Westinghouse

Westinghouse Electric Company
Nuclear Plant Projects
P.O Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555

Direct tel 412-374-5355
Direct fax 412-374-5456
e-mail corletmm@westinghouse.com

Your ref 52-006
Our ref. DCP/NRC1540

December 2, 2002

SUBJECT: Transmittal of Westinghouse Document, "Evaluation of the AP1000 Conformance to Inter-System Loss-of-Coolant Accident Acceptance Criteria," WCAP-15993, Rev. 0, Non-Proprietary, dated November 2002

Attached please find WCAP-15993 "Evaluation of the AP1000 Conformance to Inter-System Loss-of-Coolant Accident Acceptance Criteria," dated November 2002. This report is referenced in the Westinghouse response to NRC RAI 440.045 that has been transmitted to the NRC in Westinghouse letter DCP/NRC1535 dated November 26, 2002.

Please contact me at 412-374-5355 if you have any questions concerning this submittal.

Very truly yours,

Michael M. Corletti
M. M. Corletti
Passive Plant Projects & Development
AP600 & AP1000 Projects

/Attachment

1. WCAP-15993, Rev. 0, "Evaluation of the AP1000 Conformance to Inter-System Loss-of-Coolant Accident Acceptance Criteria," dated November 2002

D063

Attachment 1

WCAP-15993, Rev. 0

"Evaluation of the AP1000 Conformance to Inter-System Loss-of-Coolant Accident Acceptance Criteria"

dated November 2002

Westinghouse Non-Proprietary Class 3

WCAP-15993
Revision 0

November 2002

Evaluation of the AP1000 Conformance to Inter-System Loss-of-Coolant Accident Acceptance Criteria

Westinghouse

AP1000 DOCUMENT COVER SHEET

TDC: ______ Permanent File: ______ S ______

RFS#: ______ RFS ITEM #: ______

AP1000 DOCUMENT NO.	REVISION NO.		ASSIGNED TO
APP-GW-GLR-002	0	Page 1 of 32	W–R. P. Vijuk

ALTERNATE DOCUMENT NUMBER: WCAP-15993, Revision 0 WORK BREAKDOWN #:

ORIGINATING ORGANIZATION: Westinghouse Electric Company LLC

TITLE: **Evaluation of the AP1000 Conformance to Inter-System Loss-of-Coolant Accident Acceptance Criteria**

ATTACHMENTS:	DCP #/REV. INCORPORATED IN THIS DOCUMENT REVISION:
CALCULATION/ANALYSIS REFERENCE:	

ELECTRONIC FILENAME	ELECTRONIC FILE FORMAT	ELECTRONIC FILE DESCRIPTION
6078.doc	Microsoft Word	N/A

ORIGINATOR T. K. Meneely	SIGNATURE/DATE T. K. Meneely 11/25/02	
REVIEWERS	SIGNATURE/DATE	
INDEPENDENT VERIFIER M. M. Corletti	SIGNATURE/DATE M M Corletti 11/26/02	
AP1000 RESPONSIBLE MANAGER R. P. Vijuk	SIGNATURE* R. P. Vijuk	APPROVAL DATE 11/26/02

*Approval of the responsible manager signifies that document is complete, all required reviews are complete, electronic file is attached and document is released for use.

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15993
Revision 0

Evaluation of the AP1000 Conformance to Inter-System Loss-of-Coolant Accident Acceptance Criteria

T. K. Meneely

November 2002

AP1000 Document: APP-GW-GLR-002

Westinghouse Electric Company LLC
P.O. Box 355
Pittsburgh, PA 15230-0355

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1 INTRODUCTION

1.1 BACKGROUND

In conducting studies directed at finding vulnerabilities of pressurized water reactor (PWR) plants to inter-system loss-of-coolant accidents (ISLOCAs), the Nuclear Regulatory Commission (NRC) staff concluded that the core damage frequency caused by ISLOCAs could be substantially greater than previous Probabilistic Risk Assessment (PRA) estimates.[1] In NRC Information Notice 92-36 (Reference 1), the NRC staff indicated that these PRAs have typically been limited to modeling ISLOCA sequences that include only the catastrophic failures of check valves that isolate the Reactor Coolant System (RCS) from low-pressure systems. Also, the PRAs included little consideration of human errors leading to an ISLOCA and the effects of the accident-caused harsh environment or flooding on plant equipment and recovery activities.

The results of these NRC studies have suggested that ISLOCA precursors most likely would be initiated by human errors or because of procedural deficiencies. This may be attributed to the general lack of awareness of the possibility or consequences of an ISLOCA.

The NRC has developed a position on design requirements necessary to minimize the potential for ISLOCAs. The staff position is addressed in numerous NRC documents, including References 1 through 7. Westinghouse has evaluated the AP1000 design and concludes that it complies with the stated NRC position.

1.2 OBJECTIVE

The purpose of this report is to perform a systematic evaluation of the systems that interface with the RCS and to demonstrate that the design of the systems meets the ISLOCA acceptance criteria, which are described in section 2.2 of this report.

1.3 SCOPE

The scope of this evaluation is applicable to the AP1000 systems and subsystems that interface directly or indirectly with the RCS and are susceptible to ISLOCA challenges.

1. AP1000 PRA results show that ISLOCAs provide only a minor contribution to core damage frequency. In current calculations, this contribution accounts for approximately 5.0E-11 per reactor year, which is less than one-tenth of one percent of the overall AP1000 core damage frequency at-power, calculated to be approximately 2.4E-7 per reactor year.

2 DESIGN REQUIREMENTS AND APPROACH

2.1 ISLOCA DEFINITION

An ISLOCA is defined in NRC Information Notice 92-36 (Reference 1) as a class of events in which a break occurs outside containment in a system connected to the RCS, causing a loss of primary system inventory outside containment. This is interpreted as a beyond-design-basis event for systems connected directly or indirectly to the RCS. The pressurization pathway can be established by an inadvertent opening of a valve or valves, a failure of containment isolation, or the postulation that valves are fully open (for example, check valves). This interpretation is believed to address all sources that may challenge low-pressure systems. Based on this definition of an ISLOCA, an evaluation was performed to assess the ability of the AP1000 design to withstand an overpressure event.

2.2 ISLOCA ACCEPTANCE CRITERIA

The design of systems that interface with the RCS is evaluated against acceptance criteria consistent with the following NRC guidance provided in SECY-90-016 (Reference 5).

- All systems and subsystems connected to the RCS are to be designed to withstand the full RCS pressure to the extent practicable.
- Systems that are not designed to full RCS pressure should include:
  - the capability for leak-testing of the pressure isolation valves
  - valve position indication that is available in the control room when isolation valve operators are deenergized, and
  - a high-pressure alarm to warn control room operators when rising reactor coolant pressure approaches the design pressure of attached low-pressure systems and both isolation valves are not closed.
- Systems not designed in the above methods should include other proper design features to prevent ISLOCAs to the extent practicable.

2.3 ISLOCA EVALUATION PROCESS

The systematic evaluation performed for this study of ISLOCA challenges and the subsequent determination of appropriate design responses can be summarized in the following steps:

1. The AP1000 RCS piping and instrumentation diagram (P&ID) was reviewed to identify systems or subsystems that directly interface with the RCS. The P&IDs of these primary interfacing systems were also reviewed to identify secondary interfacing systems or subsystems that directly interface with the primary interfacing systems.

2. The design pressure of each of the primary and secondary interfacing systems was identified and categorized as follows:

   A – Design pressure ≥ RCS Design Pressure
   B – Ultimate Rupture Strength (URS) ≥ RCS Design Pressure
   C – Low-Pressure System

3. Any system or subsystem that interfaces with a primary interfacing system categorized as A or B above was then itself evaluated as a primary interfacing system for the following reason: If a primary interfacing system is designed for full RCS pressure, then it can be considered (for this study) an extension of the reactor coolant pressure boundary (RCPB), and therefore, any system interfacing with it should be subjected to the ISLOCA evaluation criteria.

   Systems interfacing with a category C system were not evaluated as primary interfacing systems because it was assumed that the justification and design response for the category C system would also protect any system connected to that system.

   For each interfacing system or subsystem categorized as B or C above, justification for ISLOCA compliance is identified and categorized as follows:

   (1) All parts of system or subsystem are located inside the containment.

   (2) System or subsystem is designed to a URS at least equal to the full RCS pressure.

   (3) System or subsystem includes the following design features:

   – the capability for leak-testing of the pressure isolation valves

   – valve position indication that is available in the control room when isolation valve operators are deenergized, and

   – a high-pressure alarm to warn control room operators when rising reactor coolant pressure approaches the design pressure of attached low-pressure systems and both isolation valves are not closed.

   (4) System or subsystem includes other design features specific to them that prevent an ISLOCA to the extent practicable. These design features are discussed in section 3 of this report.

4. A design evaluation is performed for all category B and C primary and secondary interfacing systems with compliance justification other than (1). Each interface in the pressurization pathways was analyzed relative to the ISLOCA acceptance criteria.

Tables 2-1 through 2-11 summarize the results of the evaluation process described above. The first system in each table is the primary interfacing system. The remaining systems in each table are the secondary interfacing systems that interface with that primary system. Section 3 of this report contains design evaluations for the category B or C systems identified with justifications that do not include justification (1) (system is located entirely inside containment).

Table 2-1 Normal Residual Heat Removal System						
Interfacing System	Design Pressure(1)	Justification(2)				Design Evaluation (Section)
		1	2	3	4	
Normal Residual Heat Removal System (RNS) Pump seal	A/B C		X	 X		3.1
Passive Core Cooling System (PXS) test header	A	X	X			
Chemical and Volume Control System (CVS) purification return line	A	X	X			
PXS direct vessel injection line	A	X	X			
In-containment refueling water storage tank (IRWST) sparger	C	X				
CVS purification line	A	X	X			

1. See subsection 2.3.2 for an explanation of design pressure codes.
2. See subsection 2.3.3 for an explanation of justification codes.

Table 2-2 Chemical and Volume Control System Purification Loop						
Interfacing System	Design Pressure	Justification				Design Evaluation (Section)
		1	2	3	4	
CVS purification loop	A	X				
RNS discharge and return headers	A	X				
Solid Radwaste System (WSS)	C				X	3.5
Containment sump	C	X				
Demineralized Water Transfer and Storage System (DWS)	C	X			X	3.6
Primary Sampling System (PSS)	A		X			3.4
CVS makeup line Makeup pump suction line	A C		X		 X	3.3
Hydrogen addition line	A		X			
RCS pressurizer spray	A	X				

Table 2-3 Chemical and Volume Control System Letdown Line						
Interfacing System	Design Pressure	Justification				Design Evaluation (Section)
		1	2	3	4	
CVS letdown line	C			X	X	3.2
Liquid Radwaste System (WLS) degasifier	C			X	X	3.2
WLS effluent holdup tank	C			X	X	3.2

Table 2-4 Chemical and Volume Control System Makeup Pump Discharge Line						
Interfacing System	Design Pressure	Justification				Design Evaluation (Section)
		1	2	3	4	
CVS makeup pump discharge line	A		X			
PXS test header	A	X	X			
Spent fuel pool	C				X	3

Table 2-5 Chemical and Volume Control System Makeup Pump Suction Line						
Interfacing System	Design Pressure	Justification				Design Evaluation (Section)
		1	2	3	4	
CVS makeup pump suction line	C				X	3.3
Spent fuel pool	C				X	3
Waste holdup tank	C				X	3.3
Demineralized water storage tank	C				X	3.3

Table 2-6 Chemical and Volume Control System Hydrogen Injection Line						
Interfacing System	Design Pressure	Justification				Design Evaluation (Section)
		1	2	3	4	
CVS hydrogen injection line	A		X			

Table 2-7 Primary Sampling System						
Interfacing System	Design Pressure	Justification				Design Evaluation (Section)
		1	2	3	4	
PSS Grab sample panel	A C		X		 X	3.4
DWS	C	X			X	3.6
PXS accumulators	C	X				
PXS core makeup tanks (CMTs)	A	X	X			
CVS demineralizers	A	X	X			
WLS degasifier	C				X	3.4

Table 2-8 Passive Core Cooling System Core Makeup Tanks						
Interfacing System	Design Pressure	Justification				Design Evaluation (Section)
		1	2	3	4	
PXS CMTs	A	X	X			
Reactor coolant drain tank (RCDT)	C	X				
PSS	A		X			
CVS makeup line	A		X			

Table 2-9 Passive Core Cooling System Direct Vessel Injection Line						
Interfacing System	Design Pressure	Justification				Design Evaluation (Section)
		1	2	3	4	
PXS direct vessel injection line	A	X				
IRWST	C	X				
PXS accumulators	C	X				

Table 2-10 Passive Residual Heat Removal Heat Exchangers						
Interfacing System	Design Pressure	Justification				Design Evaluation (Section)
		1	2	3	4	
Passive residual heat removal (RHR) heat exchangers	A	X	X			

Table 2-11 Passive Core Cooling System Test Header						
Interfacing System	Design Pressure	Justification				Design Evaluation (Section)
		1	2	3	4	
PXS test header	A	X	X			
CVS makeup line	A		X			
PXS accumulators	C	X				
RNS suction and discharge RCPB valves	A	X	X			
WLS RCDT	C	X				
PXS CMTs	A	X				
IRWST	C	X				

3 DESIGN EVALUATIONS

This section presents evaluations of the systems and subsystems identified in section 2.3 as requiring evaluation with regard to ISLOCA criteria. These systems or subsystems are connected directly to the RCS, or connect to high-pressure systems that connect directly to the RCS during some mode of operation, such that they must be evaluated for susceptibility to an ISLOCA. Based on the results of the evaluation process described in section 2.3, the following systems were selected for a detailed design evaluation:

- Normal Residual Heat Removal System (RNS)
- CVS letdown line to the WLS
- CVS makeup pump suction line
- Primary Sampling System (PSS)
- Solid Radwaste System (WSS)
- Demineralized Water Transfer and Storage System (DWS)

This section provides a detailed evaluation of each of these systems and subsystems. Each subsection is structured as follows:

- Description of Primary System Interface – A brief overview of the interfacing system under evaluation, the potential ISLOCA pathway, and operating conditions and failures necessary to create the ISLOCA pathway.

- Design Evaluation – An evaluation of the design against the ISLOCA criteria, and a description of any additional design features that address the ISLOCA issue.

- Justification of Design – A summary of the adequacy of the AP1000 system or subsystem design with respect to potential ISLOCA challenges.

In addition to describing systems under evaluation, these sections describe portions of systems designed to full RCS pressure, designed to a URS equal to full RCS pressure, or designed for low pressures. A system or portion of a system designed to full RCS pressure will have a design pressure of at least 2485 psig. A system or portion of a system designed to an URS equal to full RCS pressure will have a design pressure of at least 900 psig. A low-pressure system will have a design pressure less than 900 psig. These sections also describe piping lines from point A to point B. When this term is used, it can be assumed that all piping, valves, fittings, components, and instrument lines located in a "line" from point A to point B are designed to the pressure of the "line," unless otherwise specified.

SECY-90-016 (Reference 5) provides practical guidance in upgrading systems to URS design pressure. As discussed in Reference 10, it is impractical to design the large, low-design-pressure tanks and tank structures that are vented to the atmosphere to URS design pressure. Tanks included in this category are as follows:

- Spent fuel pool and fuel transfer canal
- CVS boric acid tank
- Demineralized water storage tank

- WLS effluent holdup and monitor tanks
- WLS waste holdup and monitor tanks

Table 3-1 provides the approximate sizes of these tanks to show the impracticality of increasing their design pressure. Increasing the design pressure of these tanks to the URS value would result in an unnecessary dollar cost burden. In addition, the tanks that contain radioactive waste are typically designed with features such as sloped bottoms to reduce crud deposition. Such features cannot be used in tanks designed to high pressure. Tanks such as the spent fuel pool and fuel transfer canal have no top cover and are open to the auxiliary building so that their pressure cannot be increased above the static head for which they are designed.

As discussed in the following evaluations, interfacing systems or subsystems that connect directly to an atmospheric tank are excluded from further ISLOCA consideration. This is limited to the piping connected directly to the atmospheric tank, up to the first isolation valve other than a locked-open, manual isolation valve. Designing these portions of the system to a higher pressure would provide no practical benefit. Designing these systems to full RCS pressure would offer no reduction in RCS inventory lost in the event that these lines were aligned to the RCS at full RCS pressure.

Other justifications for designing interfacing systems to less than full RCS pressure are provided on a case-by-case basis.

Table 3-1 AP1000 Low-Pressure Tanks Not Designed to URS Design Pressure

Tanks	Volume (gallon)
Spent fuel pit	190,000
Fuel transfer canal	61,000
CVS boric acid tank	70,000
Demineralized water storage tank	150,000
WLS effluent holdup tank	28,000
WLS waste holdup tank	15,000
WLS waste monitor tank	15,000

3.1 NORMAL RESIDUAL HEAT REMOVAL SYSTEM

3.1.1 Description of Primary System Interface

The RNS is the nonsafety-related system that provides shutdown cooling for the RCS. During normal shutdown operations, the RCS is cooled and depressurized to the RNS cut-in temperature and pressure using the steam generators as a heat sink, and using pressurizer spray to reduce RCS pressure. Once RCS pressure and temperature have been reduced to the conditions for RNS initiation, the RNS suction line isolation valves are opened, and the RNS pumps are started to provide shutdown cooling. Cooldown to refueling conditions continues with the RNS operating in this mode of shutdown cooling. Design Control Document (DCD) subsection 5.4.7 provides a complete description of the various functions and operations associated with the RNS. Figure 3-1 is the RNS P&ID modified to clearly indicate all high-pressure/low-pressure interfaces.

The RNS takes suction from an RCS hot leg and discharges to the reactor vessel direct vessel injection (DVI) lines. The lines represent the two potential paths of overpressurization for the RNS. As shown in Figure 3-1, the RNS suction line contains three normally closed isolation valves in series, with a design pressure equal to RCS design pressure. This represents the first potential pressurization pathway. The RNS inner and outer suction line isolation valves (V001A and B, and V002A and B) are RCPB valves. These valves have power removed at the valve motor control centers and are interlocked so that they cannot be opened unless RCS pressure is reduced to a pressure within the design pressure of the RNS (450 psig). The third normally closed isolation valve (V022) is designed to full RCS pressure and is a containment isolation valve. Overpressurization would occur only if either all three motor-operated gate isolation valves leaked excessively, or if the valves were inadvertently opened with the RCS pressure above the design pressure of the low-pressure portions of the RNS.

The second potential overpressurization pathway for the RNS is via the discharge branch lines, which each connect to a DVI line. Each RNS branch line contains two normally closed check valves that are RCPB valves, and as such, are designed to the RCS design pressure. The branch lines then connect to a common header that penetrates containment. The common header contains two containment isolation valves, a check valve inside containment (V013), and a motor-operated gate valve outside containment (V011). All the valves and piping up to and including the motor-operated gate valve are designed to full RCS pressure. Overpressurization would occur only if three check valves and the motor-operated gate isolation valve (in series) all leaked excessively.

3.1.2 Design Evaluation

The RNS suction line from the RCS hot leg to the outside-containment isolation valve (V022) is designed to full RCS pressure. Likewise, the RNS discharge lines from the DVI line back to the outside-containment isolation valve (V011) is designed to full RCS pressure. The portions of the RNS between these isolation valves are designed to a URS equal to the design pressure of the RCS, with the exception of the RNS pump shaft seal. The following is a summary of the specific design features incorporated in the AP1000 RNS design to address the ISLOCA issue.

Quality Assurance/Seismic Protection

The portions of the RNS located outside containment (that serve no active safety functions) are classified as AP1000 Equipment Class C so that the design, manufacture, installation, and inspection of this pressure boundary is controlled by the following industry and regulatory safety-related quality assurance requirements: 10CFR21; 10CFR50, Appendix B; Regulatory Guide 1.26 Quality Group C; and American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Class 3. In addition, this pressure boundary is classified as Seismic Category I so that it is protected from failure following a safe shutdown earthquake.

Increased Design Pressure

The portions of the RNS from the RCS to the containment isolation valves outside containment are designed to the operating pressure of the RCS. The portions of the system downstream of the suction line containment isolation valve and upstream of the discharge line containment isolation valve are designed with a URS not less than RCS operating pressure. Specifically, the piping is designed as Schedule 80S, and the flanges, valves, and fittings are specified to be greater than or equal to ANS class 900. Although the design pressure of the system has been increased to 900 psig, the maximum operating pressure has remained consistent with previous designs, and therefore, the actual margin between the maximum operating pressure and the design pressure of the RNS is increased by a factor of 3 (from 150 to 450 psig).

Reactor Coolant System Isolation Valve

The AP1000 RNS contains an isolation valve in the pump suction line from the RCS. This motor-operated containment isolation valve is designed to the RCS pressure. It provides an additional barrier between the RCS and lower-pressure portions of the RNS.

Normal Residual Heat Removal System Relief Valves

The inside-containment AP1000 RNS relief valve is connected to the RHR pump suction line inside containment. This valve is designed to provide low-temperature overpressure protection of the RCS as described in DCD subsection 5.2.2. It is connected to the high-pressure portion of the pump suction line, and it will reduce the risk of overpressurizing the low-pressure portions of the system. In addition, the RNS discharge header contains a relief valve provided to prevent overpressure in the RNS pump discharge line. Overpressure could occur if the three check valves (V013, V015, and V017) and the motor-operated containment isolation gate valve (V04) leaked back to the low-pressure portions of the RNS. The discharge of this relief valve is routed to the WLS effluent holdup tanks.

Features Preventing Inadvertent Opening of Isolation Valves

An interlock is provided for the normally closed, motor-operated RNS inner and outer suction isolation valves (RNS-V001A and B, and V002A and B). The interlock prevents the suction valves for the RNS from being opened by operator action unless the RCS pressure is less than a preset pressure and the following valves are in a closed position:

- IRWST suction isolation valve (RNS-V023)
- IRWST discharge isolation valve (RNS-V024)

Alarms are also provided in the main control room and on the remote shutdown workstation to alert the operator if RCS pressure exceeds the RNS design pressure after the valves are opened.

Reactor Coolant System Pressure Indication and High Alarm

The AP1000 RNS contains an instrumentation channel that indicates pressure in each RHR pump suction line. A high-pressure alarm is provided in the main control room to alert the operator to a condition of rising RCS pressure, which could eventually exceed the design pressure of the RNS.

The only portion of the RNS not designed to full RCS pressure, or to a URS pressure equal to the RCS design pressure, is the RNS pump shaft seal. The RNS pumps contain a shaft seal that has a design pressure of 900 psig. In addition, the pump is fitted with a disaster bushing that limits seal leakage in the event of a catastrophic failure of the pump seal to within the capabilities of the normal makeup system. The seal leakoff line is routed to a floor drain that is routed to the auxiliary building sump.

3.1.3 Justification of Design

This section provides justification for the adequacy of the RNS design with regard to ISLOCA criteria. Justification for the portions of the RNS other than the RNS pump mechanical seal is provided in subsection 3.1.3.1. Subsection 3.1.3.2 contains the justification for the design of the RNS pump shaft seal.

3.1.3.1 Design Justification for Normal Residual Heat Removal System

The design of the RNS meets the acceptance criteria for ISLOCA because the system is designed to either full RCS pressure or to a URS pressure equal to the RCS design pressure. In addition, design features are provided that exceed the ISLOCA criteria. The design features of the RNS contribute to the low core damage frequency attributed to ISLOCA calculated in the AP1000 PRA.

3.1.3.2 Design Justification for Normal Residual Heat Removal Pump Mechanical Seal

The RNS pumps contain a mechanical seal that permits proper operation of the RNS pump while limiting shaft leakage. The RNS pump shaft seal has a design pressure of 900 psig, and a maximum operating pressure of ~565 psig, with an expected operating range from 450 to 0 psig.

A fundamental problem with designing an RNS pump seal that can withstand full RCS pressure is that any type of seal that can withstand full RCS pressure will likely have abnormally fast wear of the seal faces during normal plant operation at low seal pressures. This increased wear at normal plant operating conditions could prevent the seal from maintaining the pressure boundary if ever exposed to the full RCS pressure. High-pressure seals would also require more frequent maintenance during normal operation. Therefore, a seal can be designed for normal-low pressure operation or for full-RCS-pressure conditions, but it is impractical to design a seal that would maintain the RCS pressure boundary with no leakage, and also operate satisfactorily at low-pressure conditions.

The AP1000 RNS pump mechanical seal is designed to minimize the amount of leakage if exposed to full RCS pressure. NUREG/CR-5603 (Reference 9) documented an evaluation of the pumps at the Davis Besse Nuclear Power Station under potential ISLOCA conditions. This study concluded the following for the Davis Besse Decay Heat Removal (DHR) System pumps.

Based on extensive discussions with the seal manufacturer, it was found that the rotating seal would maintain its structural integrity to pressures in excess of 2500 psi. The mechanical seals are designed to withstand a pressure of 1200 to 1250 psi without leaking. At greater pressures, the rotating face begins to distort creating a rotation at the contact surface. At 2500 psi, the rotation is three times the maximum allowable value. Thus, it is recommended that the potential for leakage through the pump seals be characterized assuming a nominal leak rate of 100 to 200 mg/sec together with an uncertainty variability of about 0.20.

The Davis Besse DHR pumps use a mechanical seal of a similar design as the AP1000 RNS pumps. Furthermore, the design pressure of the AP1000 mechanical seal is 900 psig as opposed to 450 psig for the Davis Besse DHR pumps. Since the design pressure of the AP1000 RNS mechanical seal is higher than that of the DHR pump in NUREG/CR-5603 (Reference 9), the expected leakage for the AP1000 RNS pump is less than that of the Davis Besse DHR pumps. Seal manufacturers contacted would not claim as low a leakage as specified in the reference study; they claimed their seals would meet the requirement that leakage at full RCS pressure be limited to within the capabilities of the normal makeup system.

The AP1000 RNS pump also has a disaster bushing that limits the leakage from the pump to within the capabilities of the normal makeup system in case of a catastrophic mechanical seal failure. The combination of a highly reliable single-seal design, in conjunction with a sturdy disaster bushing, maximizes the reliability of the seal during normal RNS operation and minimizes maintenance and associated radiation exposure. Furthermore, this design approach minimizes RNS pump leakage in the event of catastrophic mechanical seal failure. Leakage can be controlled so that only a small portion of the water that leaks past the primary seal faces escapes to the pump cubicle and most leakage is piped to a controlled drain. This is more favorable than a seal specially designed for full RCS pressure at the expense of normal-condition reliability.

3.2 CHEMICAL AND VOLUME CONTROL SYSTEM LETDOWN LINE TO LIQUID RADWASTE SYSTEM

3.2.1 Description of Primary System Interface

The CVS is the nonsafety-related system that provides for purification and makeup flow for the RCS. Unlike current PWRs that use continuous charging and letdown flow to maintain RCS chemistry and inventory control, the AP1000 uses a high-pressure purification loop totally within containment that uses reactor coolant pump (RCP) head to provide the motive force to drive purification flow. This eliminates the need for continuous charging and letdown, and therefore, letdown operations (that is, letdown of the RCS to the WLS) are limited to off-normal situations. DCD subsection 9.3.6 provides a complete description of the various functions and operations associated with the CVS. Figure 3-2 is the CVS P&ID modified to clearly indicate all high-pressure/low-pressure interfaces.

As shown in Figure 3-2, the CVS letdown line connects to the high-pressure CVS purification loop inside containment. Immediately downstream of this connection is the high-pressure, multi-stage letdown orifice, which reduces pressure in the letdown line from RCS operating pressure to below the design pressure of the low-pressure portion of the letdown line. The letdown line also contains a locked-closed bypass line around the letdown orifice. This line contains a locked-closed manual isolation valve (V043), which is opened only at shutdown when the RCS is depressurized. The letdown orifice must be bypassed when the RCS is depressurized to ensure sufficient letdown flow when required.

Downstream of the letdown orifice are two normally closed, fail-closed containment isolation valves (V045 and V047). The portions of the letdown line, from the purification loop up to and including the second containment isolation valve, are designed to full RCS pressure. The WLS portion of the letdown line contains a three-way valve that normally routes the letdown flow to the WLS degasifier package, and can be aligned to route the letdown flow to the WLS effluent holdup tanks. The discharge of the degasifier package is also routed to the WLS effluent holdup tanks.

A potential ISLOCA overpressurization pathway could exist from the RCS through the CVS purification loop, and through the CVS letdown line to the low-pressure WLS.

3.2.2 Design Evaluation

During power operation, the WLS is protected from overpressurization by the letdown orifice. The orifice design limits WLS pressure during letdown operation. In addition, a relief valve is provided in the low-pressure portion of the CVS letdown line in case a valve in the letdown line is inadvertently mispositioned and consequently causes an overpressurization of a low-pressure line. As seen in Figure 3-2, relief valve V057 is provided to limit the pressure in the WLS if manual isolation valve V048 were inadvertently closed, and the letdown isolation valves were opened. Discharge from relief valve V057 is routed directly to the WLS waste holdup tank.

During shutdown operation, with the letdown orifice bypassed, the relief valve in the CVS letdown line is required to protect the letdown line in the event of a cold overpressure transient. If the letdown isolation valves were opened and a cold overpressure transient occurred, the pressure excursion in the RCS would be limited to the set pressure of the RNS relief valve (plus accumulation pressure). Relief valve V057 is sized to provide sufficient flow for this event such that the pressure drop in the letdown line would limit the maximum WLS pressure to within 110 percent of its design pressure.

Because of the passive features in the CVS letdown line (that is, the letdown orifice and relief valve V057), inadvertent pressurization of the low-pressure portion of the letdown line is avoided. However, other events, such as excessive letdown operation or valve mispositioning that causes relief valve V057 to open and discharge to the WLS effluent holdup tanks, could cause a depletion in reactor coolant inventory. For any event that results in the depletion in the pressurizer water level (including excessive letdown or a letdown line ISLOCA), the letdown line isolation valves receive separate automatic signals to close. The letdown line isolation valves receive a control-grade automatic signal to close on normal low pressurizer level (~40 to 55 percent based on power level). This signal will terminate any letdown line ISLOCA or other excessive letdown event. Furthermore, the letdown isolation valves and the purification loop isolation valves (V001 and V002) also receive a safety-related signal to close on an abnormally low pressurizer level (~25 percent). Finally, the letdown line isolation valves and the purification loop isolation valves also close on a safeguards actuation signal, which would occur as a result of a LOCA that continued until the low-pressure safeguards actuation setpoint was reached. These four safety-related valves isolate the letdown line and would terminate any letdown line ISLOCA before it became a challenge to core cooling.

3.2.3 Justification of Design

The CVS letdown line meets ISLOCA criteria for low-pressure systems. The letdown isolation valves are containment isolation valves, and as such, have the capability for leak-testing, and are provided with valve position indication in the control room at all times. Furthermore, the WLS degasifier column contains a high-pressure alarm (via pressure switch PS-014), which would warn the control room operators that the WLS pressure was approaching the design pressure and that rising reactor coolant pressure could result in an ISLOCA. Also, the multiple safety-related isolation valves, which close automatically on low pressurizer level and on a safeguards actuation signal, protect against a letdown line ISLOCA, which could cause a loss of core cooling.

The flow rate from any excessive letdown or letdown line ISLOCA event would be within the capabilities of the normal makeup system. If the makeup pumps operate such that RCS inventory and pressure remain within the RCS operating limits (that is, pressurizer level >25 percent, RCS pressure >1800 psig), then it is assumed that the operator would identify the break and determine the actions to terminate the leak within 30 minutes. The radioactive releases from such an event are within the design basis analysis contained in DCD subsection 15.6.2.

It is not practicable to design the low-pressure portions of the letdown line to a higher design pressure. The letdown line is routed to either the degasifier package or the effluent holdup tanks. As discussed in section 3, it is not practicable to design the WLS effluent holdup tanks to a higher design pressure. It is also not practicable to design the WLS degasifier package to a higher design pressure. This degasifier package includes a degasifier column and a degasifier separator, four low-pressure pumps, and a low-pressure heat exchanger. A significant cost and development effort would be required to redesign this equipment to withstand full RCS design pressure. In addition, the degasifier package discharges directly to the WLS effluent holdup tanks, and therefore, designing the degasifier package to high pressure, if practicable, would provide no benefit. This is because the system interfaces directly with large, low-pressure tanks for which higher design pressures are impractical.

3.3 CHEMICAL AND VOLUME CONTROL SYSTEM MAKEUP PUMP SUCTION LINE

3.3.1 Description of Primary System Interface

The AP1000 CVS makeup pumps operate intermittently to make up for RCS leakage. The pumps start automatically when the pressurizer level reaches the bottom of the normal level band, and stop when the level reaches the top of the band. The makeup pumps take suction from either the boric acid tank, the demineralized water storage tank, or both, and inject makeup into the CVS purification loop return stream. DCD subsection 9.3.6 provides a complete description of the various functions and operations associated with the CVS. Figure 3-3 is the CVS P&ID modified to clearly indicate all high-pressure/low-pressure interfaces.

As shown in Figures 3-2 and 3-3, the CVS makeup line from the makeup pump discharge to the RCS, has a design pressure greater than or equal to the RCS design pressure. Pressurization is postulated from the RCS through the purification loop, through the makeup line connection to the purification loop, back through the makeup line and makeup pumps, and to the low-pressure makeup pump suction line. This pressurization pathway exists only if the makeup pumps are not operating. If the makeup pumps are operating, the system hydraulic phenomena prevent pressurization of the suction piping. It should be noted that two normally closed check valves in the makeup line isolate the pump suction line from the high-pressure purification loop. In addition, each makeup pump suction line contains a relief valve that protects the low-pressure piping in the event that leakage through the check valves causes the suction piping to become overpressurized.

The makeup pumps can take suction from either the boric acid tank (BAT), the demineralized water storage tank, the waste holdup tanks, or the spent fuel pool. Each suction line contains a check valve to prevent flow between water storage tanks. In addition, the spent fuel pool and waste holdup tank suction lines contain a normally closed manual valve.

3.3.2 Design Evaluation

As discussed in section 3, the tanks that the CVS can take suction from are all large, low-pressure tanks for which high-pressure designs are impractical. As such, these tanks and the piping up to the first manual isolation valve, are excluded from ISLOCA consideration. As shown in Figure 3-3, each makeup pump suction line contains a check valve and at least one manual isolation valve. To prevent overpressurization of the makeup pump suction line, relief valves V158A and B are provided in case the check valves (V064, and V156A and B) in the makeup pump discharge line leak when the pumps are not running. These relief valves prevent an ISLOCA in the makeup pump suction piping.

In the event that makeup line check valve failure causes the relief valves to open, the relief valves would discharge to the WLS effluent holdup tanks. This would eventually lead to a low normal pressurizer level signal, causing the makeup pumps to start, and effectively terminating the ISLOCA. If the nonsafety-related makeup pumps failed to start, safety-related isolation of the makeup line would be achieved by isolation of the purification loop isolation valves (V001 and V002), the makeup line containment isolation valves (V090 and V091), and the RCS boundary check valves in the makeup line (V081 and V082). These safety-related valves isolate the makeup line and would terminate any makeup suction line ISLOCA before it became a challenge to core cooling.

3.3.3 Justification of Design

The CVS suction line piping meets ISLOCA criteria for low-pressure systems. The makeup line isolation valves are containment isolation valves, and as such, have the capability for leak-testing, and are provided with valve position indication in the control room at all times. In the event of an ISLOCA, the makeup pumps would be operated (either manually or automatically on low pressurizer level), and the mechanism for overpressurizing the suction piping would not exist. If the makeup pumps did not start, and the mechanism was still available to overpressurize the suction piping, the containment isolation valves would automatically terminate the ISLOCA. These valves are closed on a safeguards actuation signal coincident with low pressurizer level. In addition, the RCS pressure boundary valves in the purification loop are also closed on a safeguards actuation signal. These multiple, safety-related isolation valves prevent an ISLOCA in the makeup pump suction line that could result in a loss of core cooling.

It is not practicable to design the low-pressure portions of the makeup pump suction line to a higher design pressure. The suction line contains relief valves that protect the low-pressure portions of the piping from overpressure in events such as leaking check valves in the discharge line or thermal expansion in case of a loss of miniflow cooling. A loss of miniflow cooling could occur if component cooling water to the miniflow heat exchanger was lost. If the design pressure of the piping were increased to the URS pressure, the relief valves would still be necessary to protect against leaking check valves or thermal expansion. An increase in the valve set pressure (to correspond to the higher design pressure) would significantly impact design pressure of the pump discharge line for cases of a loss of miniflow heat exchanger cooling. And while designing the suction piping to full RCS pressure would address the case of leaking check valves in the discharge piping, it would not solve the thermal expansion issue.

Another consideration is that the makeup pump suction lines each contain a check valve that separates the suction piping from a large atmospheric tank. The suction line check valves are designed to open on low differential pressure, and industry experience has shown that low-differential-pressure check valves have a high tendency to leak. Therefore, assuming that the two discharge line (high-differential-pressure) check valves (in series) leak, it should also be assumed that the suction piping check valves would also tend to leak. Therefore, designing the suction pipe to a higher pressure will only increase the likelihood that the RCS leak extends on to one of the atmospheric tanks.

With the AP1000 design, the relief valves provide overpressure protection and direct any leakage from the discharge line check valves to the WLS effluent holdup tanks, a satisfactory arrangement, as opposed to leaking into the clean tanks from which the makeup pumps normally take suction. The WLS effluent holdup tank is designed to handle radioactive fluids, and its level is monitored by remote instrumentation (see section 4 regarding detection of ISLOCAs). Therefore, low-pressure suction piping with appropriately sized relief valves is a preferable arrangement to higher-design-pressure suction piping.

Adding an interlock to isolate the makeup line on indication of high makeup pump suction pressure was considered but not incorporated. The added complication of potentially isolating the makeup line on spurious signals, combined with the low probability of a makeup pump suction line ISLOCA, make this interlock undesirable.

3.4 PRIMARY SAMPLING SYSTEM

3.4.1 Description of Primary System Interface

The PSS collects representative samples of fluids from the RCS and associated auxiliary system process streams, and the containment atmosphere for analysis by the plant operating staff. Since fluids are collected outside the containment, the PSS is the system that connects directly to the RCS and carries reactor coolant outside containment. DCD subsection 9.3.3 provides a complete description of the various functions and operations associated with the PSS. Figure 3-4 is the PSS P&ID modified to clearly indicate all high-pressure/low-pressure interfaces. As shown, almost the entire PSS is designed to withstand full RCS pressure.

The following portions of the PSS are designed to lower pressure than the full RCS pressure in the PSS:

- Eductor water storage tank (EWST)
- Demineralized water supply line

The PSS connects to the RCS at several locations, including the pressurizer steam space, pressurizer liquid space, and each hot leg. Each connection contains a flow-restricting orifice that limits the flow from the RCS in the event of a break of a sample line. These orifices also reduce the pressure in the sampling lines during sampling operations. During the sampling of the RCS, the operator opens the appropriate sample line isolation valve (for example, V003 for RCS pressurizer liquid sample) and opens the two remotely operated containment isolation valves (V010A or B, and V011). The sample passes through a sample cooler, and it is collected in the appropriate sample bottle. For a typical sample operation, the operator will purge the sample line to the WLS degasifier. When a sufficient volume of coolant has been purged, the operator closes the isolation valves downstream and upstream of the appropriate sample chamber, and then closes the remotely operated valves.

3.4.2 Design Evaluation and Justification

It is not practicable to design the low pressure portions of the PSS to a higher design pressure. These portions of the PSS are at atmospheric pressure and connect to the low-pressure demineralized water system (DWS). Designing the low-pressure EWST to high pressure, to meet ISLOCA criteria, would then require the DWS to be designed for high pressure. As discussed in section 3.6, this is not practicable.

During sampling operations, flow limiting orifices plus the small diameter of the PSS lines limit flow to approximately 0.5 gpm, and the PSS lines are never pressurized above the design pressure of the low-pressure portions of the PSS. The PSS high pressure/low pressure interface occurs within the grab sample panel, which is a standard panel with design features to prevent backflow and overpressurization of the low pressure portions of the system. Even in the unlikely event that overpressurization would occur, leakage flow from the RCS would be well within the makeup capability of the normally operating makeup system. At any time, the operator would be able to isolate the leak by closing the PSS containment isolation valves.

For this event, assuming operation of the normal makeup system, the operator would identify the break, and/or the radiation monitors and alarms in the auxiliary building, and take actions to terminate the leak within 30 minutes. The radioactive releases resulting from such a beyond-design-basis event are within the design basis analysis contained in DCD subsection 15.6.2. For this event, assuming the normal makeup system is not available, the PSS containment isolation valves would automatically close on the safeguards actuation signal resulting from the loss of coolant and terminate the event.

3.5 SOLID RADWASTE SYSTEM

3.5.1 Description of Primary System Interface

The solid radwaste system (WSS) provides the storage facilities for both wet and dry solid wastes prior to and subsequent to processing and packaging. As shown in Figure 3-2, the WSS connects to the high-pressure CVS demineralizers to facilitate transfer of the spent resin from the CVS demineralizers to the spent resin storage tanks. The spent resin header connects to each of the three high pressure CVS demineralizers with an individual, normally closed isolation valve in each line. The spent resin header then penetrates containment with two normally closed, locked-closed, containment isolation valves (V040 and V041). A manual valve, placed downstream of the second containment isolation valve, isolates the downstream piping to facilitate containment isolation leak-testing. Figure 3-2 shows the high-pressure/low-pressure interface across this valve (V039).

3.5.2 Design Evaluation and Justification

It is not practical or necessary to design the WSS to a higher design pressure. The system contains many low-pressure components, such as spent resin tanks and resin transfer and resin mixing pumps. The WSS spent resin line meets the ISLOCA criteria for low-pressure systems by providing locked-closed isolation valves and administrative procedures to protect the low-pressure portion of the system.

The WSS spent resin line is normally isolated by the locked-closed manual containment isolation valves. These containment isolation valves are administratively controlled and are leak-tested in accordance with the AP1000 In-Service Testing (IST) Plan DCD subsection 3.9.6. The CVS demineralizers are inside containment and normally circulate reactor coolant at RCS operating pressure. As such, resin transfer operations cannot be performed at normal power operations. These operations are conducted during refueling operations, when the RCS is fully depressurized. Therefore, since this spent resin line can be opened only when the RCS is depressurized, and the high-pressure valves in the spent resin line that isolates the low-pressure portion of the system are administratively locked closed and regularly leak-tested, the WSS spent resin lines are not required to be designed to a higher design pressure.

3.6 DEMINERALIZED WATER TRANSFER AND STORAGE SYSTEM

3.6.1 Description of Primary System Interfaces

The DWS is a low-pressure water transfer system consisting of tanks, pumps, piping, valves, and associated instrumentation and controls. It interfaces with the high-pressure portion of the PSS as shown in Figure 3-4, and the high-pressure CVS purification loop as shown in Figure 3-2. Each interface is discussed separately as follows.

Demineralized Water Transfer and Storage System Interface with Primary Sampling System

The DWS contains a supply header inside containment that interfaces with the PSS piping. Before RCS sampling, the operator uses demineralized water to flush the PSS lines by opening the DWS isolation valve V007. After the line has been flushed, the valve is reclosed and the appropriate sample isolation valve is opened.

As discussed in section 3.4, the PSS is protected from overpressurization by the passive flow- restricting orifice in the PSS connections to the RCS, and the pressure drop in the PSS lines. Pressurization of the PSS cannot occur unless valve V037 is inadvertently closed during RCS sampling. In that event, the DWS is protected from overpressurization by the closed isolation valve (V007) and a check valve (V013). In the event that valve V007 were left open at the time that V037 was inadvertently closed, check valve V013 would protect the DWS from overpressurization. Furthermore, check valve V013 leakage or failure to close would result in the overpressurization of the DWS header inside containment.

Demineralized Water Transfer and Storage System Interface with Chemical and Volume Control System Purification Loop

The DWS supply header inside containment also connects to the CVS demineralizers. During shutdown operations, demineralized water is used to sluice resin to the WSS as discussed in section 3.5. To perform these operations, the operator must open manual valves in the CVS. As discussed in section 3.5, these operations can be performed only at shutdown when the RCS is fully depressurized. A potential pressurization pathway could exist if the operators failed to reclose manual valves in the CVS (such as V022A or B) before returning to power operation. In this case, the DWS would be protected from overpressurization by a single check valve (V026). If check valve V026 subsequently leaked or failed to close, the DWS header inside containment would become overpressurized.

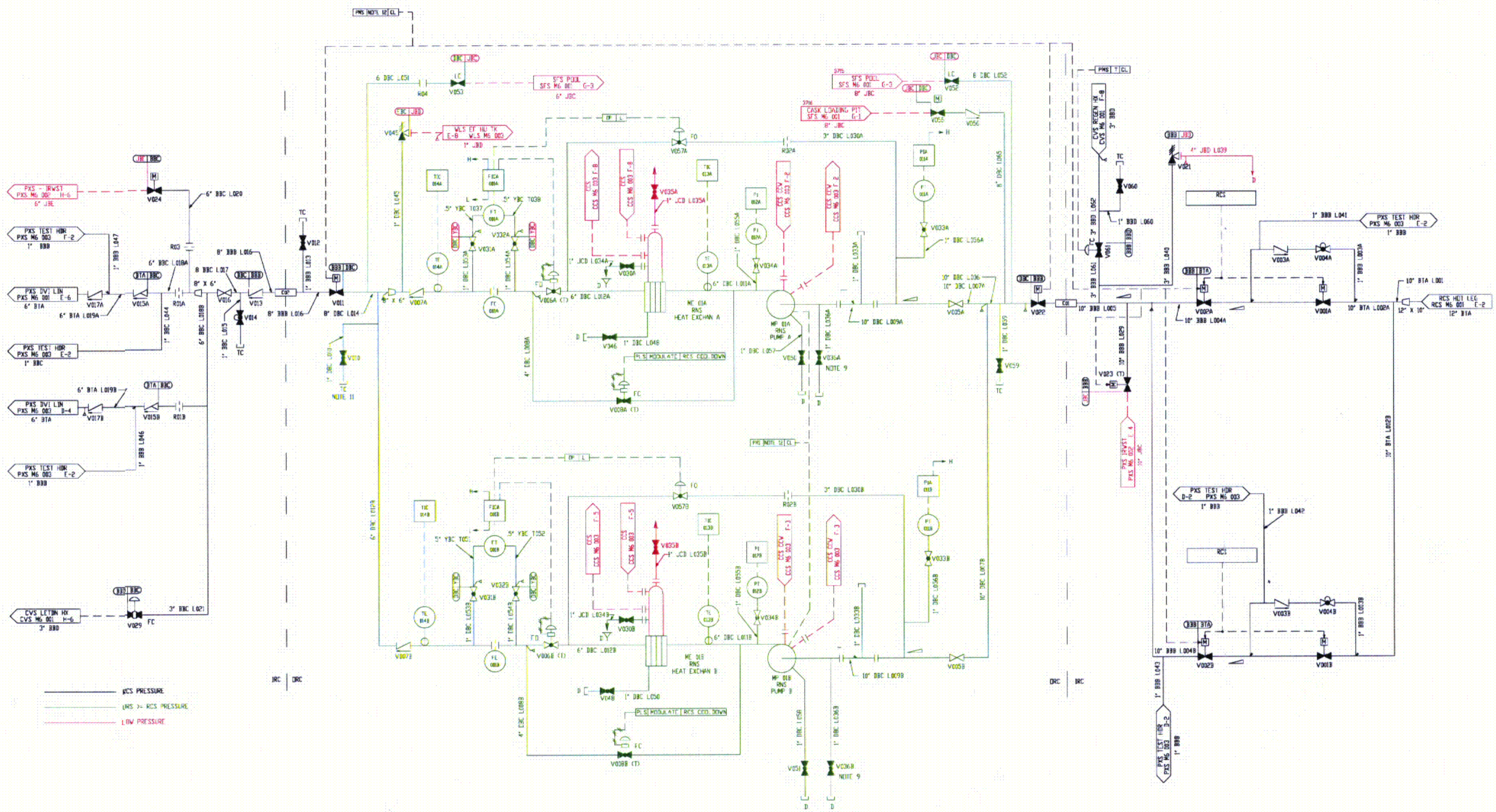
3.6.2 Design Evaluation

The overpressurization pathways for the DWS initiate inside containment. Therefore, an overpressurization of this system would most likely result in the rupture of the DWS header inside containment. This would not result in an ISLOCA, as discussed in section 2 of this report. Any resulting loss of coolant would be maintained inside containment. If the source of the pressurization were the PSS, the scope of the event would be limited to a leak inside containment within the capabilities of the CVS makeup pumps. However, if the source of the pressurization pathway were the CVS purification loop, the break size could be larger, and most likely, would result in a safeguards actuation signal. The safeguards actuation signal would isolate the CVS purification loop and terminate the event.

A relief valve has been added to the DWS header inside containment to preclude the possibility of overpressurizing the DWS for these events. This relief valve, shown in Figure 3-5, discharges to the containment.

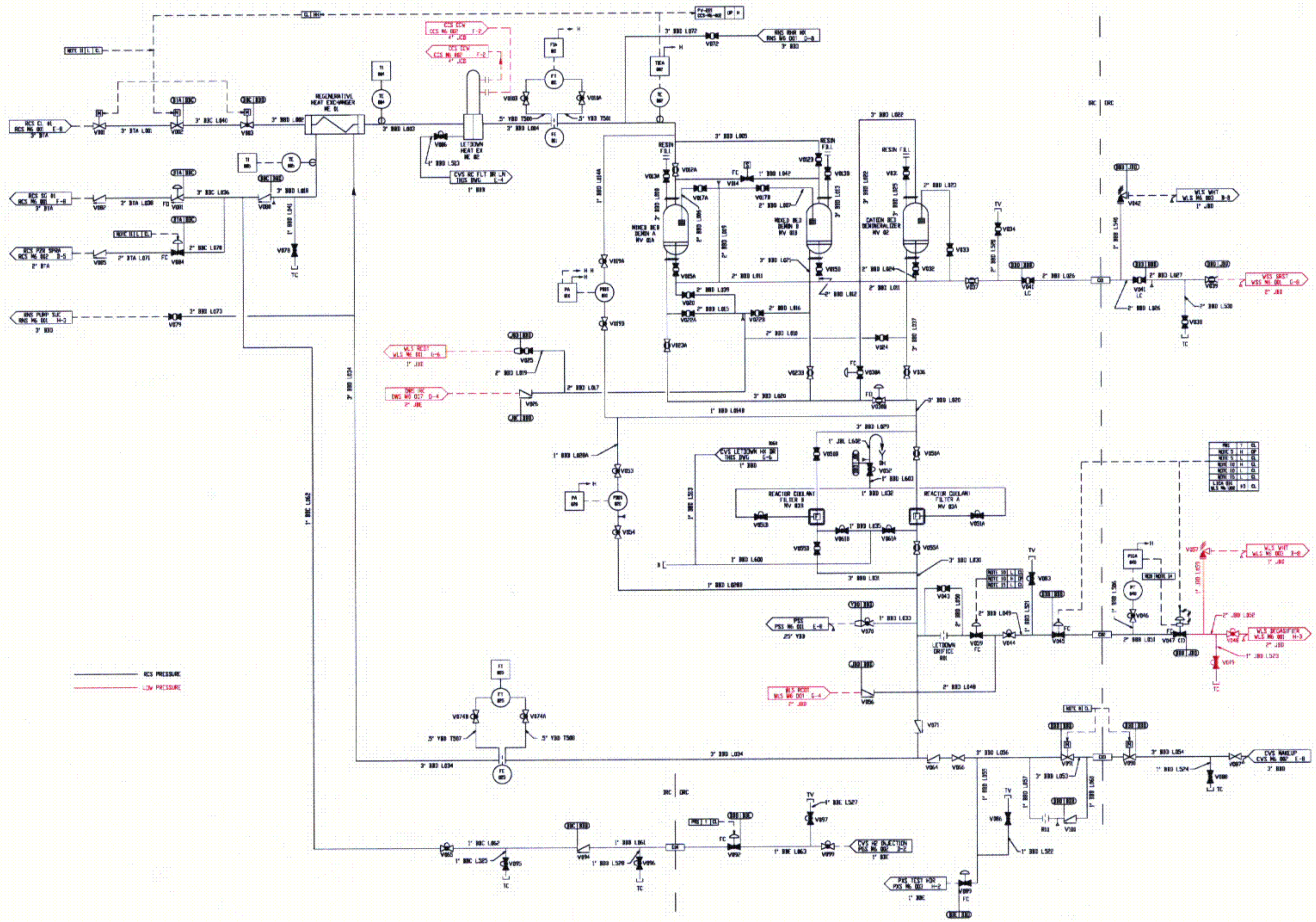
3.6.3 Justification of Design

The DWS meets the ISLOCA criteria for low-pressure systems because an overpressurization of the system from the high-pressure RCS does not result in a loss of coolant outside containment. The DWS inside-containment supply header interfaces with two potentially high-pressure systems containing reactor coolant. In either case, overpressurization can only occur if there are multiple failures and misalignments of isolation valves and check valves in the high-pressure systems. For those events, the relief valve in the DWS supply header prevents an ISLOCA.



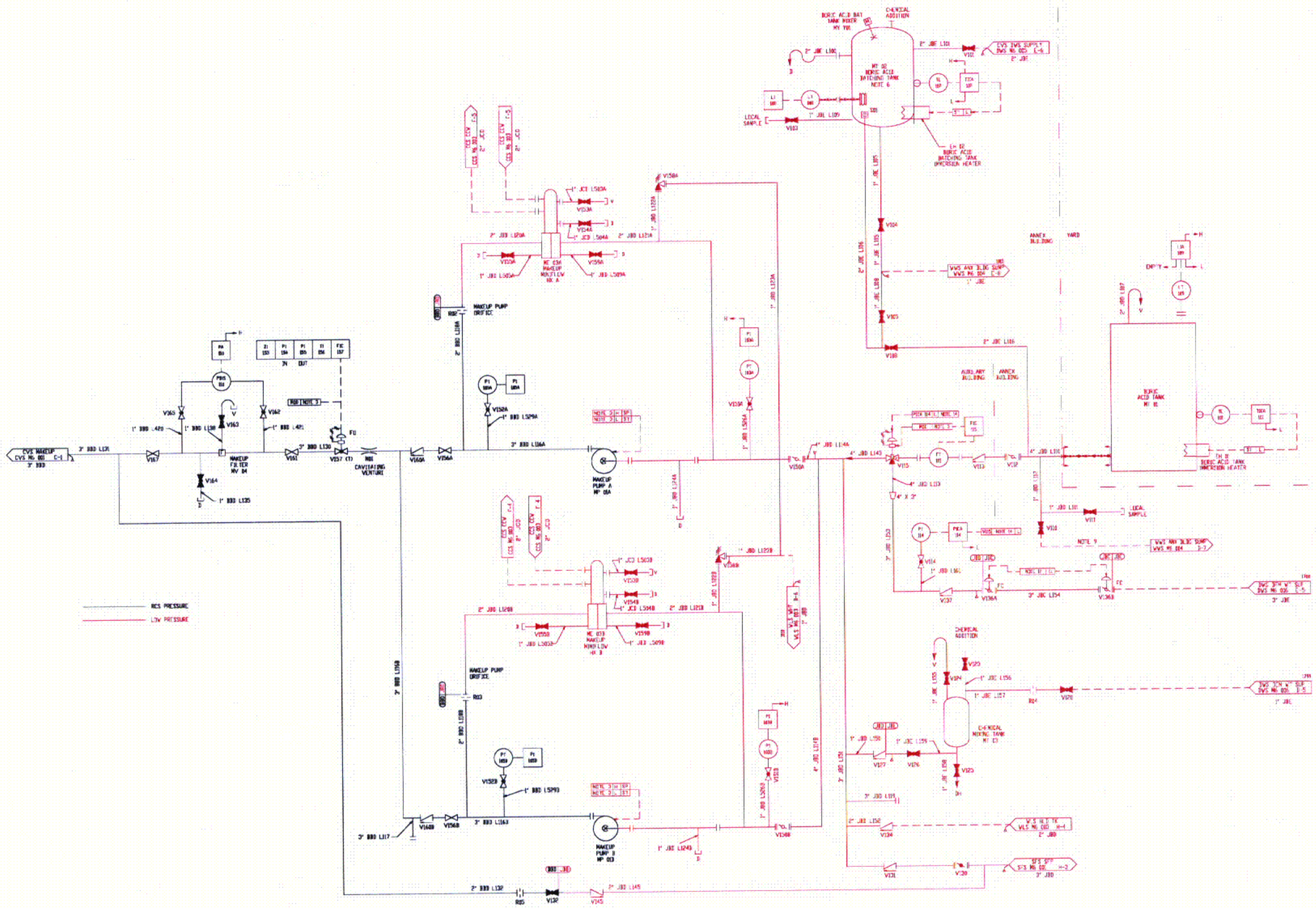
C01

Figure 3-1
Normal Residual Heat Removal System



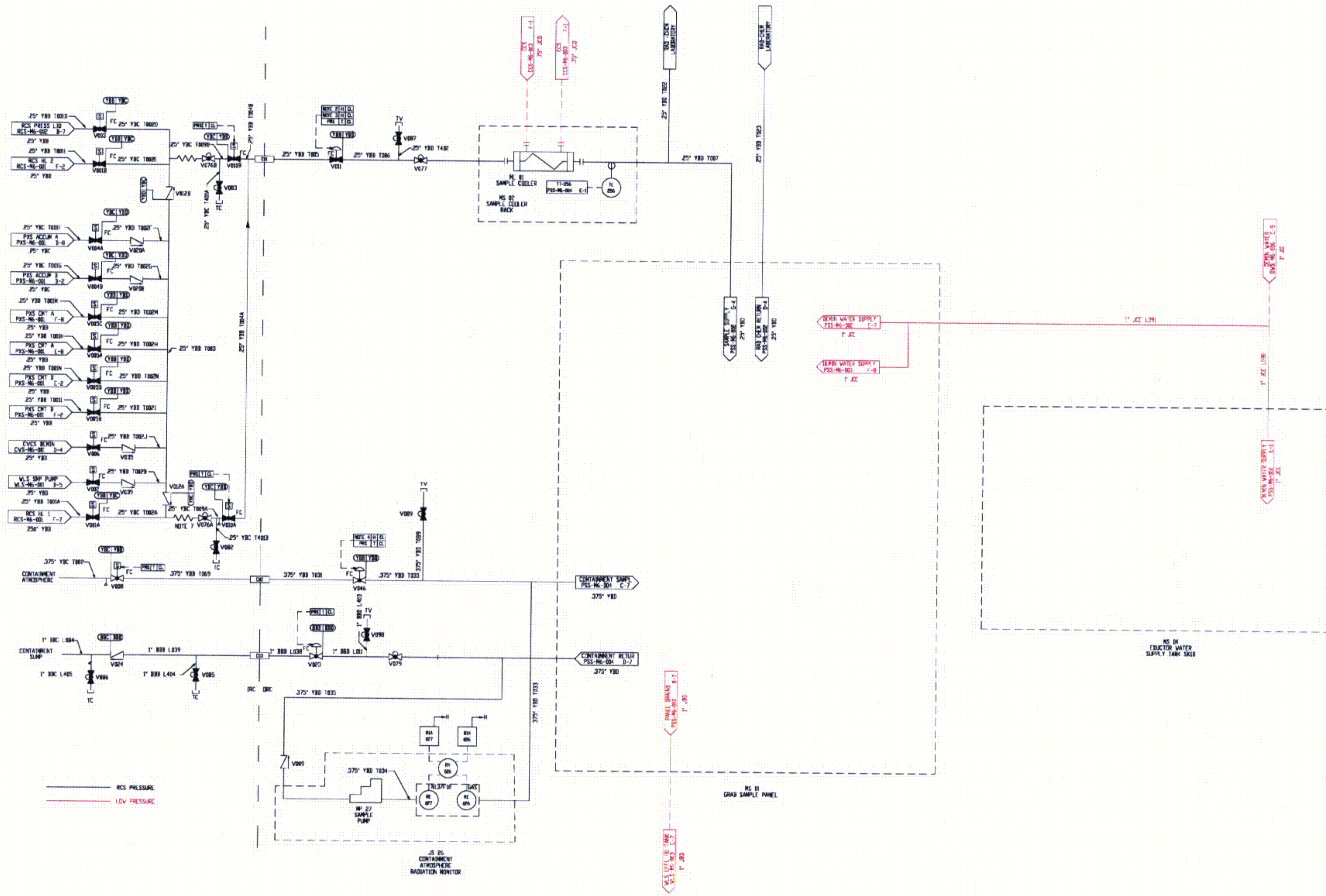
C02

Figure 3-2
Chemical and Volume Control System
Purification Loop



C03

Figure 3-3
Chemical and Volume Control System
Makeup Pumps



C04

Figure 3-4
Primary Sampling System

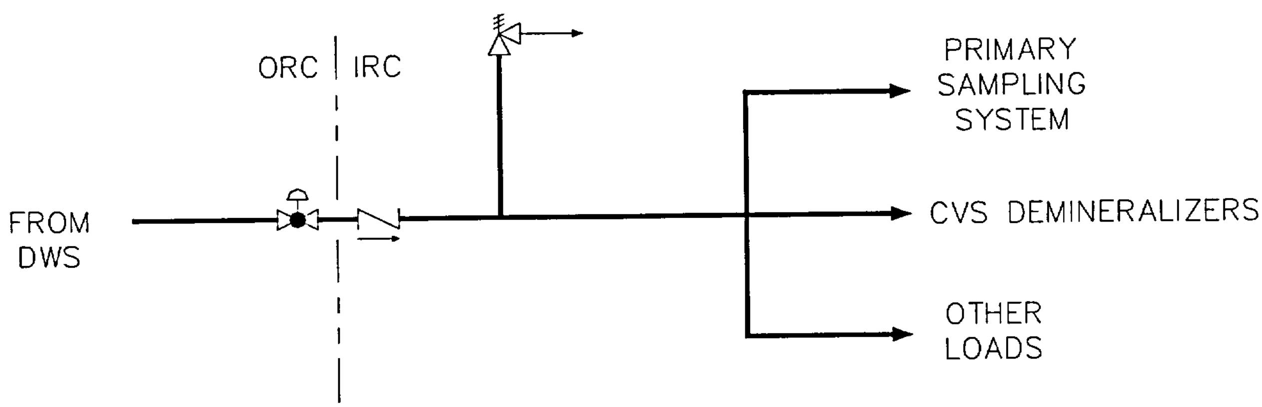


Figure 3-5 Demineralized Water System Supply Header Inside Containment

4 CONCLUSIONS

The AP1000 has incorporated various design features to address ISLOCA challenges. These design features have resulted in the low AP1000 core damage frequency for ISLOCA compared with that of current plants. These design features are primarily associated with the RNS and are discussed in detail in section 3 of this report as well as DCD subsection 5.4.7. This report was prepared to document the comprehensive systematic evaluation of the AP1000 design for conformance to the ISLOCA acceptance criteria in the various referenced NRC documents. As a result of this study, additional design features have been incorporated in the AP1000 design and are documented in the AP1000 DCD. The following table provides a summary of AP1000 design features incorporated to meet the ISLOCA acceptance criteria.

Table 4-1 Summary of AP1000 ISLOCA Design Features

System/Subsystem	Major Design Features	Figure Number
RNS	• Increased design pressure of the RNS outside containment to a URS equal to full RCS pressure	3-1
Letdown line	• High-pressure purification loop inside containment to eliminate high-energy letdown outside containment • Letdown orifice to limit leakage from a letdown line ISLOCA • Automatic isolation of letdown on safeguards actuation • Relief valve added to prevent overpressurization of letdown line	3-2
Makeup pump suction	• Relief valves added to minimize the consequences of pump suction overpressurization • High-pressure alarm in pump suction line to alert the operator to overpressurization	3-3
PSS	• Most of PSS designed to full RCS pressure • Flow-restricting orifices to limit scope of ISLOCA • Automatic isolation of PSS on a safeguards actuation signal	3-4
DWS	• Relief valve added to prevent overpressurization of DWS inside containment • Automatic isolation of DWS lines outside containment on safeguards actuation	3-5

5 REFERENCES

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2. NRC Information Notice 92-36, Supplement 1, "Intersystem LOCA Outside Containment," February 22, 1994.

3. NRC Letter, "Preliminary Evaluation of the Resolution of the Intersystem Loss-of-Coolant-Accident (ISLOCA) Issue for the Advanced Boiling Water Reactor (ABWR) - Design Pressure for Low Pressure Systems," Docket Number 52-001.

4. NUREG/CR-5102, "Interfacing System LOCA: Pressurized Water Reactors," February 1989.

5. SECY-90-016, "Evolutionary Light Water Reactor (LWR) Certification Issues and Their Relationship to Current Regulatory Requirement," January 12, 1990.

6. NUREG-0933, "A Status Report on Unresolved Safety Issues," U.S. Nuclear Regulatory Commission, April 1989.

7. SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor Designs," April 2, 1993.

8. NRC Letter, "Clarification of Issues for Evolutionary Advanced Light Water Reactors (ALWR)," to E. E. Kintner (ALWR Steering Committee), May 6, 1991.

9. NUREG/CR-5603, "Pressure-Dependent Fragilities for Piping Components," October 1990.

10. Letter, "Submittal Supporting Accelerated ABWR Schedule-ISLOCA, Issue #42 (GE ABWR SSAR Appendix 3M)," General Electric Company, San Jose, California, July 9, 1993.

11. WCAP-14425, "Evaluation of the AP600 Conformance to Inter-System Loss-of-Coolant Accident Acceptance Criteria," Westinghouse, July 1995.