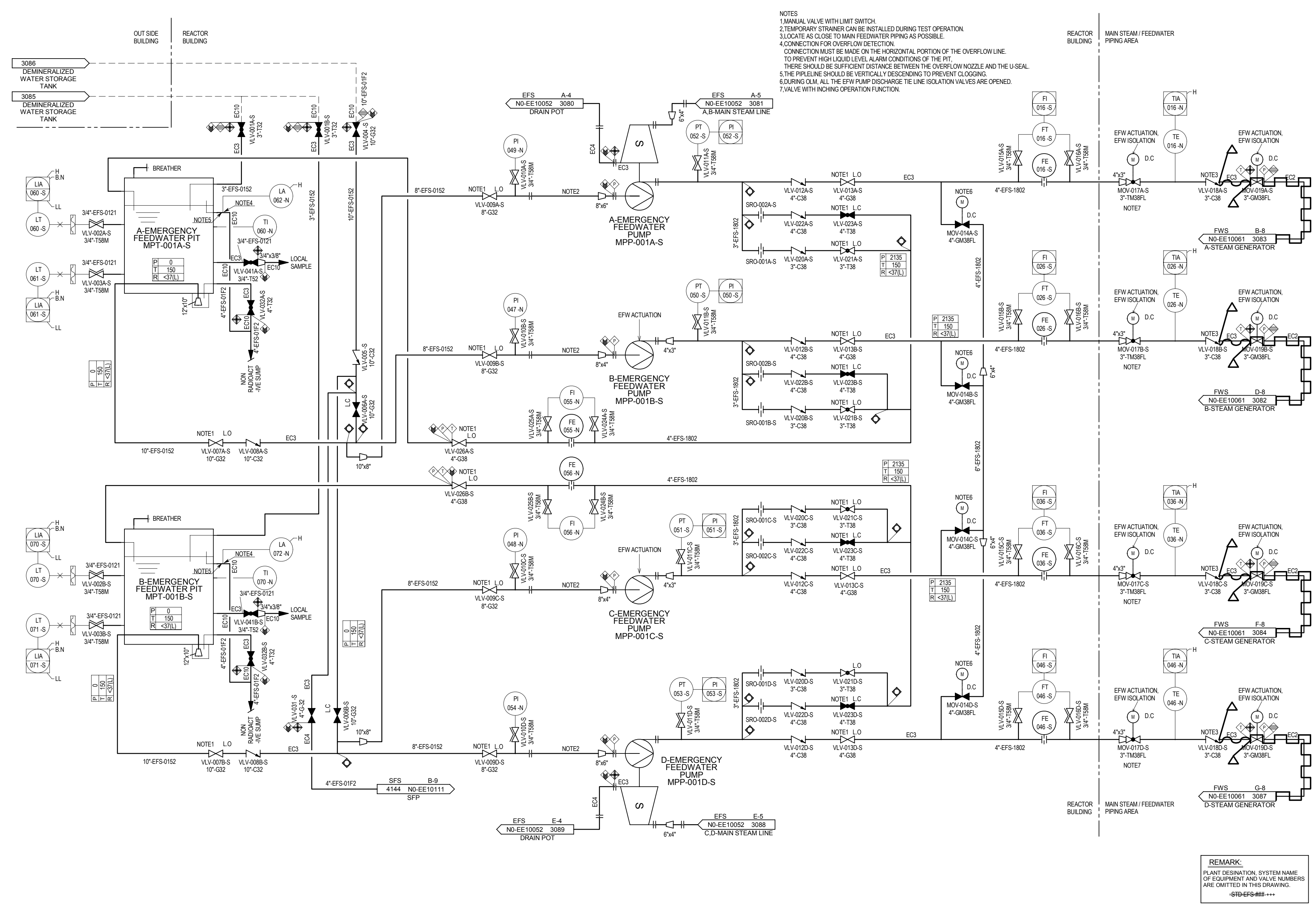


**Figure A1-8 Emergency Feed Water System Flow Diagram (1/2)**

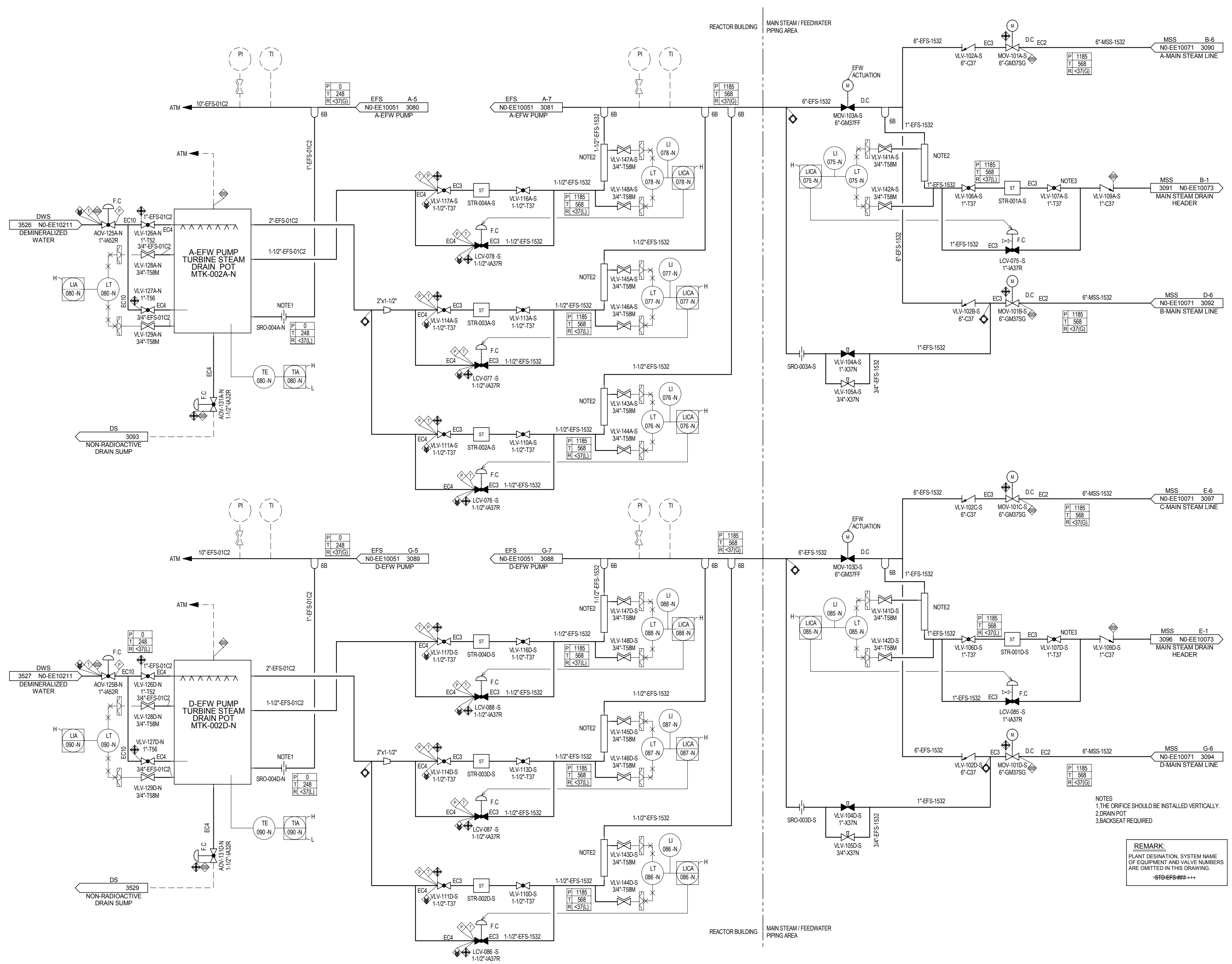



Figure A1-9 Emergency Feedwater System Flow Diagram (2/2)

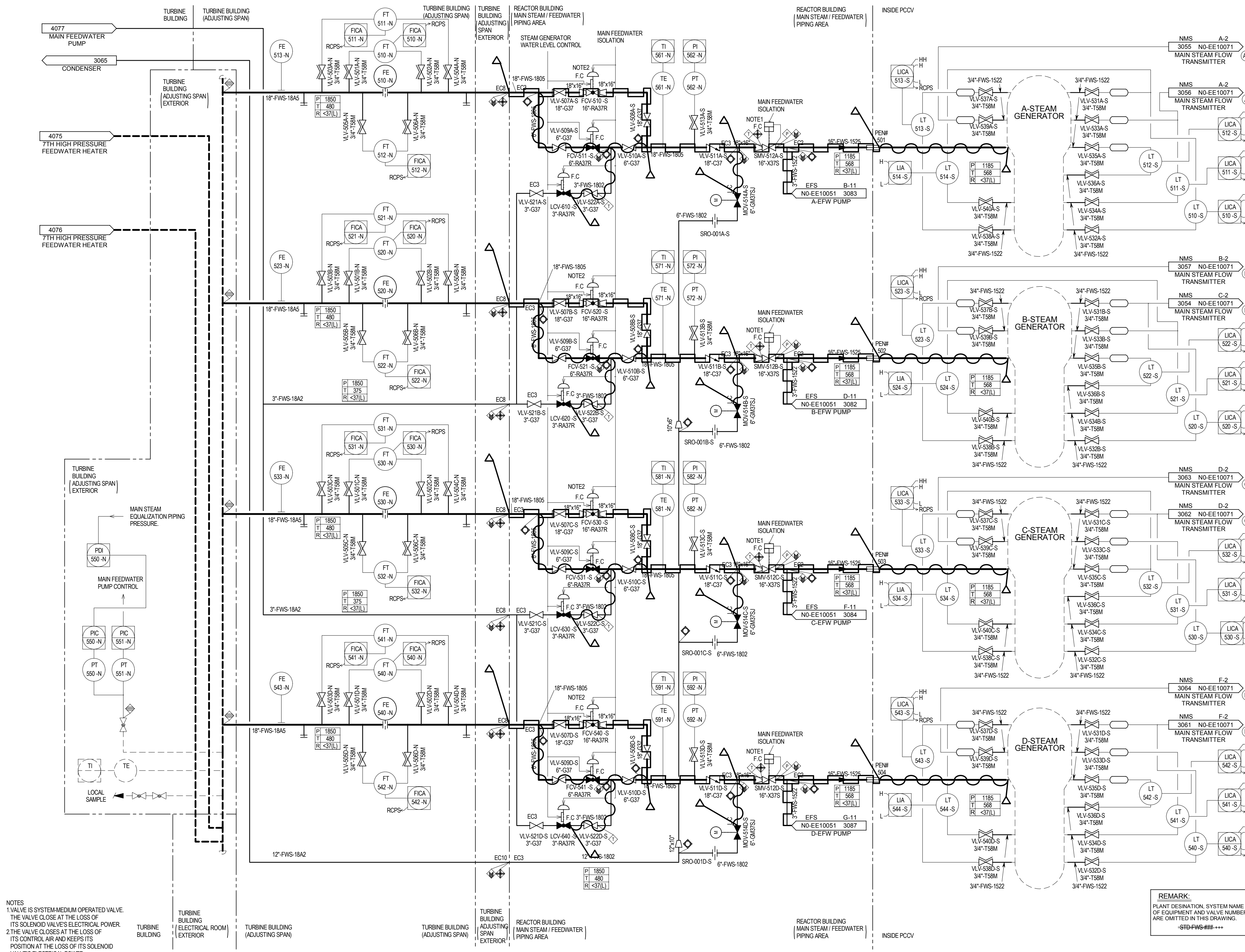


Figure A1-10 Main Feed Water System Flow Diagram

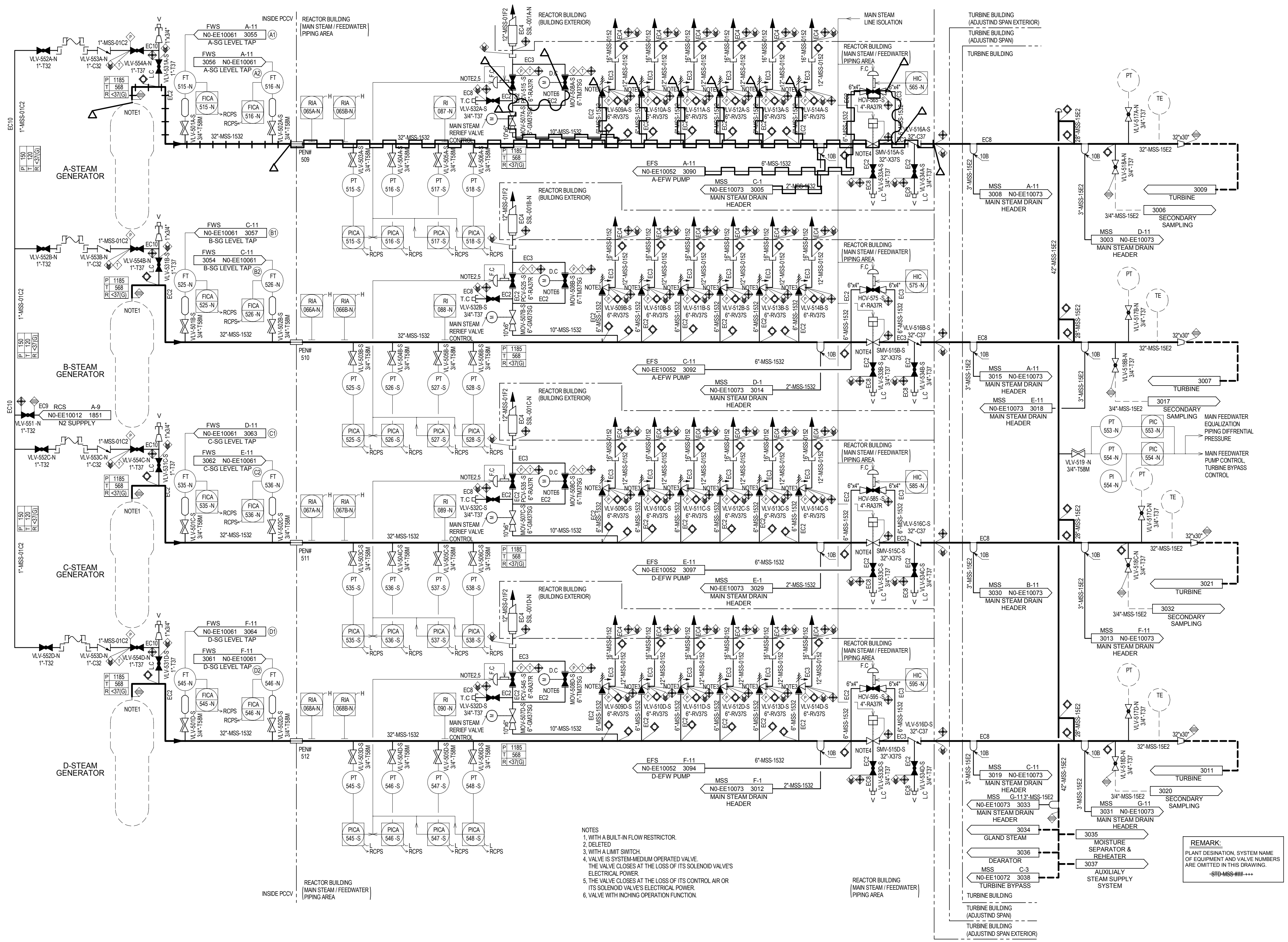


Figure A1-11 Main Steam System Flow Diagram (1/2)

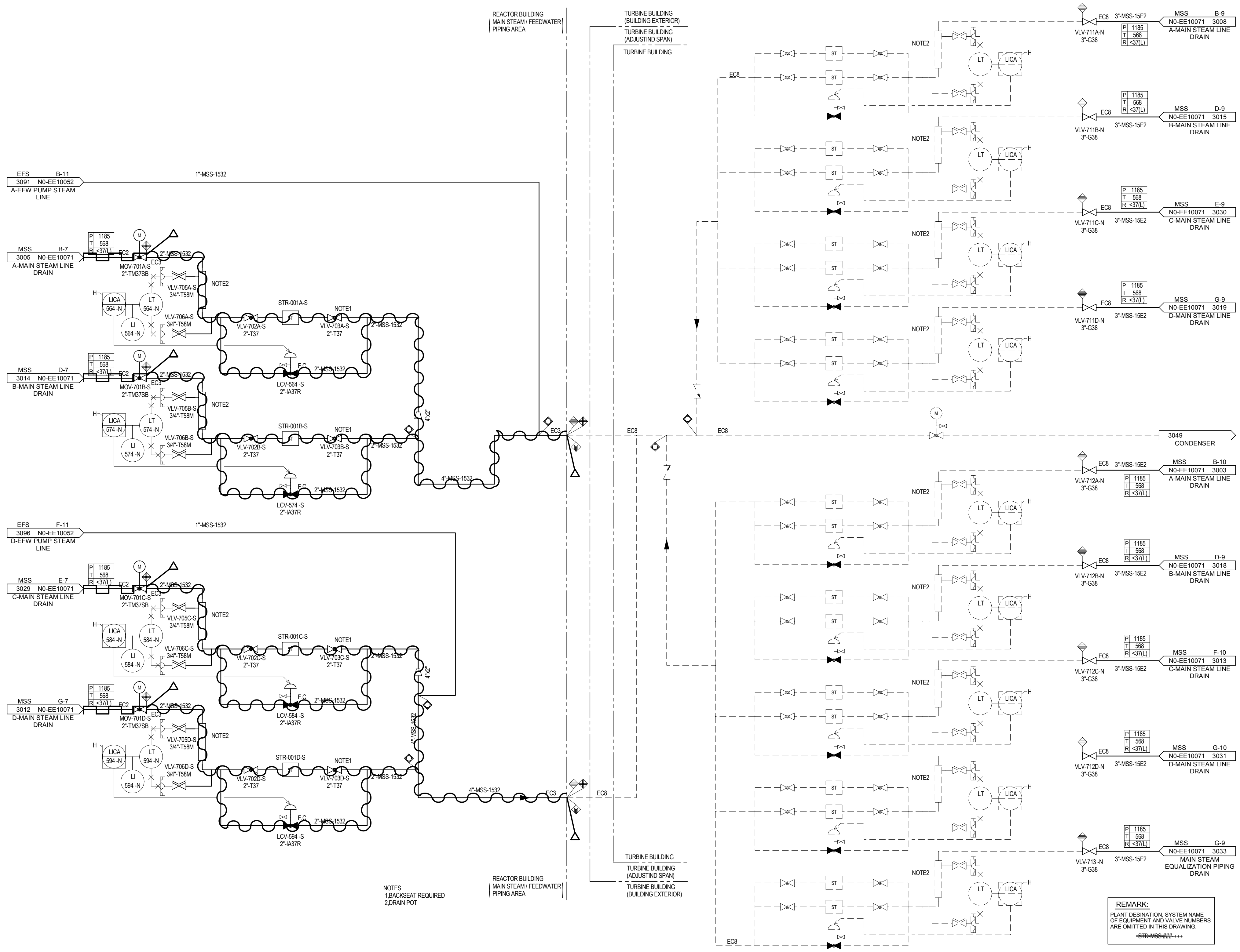


Figure A1-12 Main Steam System Flow Diagram (2/2)

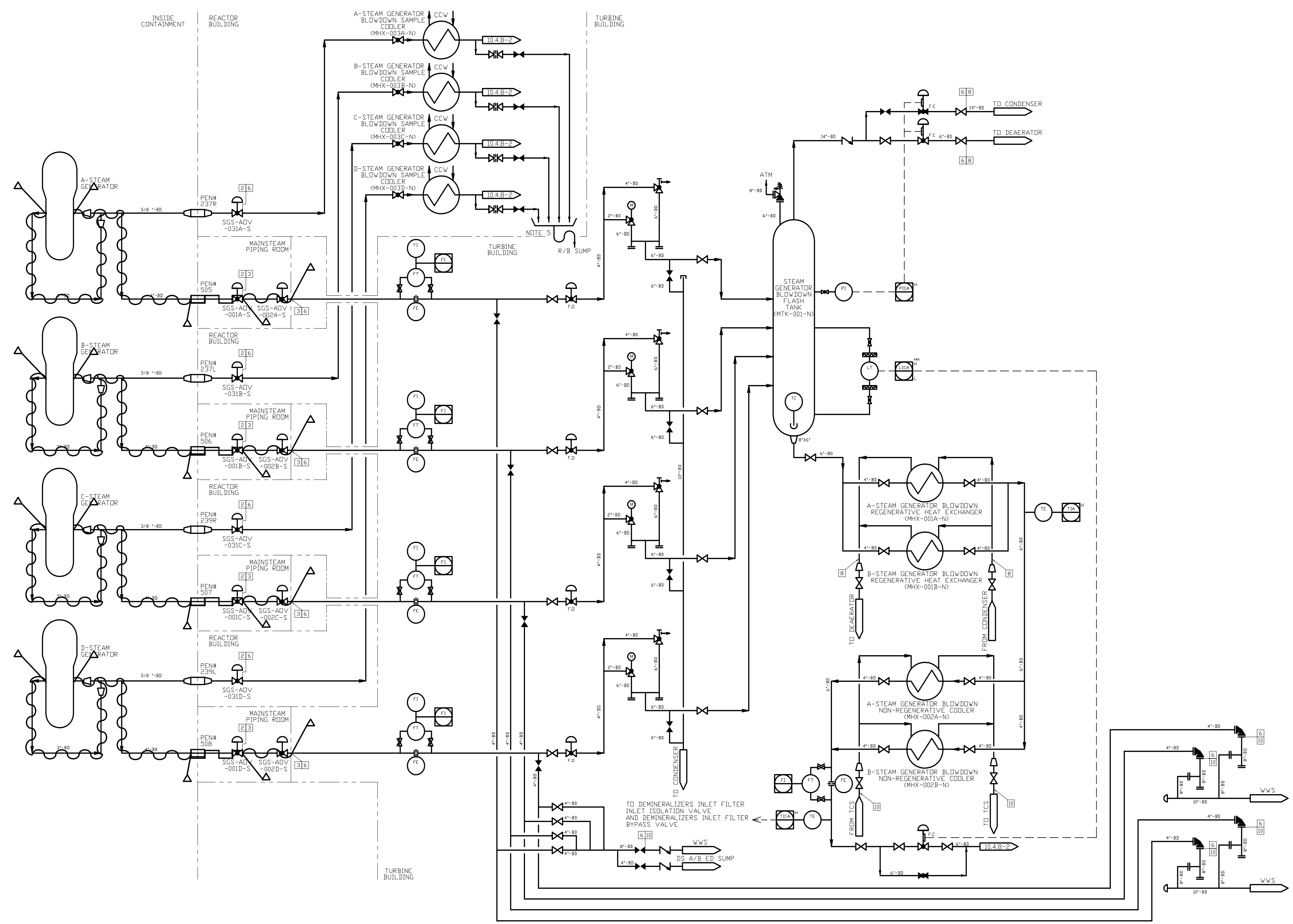



Figure A1-13 Steam Generator Blowdown System Flow Diagram

**Appendix 2 Evaluation Method on Jet Expansion and Impingement**