ENCLOSURE 2

SHINE MEDICAL TECHNOLOGIES, LLC

SHINE MEDICAL TECHNOLOGIES, LLC OPERATING LICENSE APPLICATION SUPPLEMENT NO. 2

FINAL SAFETY ANALYSIS REPORT CHANGE SUMMARY PUBLIC VERSION

Summary Description of Changes	**FSAR Impacts**
Administrative corrections, including correction of table heading, correction of a building name, removal of an uncited reference, and correction of a cross reference to a general arrangement figure.	Table 6b.1-1, Section 9b.7, Section 9b.8, Section 11.2
Update to incorporate tritium purification system (TPS) design changes. The TPS provides a supply of high purity tritium through isotopic separation of tritium and deuterium from the neutron driver assembly system (NDAS) target chamber exhaust. The core TPS technology for isotope separation is the thermal cycling absorption process (TCAP) which separates deuterium and tritium into a high purity tritium stream and a deuterium stream. The TPS design changes incorporate a three-train system, remove interface gloveboxes, remove the above-ground tritium header, provide an external deuterium source, incorporate improvements in glovebox cleanup system design, and incorporate conforming changes throughout the FSAR. The new TPS design improves system reliability and reduces single-point operational failure potential, improving overall system safety and reducing maintenance frequency and complexity. The TPS design supports the SHINE as low as reasonably achievable (ALARA) objectives.	Table 3.1-1, Section 4a2.1, Figure 4a2.1-1, Section 4a2.3, Table 6a2.1-2, Figure 6a2.1-1, Section 6a2.2, Figure 6a2.2-1, Figure 6a2.2-2, Section 7.4, Table 7.4-1, Figure 7.4-1, Figure 7.4-2, Section 7.5, Table 7.5-1, Table 7.5-2, Figure 7.5-1, Figure 7.5-4, Section 7.7, Table 7.7-1, Section 8a2.2, Table 8a2.2-1, Table 8a2.2-2, Section 9a2.1, Figure 9a2.1-3, Figure 9a2.1-4, Section 9a2.7, Table 9a2.7-1, Table 9a2.7-2, Table 9a2.7-3, Figure 9a2.7-1, Section 9b.7, Table 9b.7-5, Section 11.1, Table 11.1-5, Section 13a2.1, Section 13a2.2, Table 13a2.2-1, Table 13a2.2-2, Table 13a3-1
Update to incorporate primary closed loop cooling system (PCLS) design changes. The PCLS design has been updated to incorporate SHINE design criteria 34, confinement isolation. This change improves the reliability of PCLS isolation safety functions.	Table 3.1-1, Section 5a2.2, Figure 5a2.2-1, Section 7.4, Figure 7.4-1

Summary Description of Changes	**FSAR Impacts**
Update to incorporate irradiation facility (IF) cooling room design changes (i.e., applicable to eight cooling rooms, one for each irradiation unit [IU] cell). The cooling room design has been updated to remove the wall separating PCLS equipment from radiologically controlled area ventilation (RVZ) equipment. The wall is not needed to provide structural, shielding, or confinement functions. Several figures that are updated to remove the cooling room wall have also been updated to incorporate additional changes, including: TPS room expansion, addition of room labels, and removal of precast tank vault depictions.	Figure 1.3-1, Figure 1.3-2, Figure 3.4-7, Figure 4a2.1-1, Section 4a2.5, Figure 4a2.5-1, Section 6a2.1, Section 6a2.2, Figure 6a2.2-1, Section 9a2.1, Figure 9a2.1-1, Figure 9a2.1-2, Figure 11.1-1, Figure 11.1-2, Section 13a2.1
Correct references to American Concrete Institute (ACI) standards and Nuclear Regulatory Commission (NRC) regulatory guidance (i.e., ACI 349-13, ACI 318-08, and Regulatory Guide 1.142).	Section 4a2.5, Section 4a2.6, Section 4a2.9, Section 4b.2, Section 4b.5
Correct the SHINE design criteria applicable to the uninterruptable electrical power supply system (UPSS) to align with the UPSS system description in Chapter 8.	Table 3.1-1
Correct the SHINE design criteria associated with the Institute of Electrical and Electronics Engineers (IEEE) standard (i.e., IEEE Standard 379-2000) applied to the target solution vessel (TSV) reactivity protection system (TRPS), the engineered safety features actuation system (ESFAS), and the neutron flux detection system (NFDS) to align with applicable system design descriptions. Also corrected the NFDS design criteria numbering.	Section 7.4, Section 7.5, Section 7.8
Correct the TRPS system description to accurately reflect the process integrated control system (PICS) and TRPS interface associated with the TSV off-gas system (TOGS) radioisotope process facility cooling system (RPCS) supply and return isolation valves, and the TOGS nitrogen vent isolation valves. The corrected interface description provides enhanced reliability associated with isolation functions.	Section 7.4
Correct the supercell confinement description to align with the ESFAS description in Section 7.5.	Section 6b.2, Figure 6b.2-1
Correct the radioactive liquid waste immobilization (RLWI) system interface description to reflect current design. The material handling system (MHS) does not interface with RLWI.	Table 9b.7-1

Summary Description of Changes	**FSAR Impacts**
Update to identify the vacuum transfer system (VTS) lower lift tank target solution valves as primary system boundary components providing redundant isolation functions in combination with the TSV dump tank drain valve isolation to support the IU Cell Safety Actuation. Also corrected the plural identification of the TSV dump tank drain valves.	Section 4a2.6, Section 7.3, Section 7.4
Update to remove FSAR discussion of the integrated safety analysis (ISA).	Section 1.2, Section 3.4, Section 4b.3, Section 12.1, Section 13a2.1, Section 13b.1
Update to incorporate additional instruments within TOGS and PCLS process flow diagrams to be consistent with Chapter 7 instrumentation description.	Figure 4a2.8-1, Figure 5a2.2-1
Update to incorporate changes to the derived air concentration (DAC) estimated levels in IF and RPF areas to reflect the current design.	Table 11.1-6

A markup of the FSAR changes is provided as Attachment 1.

ENCLOSURE 2
ATTACHMENT 1

SHINE MEDICAL TECHNOLOGIES, LLC

SHINE MEDICAL TECHNOLOGIES, LLC OPERATING LICENSE APPLICATION
SUPPLEMENT NO. 2

FINAL SAFETY ANALYSIS REPORT CHANGE SUMMARY
PUBLIC VERSION

FINAL SAFETY ANALYSIS REPORT MARKUP

273 pages follow

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
I-39	Interstate-39
I-90	Interstate-90
IE	initiating event
IF	irradiation facility
~~ISA~~	~~integrated safety analysis~~
ISG	Interim Staff Guidance
IU	irradiation unit
km	kilometer
LEU	low enriched uranium
LWPS	light water pool system
MEPS	molybdenum extraction and purification system
MeV	million electron volt
MHA	maximum hypothetical accident
mi.	miles
MIPS	molybdenum isotope product packaging system

parameters is preferred over multiple controls on a single parameter. If redundant controls on a single parameter are used, a preference is given to diverse means of control on that parameter.

1.2.4 POTENTIAL ACCIDENTS AT THE FACILITY

Potential design basis accidents (DBAs) at the SHINE facility were identified by the application of hazard analysis methodologies to evaluate the design of the facility and processes for potential hazards, initiating events (IEs), scenarios, and associated controls. As described in Chapter 13, these methodologies were applied to both the IF and the RPF. ~~This resulted in an Integrated Safety Analysis (ISA) for the SHINE facility. The ISA was prepared in accordance with applicable guidance as described in Chapter 13.~~ The list of accident categories and IEs that were the basis for the identification of potential DBAs are described in Chapter 13. The following accident categories and IEs are addressed for the SHINE facility. Some are applicable to the IF, some are applicable to the RPF, and some are applicable to both.

- Maximum hypothetical accident (MHA)
- Insertion of excess reactivity
- Reduction in cooling
- Mishandling or malfunction of target solution
- Loss of off-site power
- External events
- Mishandling or malfunction of equipment
- Large undamped power oscillations
- Detonation and deflagration in the primary system boundary
- Unintended exothermic chemical reactions other than detonation
- System interaction events
- Facility-specific events
- Critical equipment malfunction
- Inadvertent nuclear criticality in the RPF
- RPF fire
- Hazardous chemical accidents

Figure 1.3-1 – Production Facility Building General Arrangement

Figure 1.3-1 – Production Facility Building General Arrangement

Figure 1.3-2 – Production Facility Building General Arrangement Section “A-A”

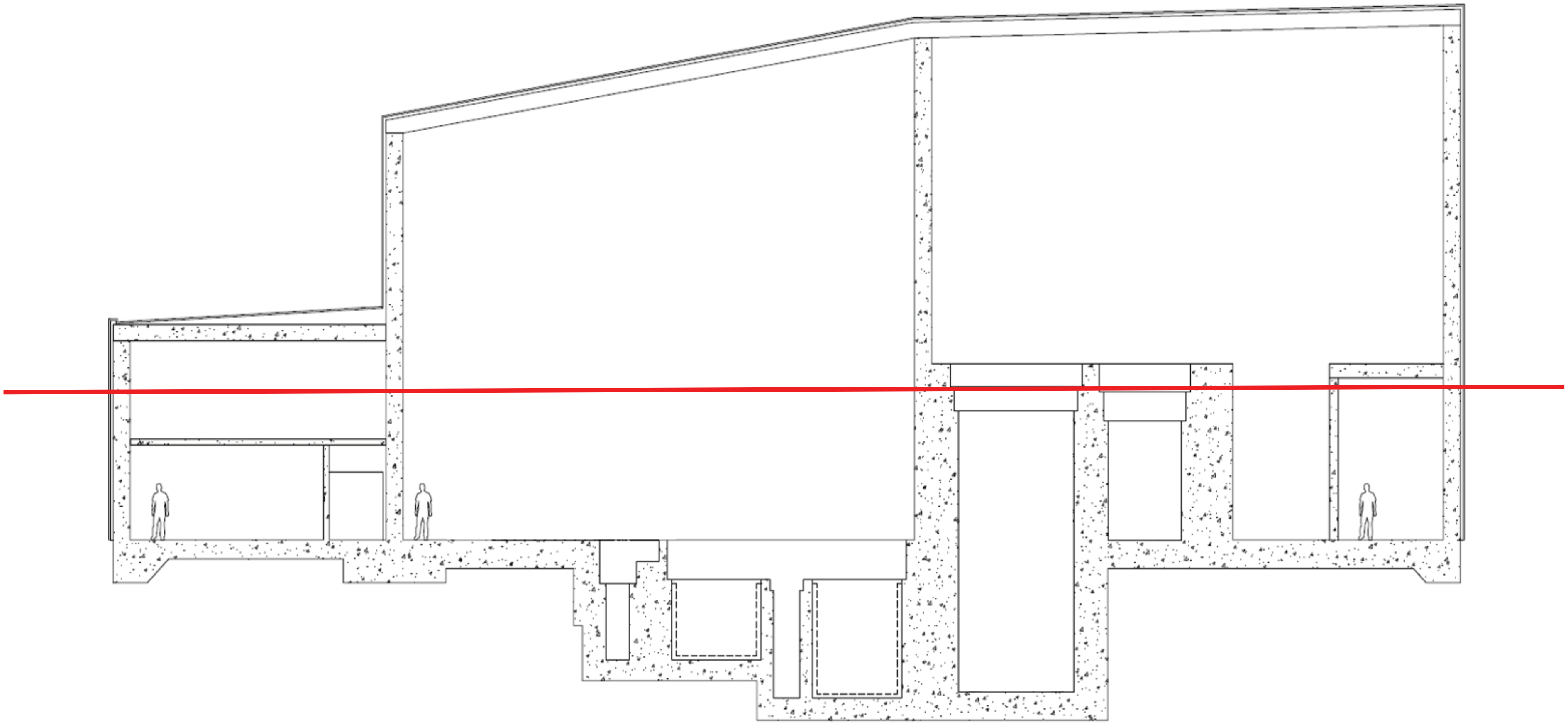


Figure 1.3-2 – Production Facility Building General Arrangement Section “A-A”

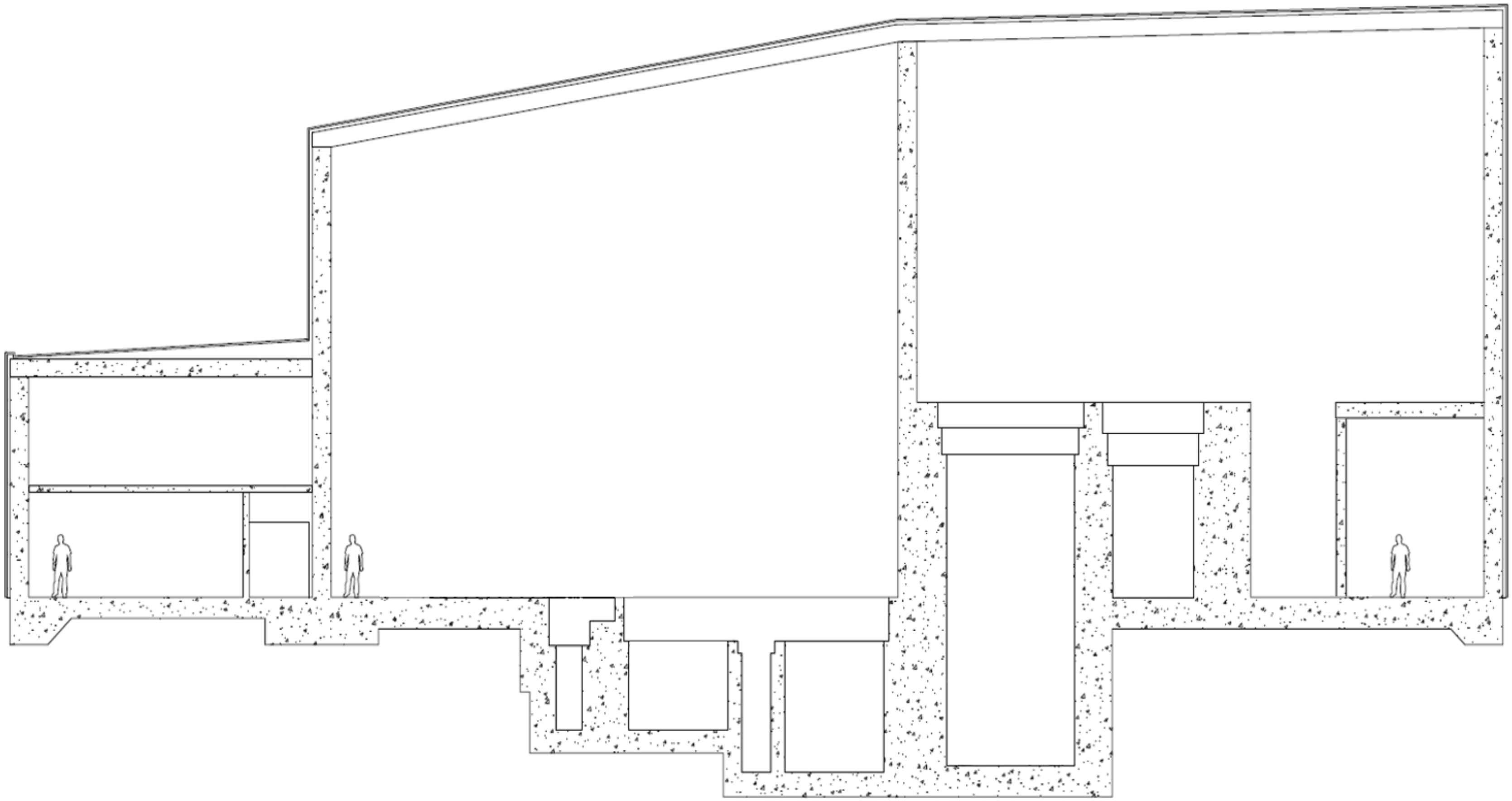


Table 3.1-1 – Safety-Related Structures, Systems, and Components (Sheet 1 of 2)

Structure, System, or Component (SSC)	Acronym	Section	Applicable Design Criteria
Engineered safety features actuation system	ESFAS	7.1.3 7.5	13-19, 37-39
Facility structure	FSTR	3.4.2	2, 6
Irradiation cell biological shield	ICBS	4a2.1 4a2.5	29-36
Iodine and xenon purification and packaging	IXP	4b.1.3 4b.3.1	9, 33, 36-37, 39
Light water pool system	LWPS	4a2.1 4a2.4.2	25, 29-32, 36
Molybdenum extraction and purification system	MEPS	4b.1.3 4b.3	27, 33, 36, 37, 39
Normal electrical power supply system	NPSS	8a2.1	27, 28
Neutron flux detection system	NFDS	4a2.1 7.1.7 7.8	13-19
Nitrogen purge system	N2PS	6b.2.3 9b.6.2	39
Primary closed loop cooling system	PCLS	4a2.1 5a2.2	9, 12, 21, 29, 33, 34
Process vessel vent system	PVVS	4b.1.3 9b.6.1	35, 39
Production facility biological shield	PFBS	4b.2	29-32, 36
Radioactive drain system	RDS	9b.7.6	36, 37
Radioactive liquid waste immobilization	RLWI	9b.7.3	35-38
Radioactive liquid waste storage	RLWS	4b.1.3 9b.7.4	35-36, 38-39
Radiological ventilation zones 1, 2, and 3	RVZ1 RVZ2 RVZ3	9a2.1	29, 30, 32-36
Subcritical assembly system	SCAS	4a2.1 4a2.2	9-11, 20, 22-25, 29-34, 36, 39

Table 3.1-1 – Safety-Related Structures, Systems, and Components
(Sheet 2 of 2)

Structure, System, or Component (SSC)	Acronym	Section	Applicable Design Criteria
Target solution preparation system	TSPS	4b.1.3 4b.4.2 9b.2.3,	29-32, 36-37
Target solution staging system	TSSS	4b.1.3 4b.4 9b.2.4	36, 37, 39
Tritium purification system	TPS	4a2.1 9a2.7.1	~~12,~~ 29-35, 38
TSV off-gas system	TOGS	4a2.1 4a2.8	12, 20, 22-24, 29, 33-34, 37, 39
TSV reactivity protection system	TRPS	7.1.2 7.4	13-19, 38-39
Uninterruptible electrical power supply system	UPSS	8a2.2	~~29-30~~27-28
Uranium receipt and storage system	URSS	4b.1.3 4b.4.2	29-33, 36-37
Vacuum transfer system	VTS	4b.1.3 9b.2.5	36-37

Note 1: This table contains SSCs where at least one constituent component is classified as safety-related.

Note 2: The generally-applicable design criteria 1-8 from Table 3.1-3 are not specifically listed even though they are generally applicable to most SSCs, with the exception of criterion 2 and criterion 6, which are specifically applied to the FSTR due to the unique relationship of these criteria to the facility structure.

Note 3: Instrumentation, control and protection system-related design criteria 13-19 from Table 3.1-3 are only applied to the ESFAS, TRPS, and NFDS (i.e., the safety-related instrumentation and control systems). Other systems that include safety-related instrumentation that provides input to the safety-related instrumentation and control systems implement these criteria via flow down requirements from the safety-related instrumentation and control systems.

Laboratory UCRL-ID-123577 (UCRL, 1997) to correspond to 99.5 percent of impact velocity probability distribution.

Each wall that protects safety-related equipment was evaluated for impacts at the center of the wall panel and at critical locations near the edge of the wall panel. Each roof that protects safety-related equipment was evaluated for impacts near the end of the roof truss, at the center of the roof truss, at the center of the roof panel between trusses.

The local response evaluation was conducted using empirical equations in accordance with DOE-STD-3014-2006 (DOE, 2006). The structure was shown to resist scabbing and perforation. A punching shear failure was not postulated based on Appendix F of ACI 349-13 (ACI, 2014). Scabbing and perforation thickness requirement was calculated using DOE-STD-3014-2006 (DOE, 2006).

Because engine diameter and engine weight are both critical for the local evaluation, the local impact evaluation was performed for the Hawker 400 as well as the Challenger 605 aircraft. The Challenger 605 and Hawker 400 are evaluated as design basis aircraft impacts.

To evaluate the capability of the structure to withstand impact from an aircraft, each wall that is subject to potential impact from an aircraft missile is evaluated. Figure 3.4-7 shows the openings in the building which are evaluated as missile barriers.

The design basis aircraft impacts have been evaluated against the acceptance criteria of ACI 349-13 (ACI, 2014) for concrete and ANSI/AISC N690-12 (ANSI/AISC, 2012) for steel and it has been demonstrated that all components of the FSTR structure that are relied upon to provide impact protection have adequate energy absorption capacity to perform their design basis function.

3.4.5.2 EXPLOSION HAZARDS

Because the SHINE facility is not licensed as an operating nuclear reactor, explosions postulated as a result of the design basis threat as defined in Regulatory Guide 5.69, Guidance for the Application of Radiological Sabotage Design-Basis Threat in the Design, Development and Implementation of a Physical Security Program that Meets 10 CFR 73.55 Requirements (USNRC, 2007e), are not considered. However, accidental explosions due to transportation or storage of hazardous materials outside the facility and accidental explosions due to chemical reactions inside the facility are assessed~~ in the integrated safety analysis~~.

The maximum overpressure at any safety-related area of the facility from any credible external source is discussed in Subsection 2.2.3). The seismic area is protected by outer walls and roofs consisting of reinforced concrete robust enough to withstand credible external explosions as defined in Regulatory Guide 1.91, Revision 2, Evaluations of Explosions Postulated to Occur at Nearby Facilities and on Transportation Routes Near Nuclear Power Plants (USNRC, 2013c).

Figure 3.4-7 – Building Envelope Openings Evaluated as Missile Barriers

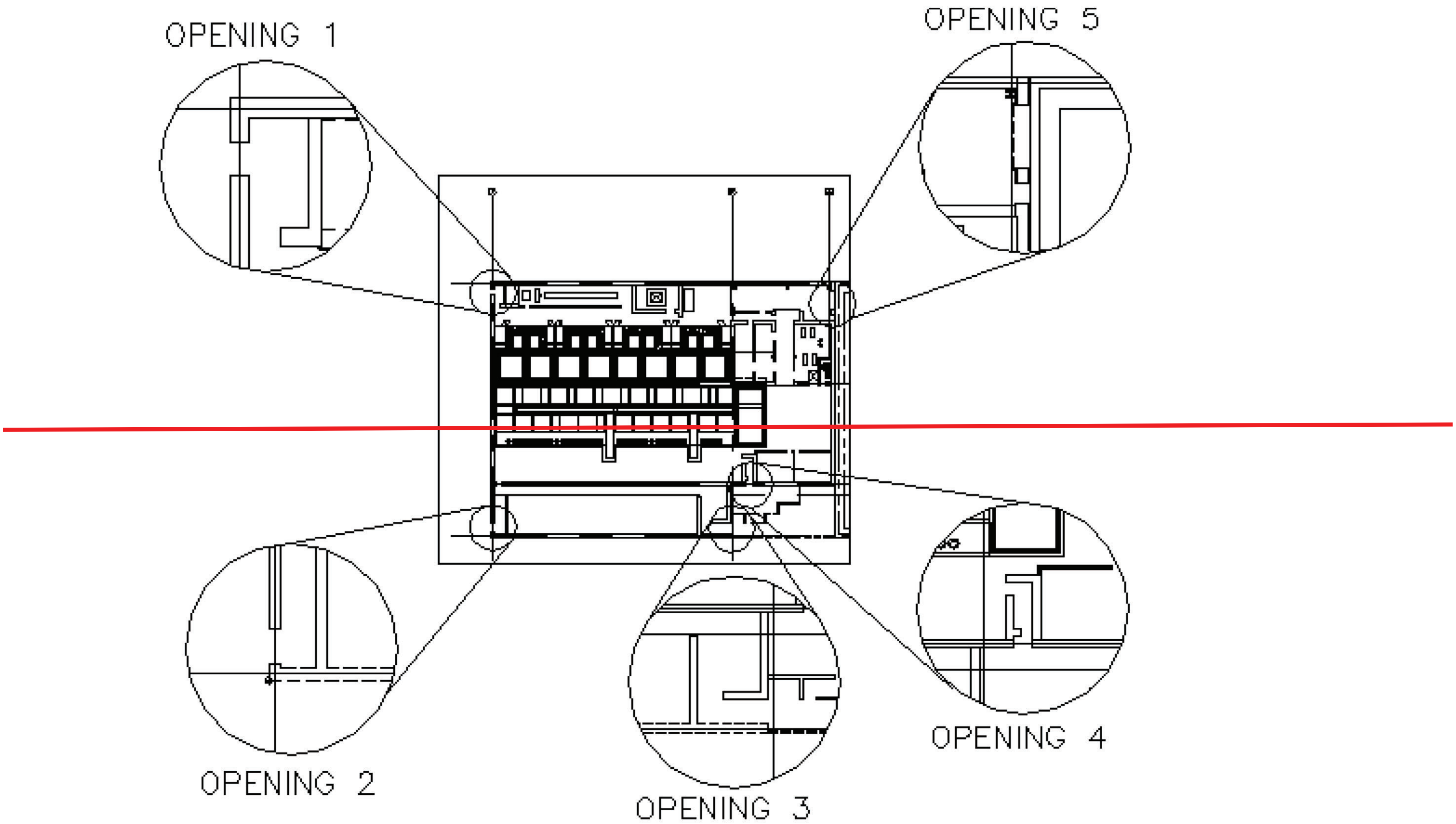
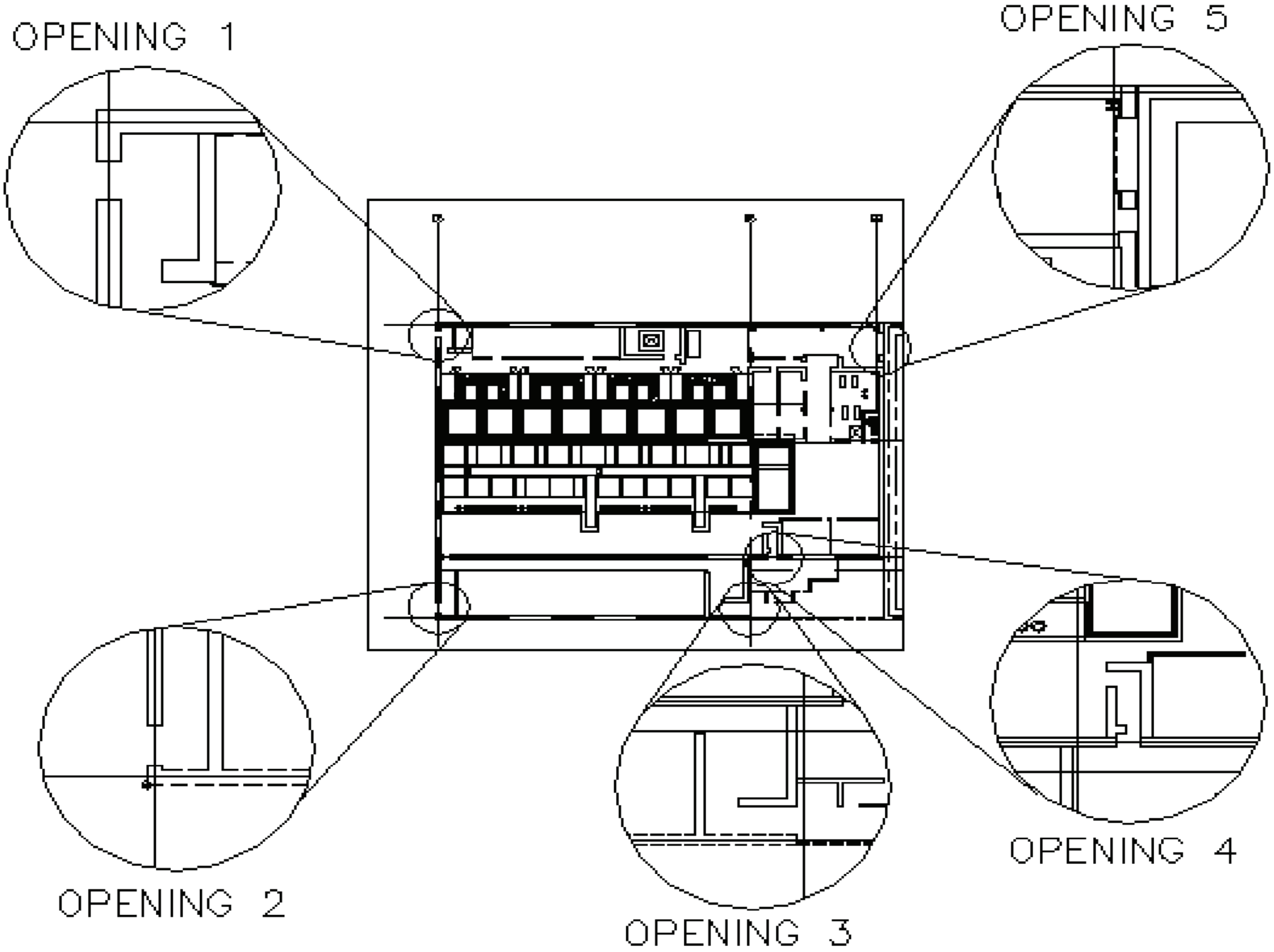


Figure 3.4-7 – Building Envelope Openings Evaluated as Missile Barriers



4a2 IRRADIATION FACILITY DESCRIPTION

This section describes the SHINE irradiation units and supporting systems used for the irradiation of uranyl sulfate target solution as part of the irradiation facility (IF).

4a2.1 SUMMARY DESCRIPTION

An irradiation unit (IU) is an accelerator-driven subcritical operating assembly used for the irradiation of an aqueous uranyl sulfate target solution, resulting in the production of molybdenum-99 (Mo-99) and other fission products. An accelerator is used to create deuterium-tritium fusion reactions, resulting in the formation of 14 million electron volt (MeV) neutrons. These high-energy neutrons cause various multiplying reactions in the neutron multiplier, which increase the neutron population entering the target solution vessel (TSV). The neutron population in the TSV leads to fissioning of the uranium solution. Without operation of the accelerator, the fission process essentially terminates. Key operating parameters for the IU are provided in Table 4a2.1-1.

An IU cell is comprised of the following (see Figure 4a2.1-1):

- Biological shielding: The IUs are surrounded by a biological shield that protects facility workers from sources of radiation inside the IU cell. A detailed description of the biological shield is provided in Section 4a2.5.
- Neutron driver assembly system (NDAS): An accelerator-based assembly is used to produce 14 MeV neutrons by the fusion of deuterium and tritium in the tritium target chamber. These neutrons then drive the fission reactions required for the production of Mo-99 and other fission products. The neutron driver is suspended above the subcritical assembly on support beams attached to the IU cell walls and is intended to be regularly replaced over the operating life of the facility. A detailed description of the NDAS is provided in Section 4a2.3.
- Light water pool: The light water pool serves two primary functions: shielding and cooling. The light water pool is the safety-related feature provided for heat removal from the subcritical assembly. In the event of a failure of the primary closed loop cooling system (PCLS), the target solution is drained to the TSV dump tank and the thermal mass provided by the light water pool provides sufficient decay heat removal capacity. See Section 4a2.4 for more information on the light water pool. Finally, the light water pool provides shielding necessary to allow manned entry to the IU cells when the IU is shut down and reduces biological shield wall thickness requirements.
- Subcritical assembly system (SCAS): The SCAS consists of the TSV, neutron multiplier, subcritical assembly support structure (SASS), subcritical multiplication source, and other components to safely contain the target solution during the irradiation process.
- Neutron flux detection system (NFDS): Neutron flux monitors are located as shown in Figure 4a2.1-2. A detailed description of the NFDS is provided in Section 7.8.

The systems supporting the IU cell include:

- Tritium purification system (TPS): The TPS is located outside the IU cell except for lines interfacing with the NDAS. The neutron driver is connected to the ~~common~~ tritium system by supply and return lines that pass through the IU cell shield wall. During operation, purified tritium gas is supplied to the tritium target chamber, ~~purified~~ deuterium gas is

Figure 4a2.1-1 – Irradiation Unit Cell Schematic

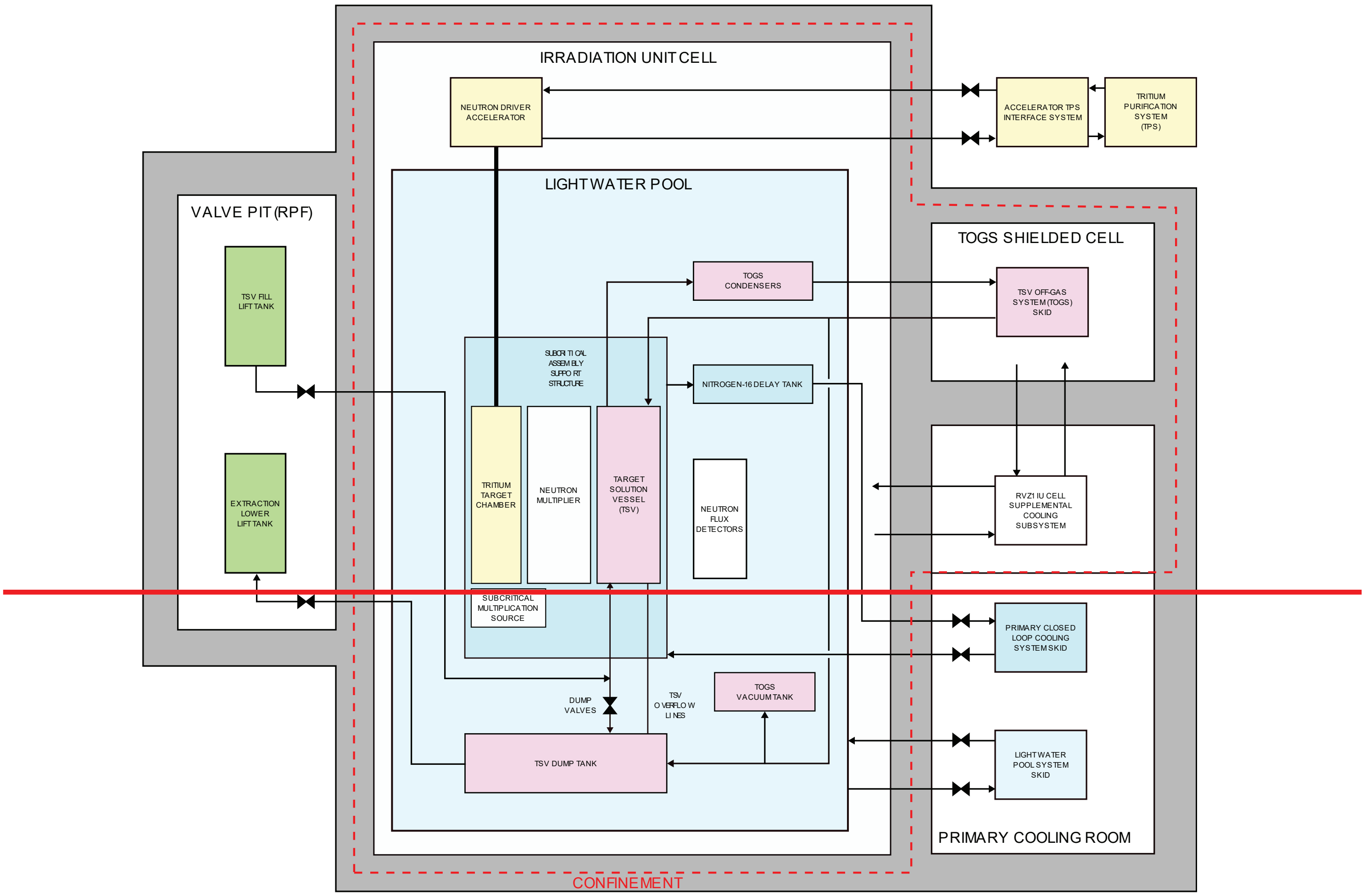
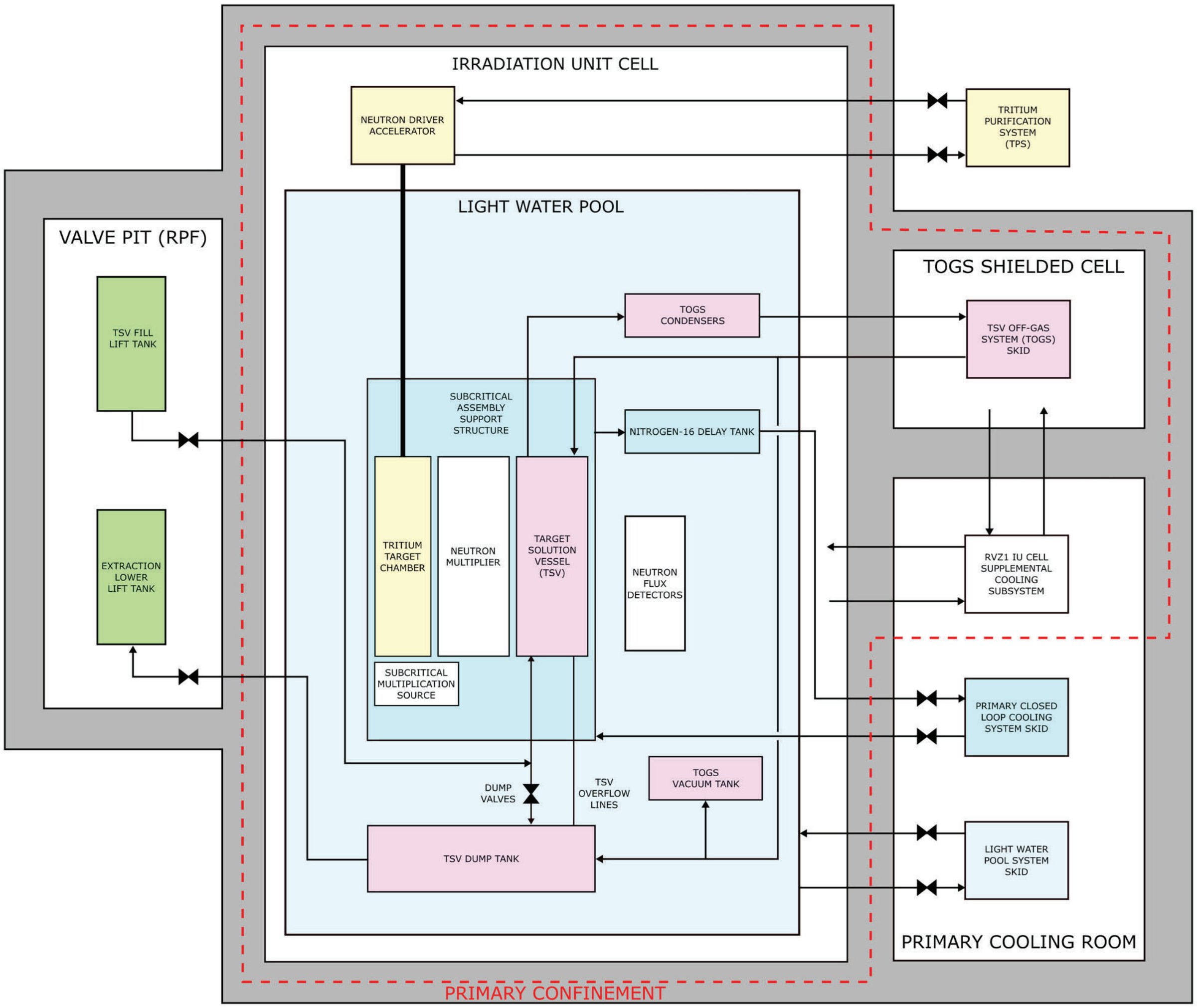


Figure 4a2.1-1 – Irradiation Unit Cell Schematic



4a2.3 NEUTRON DRIVER ASSEMBLY SYSTEM

Within the irradiation facility (IF) there are eight neutron driver assembly systems (NDAS). The NDAS is the source of neutrons used to generate the neutron fluxes required to create medical isotopes in the target solution vessel (TSV) which holds the target solution during irradiation. In the IF, the eight NDAS units operate independently of each other.

The NDAS primary interfaces to the other IF structures, systems, and components (SSCs) include:

- The subcritical assembly system (SCAS) surrounds the NDAS target chamber. The neutrons produced by the NDAS in the target chamber irradiate the solution held by the SCAS. The SCAS is described in Section 4a2.2.
- The tritium purification system (TPS) processes mixed tritium and deuterium gas from the NDAS and returns purified ~~deuterium and~~ tritium to the NDAS. The TPS also provides deuterium to the NDAS as well as cleanup of the NDAS secondary enclosure atmosphere. The TPS is described in Section 9a2.7.
- When necessary, the TSV reactivity protection system (TRPS) can initiate an IU Cell Safety Actuation, which de-energizes the NDAS. The TRPS is described in Section 7.4.

The NDAS produces neutrons by colliding a deuterium (D) ion beam with tritium (T) gas. D-T reactions have a lower energy threshold than any other neutron-producing, accelerator-driven reaction. D-T reactions also have a large cross section and therefore yield neutrons efficiently. Table 4a2.3-1 lists nominal design parameters for the NDAS. The NDAS is part of the tritium process boundary. In order to mitigate tritium leaks, NDAS components that contain tritium gas are designed for vacuum service and are maintained below atmospheric pressure. Component and system design requirements necessary to support vacuum service also inherently support tritium process boundary design objectives (see Section 9a2.7). The NDAS is designed to be able to be evacuated and flushed prior to maintenance operations that would open the tritium process boundary.

The design lifetime of NDAS components is at least [ ]PROP. Neutron fluence on all portions of the NDAS above the light water pool is predicted to be [ ]PROP/ECI. Because of this relatively low fluence, damage from radiation will not impact the NDAS internal structural components and tritium process boundary functions of NDAS components. See Subsection 4a2.3.6 for a discussion of the NDAS structural component safety support functions. Materials with low activation potential have been chosen for use in NDAS components consistent with their potential for exposure to neutron radiation, where practicable.

The NDAS is designed to allow for in-cell maintenance. It has also been designed to be lifted via a crane from the irradiation unit (IU) cell for installation and removal for major maintenance and replacement. Maintenance is performed consistent with the radiation protection controls described in Section 11.1.

Greater than 90 percent of the activity resulting from activation during irradiation operations is located beneath the pool surface. At the end of one irradiation cycle, the expected activity of the NDAS components is 146 Curies. After [ ]PROP of operation, the expected activity of the NDAS components is 210 Curies, and after [ ]PROP, the expected activity of NDAS components is 254 Curies.

Subsection 4a2.6.1.2. NDAS operational variations and TSV power response is described in Subsection 13a2.1.8.

4a2.3.5 TRITIUM DESIGN

The maximum tritium inventory of an individual neutron driver is [ ]$^{\text{PROP/ECI}}$ during operation. Target gas and ion source gas are provided by the TPS which also controls the target gas purity and composition. The TPS supplies target gas at up to approximately [ ]$^{\text{PROP/ECI}}$ per accelerator, and exhausts mixed tritium and deuterium gas from the accelerator at up to approximately [ ]$^{\text{PROP/ECI}}$ per accelerator.

NDAS components that contain tritium gas are designed for vacuum service and are maintained below atmospheric pressure. Components and system design requirements necessary to support vacuum service also inherently support tritium process boundary design objectives.

The NDAS is designed so that no single active failure can result in an uncontrolled release of tritium.

The NDAS detects abnormal in-leakage in the components and subsystems containing tritium gas. Facility operators are alerted upon detection of abnormal tritium process boundary leakage.

Evaluation of accidents involving releases of tritium from the neutron driver is discussed in Subsection 13a2.2.12.

4a2.3.6 SEISMIC DESIGN

Structural support beams support the neutron driver in the IU cell, with components installed above and adjacent to safety-related equipment. Neutron driver components within the IU cell are classified as a Seismic Category II component. The neutron driver structure is designed to maintain structural integrity during and following a design basis seismic event, preventing damage to the IU cell safety-related equipment from the neutron driver due to the event. Seismic qualification of the NDAS is consistent with the methods described in Subsection 3.4.3.

The target stage of the accelerator is connected to the subcritical assembly support structure (SASS) via a flange. This allows proper positioning of the target chamber in relation to the SCAS. The forces that the target stage would apply to the SASS during the design basis earthquake are incorporated into the design of the SASS.

4a2.3.7 TARGET CHAMBER

The target chamber vessel is fabricated from austenitic stainless steel, and is filled with low-pressure ([ ]$^{\text{PROP/ECI}}$) tritium and deuterium. The target chamber central axis is in the center of the IU cell. When the accelerated deuterium ions interact with the tritium gas in the target chamber, many atomic and nuclear interactions occur in the target chamber. One of the interactions is the D-T fusion nuclear reaction, which generates 14 MeV neutrons. The target chamber generates up to 1.5E+14 neutrons per second (n/s) during operation. The number of neutrons generated per second is correlated to subcritical assembly fission power. TSV kinetic behavior, including interactions with the number of neutrons generated by the NDAS, is described in detail in Subsection 4a2.6.1.4.

4a2.5 IRRADIATION FACILITY BIOLOGICAL SHIELD

4a2.5.1 INTRODUCTION

The irradiation cell biological shield (ICBS) provides a barrier to protect SHINE facility personnel and members of the public by reducing radiation exposure to radiation sources within the irradiation facility (IF). ICBS also provides radiation shielding to protect various components and equipment of the SHINE facility. ICBS is comprised of the following concrete enclosures:

- Irradiation unit (IU) cells
- Target solution vessel (TSV) off-gas system (TOGS) shielded cells
- Primary cooling rooms

The IU cells provide shielding from the subcritical assembly, discussed in Section 4a2.2, and from the neutron drivers, discussed in Section 4a2.3. The TOGS shielded cells provide shielding from the TOGS skids, discussed in Section 4a2.8. The primary cooling rooms provide shielding from the primary closed loop cooling system (PCLS) skids, described in Section 5a2.2. The primary cooling rooms also provide shielding from the radiological ventilation zone 1 recirculating subsystem (RVZ1r), described in Section 9a2.1.

A description of radiation source locations and source term characterizations can be found in Chapter 11.

Section 6a2.2 describes the ventilation and confinement functions of the ICBS.

The neutron driver service cell is described in Section 9a2.7.

4a2.5.2 BIOLOGICAL SHIELD DESIGN BASIS

4a2.5.2.1 Materials

The design bases for the materials to be included in the biological shield design are:

- The dose reduction by the biological shielding supports compliance with the as low as reasonably achievable (ALARA) objectives and dose limit required by 10 CFR 20, as described in Chapter 11.
- The dose reduction by the biological shielding supports radiation exposure mitigation during postulated accident conditions as described in Chapter 13.
- The design and construction of the concrete portions of the biological shield conform to NRC Regulatory Guide 1.69, Concrete Radiation Shields and Generic Shield Testing for Nuclear Power Plants (NRC, 2009), with the exception that the ICBS conforms to ACI 349-13 (ACI, 2014) instead of ACI 349-06 (ACI, 2007~~b~~), as described in Subsection 4a2.5.4.2.

4a2.5.2.2 Geometry and Configuration

The general shape of the ICBS is that of rectangular slabs comprising the walls, cover plugs, and shield doors.

subcritical assembly. The interior surface of the primary ~~shield~~cooling room wall was partitioned into two-foot by two-foot sections, and the gamma flux and dose rates in each section were calculated due to the operation of the subcritical assembly and primary cooling system.

For the primary cooling room, the magnitude of the fluxes and dose rates during irradiation is:

- Average gamma flux and dose rate impinging on the interior ~~shield~~ wall: less than 3E+04 gamma/cm^2-s, less than 9E-02 rem/hr
- Peak gamma flux and dose rate impinging on the interior ~~shield~~ wall: less than 9E+04 gamma/cm^2-s, less than 3E-01 rem/hr

4a2.5.3.2 Radiation Damage

4a2.5.3.2.1 Concrete

According to the ANSI/ANS-6.4-2006, Nuclear Analysis and Design of Concrete Radiation Shielding for Nuclear Power Plants, nuclear heating in concrete can be neglected if the incident energy fluxes are less than 1E+10 MeV per square centimeter per second (MeV/cm^2-sec) or if temperatures are maintained below 149°F (65°C) (ANSI/ANS, 2006).

During irradiation, significant neutron and gamma fluxes are created by the irradiation process in the subcritical assembly. The light water pool serves to significantly reduce the magnitude of the fluxes that reach the ICBS. The cumulative effects of the neutron and gamma fluxes from the neutron driver, SCAS, and TOGS sources have been analyzed with MCNP software, and peak energy fluxes in the concrete were found to be less than 1E+10 MeV/cm^2-sec in all areas except immediately below the TSV dump tank, which had a maximum energy flux of 6E+10. With this region of the shielding in direct contact with the light water, which has a maximum temperature of 95°F (35°C) during normal operation, heat transfer from the concrete to the pool water is sufficient to maintain the concrete temperature below the 149°F (65°C) limit. Therefore, no nuclear heating concerns exist.

With regard to degradation, NUREG/CR-7171, A Review of the Effects of Radiation on Microstructure and Properties of Concretes Used in Nuclear Power Plants (NRC, 2013), provides recommended radiation exposure limits for concrete. The most limiting of the values listed are an integrated neutron fluence up to 1E+19 n/cm^2 and an integrated dose of gamma radiation up to 1E+10 rads, which have been shown to not significantly impact structural properties. Using MCNP, analysis of the maximum neutron and gamma doses to the concrete over the 30 year lifetime were < 2E+14 n/cm^2 and < 2E+08 rads, respectively. Given these results, concrete radiation degradation is not significant and does not need additional design considerations.

4a2.5.3.2.2 Steel

No neutron fluxes that could result in degradation or activation of the primary cooling room shield doors are present in the primary cooling room.

4a2.5.3.3 Radiation Streaming

The ICBS requires a number of penetrations, inserts, and other features where the bulk shielding materials are reduced in thickness, or where the materials used in the penetration are less dense than the surrounding bulk material. Each such penetration is designed with well-demonstrated the provisions of ACI 349-13 (ACI, 2014) for applicable normal loads, severe and extreme environmental loads, and abnormal loads, as defined in Section 9.1 of ACI 349-13. See Subsection 3.4.2.6 for details on the structural analysis methodology.

4a2.5.4.1.3 Concrete Radiation Shielding – Final Minimum Thickness

The final minimum thickness of the concrete biological shield structure for the IF is based on the greater of the radiation shielding requirements and the structural requirements. Thicknesses required for shielding are listed in Subsection 4a2.5.2.2.

4a2.5.4.1.4 Load and Strength Reduction Factors

Load and strength reduction factors for the structural design of concrete shield structures and related members will be based on those prescribed in ACI 349-13 (ACI, 2014), Sections 9.2 and 9.3, respectively.

4a2.5.4.1.5 Design of Concrete for Shielding Structures

The design of the concrete for shielding structures, including materials selection, durability requirements, quality control, mixing, placement, formwork, embedded pipes, construction joints, reinforcement, analysis, and design will conform to provisions outlined in Chapters 3 through 8 of ACI 349-13 (ACI, 2014).

4a2.5.4.1.6 Exceptions for Use of ACI 349-13

Regulatory Guide 1.69, Revision 1 (NRC, 2009) includes exceptions to the use of ACI 349-06. SHINE utilizes the revision to ACI 349-06 (ACI, 2007), ACI 349-13 (ACI, 2014), and has identified the following exceptions to align with the intent of the exceptions listed in Regulatory Guide 1.69, Revision 1. ACI 349-13, Section 1.2.2, states that input and output data shall be retained as documentation when software is used for the calculation (ACI, 2014). The software itself and other related documentation shall be retained as well. It is not required that the software be updated regularly.

SHINE does not utilize the following sections of ACI 349-13:

- Section 3.3.1: The exception portion of the section is not followed.
- Section 3.3.2 references ACI 318-08, Section 3.3.2 (ACI, 200~~7b~~8). The text in ACI 318-08, Section 3.3.2 stating, “These limitations ~~may be waived~~shall not apply if, in the judgment of the ~~engineer~~licensed design professional, workability and methods of consolidation are such that concrete can be placed without honeycombs or voids,” is not followed.
- Section 5.4.1~~:~~ references ACI 318-08, Section 5.4.1 (ACI, 2008). The text in ACI 318-08, Section 5.4.1 stating, “If data required by 5.3 are not available, concrete proportions shall be based upon other experience or information, if approved by the licensed design professional. The required average compressive strength f'c~~'~~r of concrete produced with materials similar to those proposed for use shall be at least 1200 psi greater than f'c~~'~~. This alternative shall not be used if f'c~~'~~ is greater than 5000 psi,” is not followed.
- Section 5.6.2.3: “When total quantity of a given class of concrete is less than 50 yd^3, strength tests are not required when evidence of satisfactory strength is submitted to and approved by the licensed design professional,” is not followed. Instead, the provisions of

Regulatory Position 5 of Regulatory Guide 1.142 for strength testing are utilized (NRC, 2001a).

- Section 7.10~~.3:~~ references ACI 318-08, Section 7.10 (ACI, 2008). The text in ACI 318-08, Section 7.10.3 stating, “It shall be permitted to waive the lateral reinforcement requirements of 7.10, 10.13, and 18.11 where tests and structural analysis show adequate strength and feasibility of construction,” is not followed.

4a2.5.5 TEST PROGRAM

ANSI/ANS 6.3.1-1987 (R2015), Program for Testing Radiation Shields in Light Water Reactors (LWR) (ANSI/ANS, 2015), is used as a guide in the development of a test program to be used in evaluating biological radiation shielding in the SHINE facility under normal operating conditions, including anticipated operational occurrences.

4a2.5.6 TECHNICAL SPECIFICATIONS

Certain material in this section provides information that is used in the technical specifications. This includes limiting conditions for operation, setpoints, design features, and means for accomplishing surveillances. In addition, significant material is also applicable to, and may be referenced by the bases that are described in the technical specifications.

Figure 4a2.5-1 — Irradiation Facility Biological Shield (not to scale)
(Sheet 1 of 2)

Figure 4a2.5-1 — Irradiation Facility Biological Shield (not to scale)
(Sheet 1 of 2)

4a2.6 NUCLEAR DESIGN

The irradiation unit (IU) for the SHINE facility employs an aqueous homogeneous target solution of uranyl sulfate which is irradiated by an external neutron source for production of medical isotopes. The irradiation facility (IF) consists of eight independent IUs, each consisting of the neutron driver assembly system (NDAS), subcritical assembly system (SCAS), primary closed loop cooling system (PCLS), target solution vessel (TSV) off-gas system (TOGS), light water pool, and supporting systems. The tritium purification system (TPS) is shared between the eight IUs. These systems operate in conjunction to achieve conditions and neutron fluxes sufficient to reach desired fission (molybdenum-99 [Mo-99] production) rates. The subsections that follow outline the nuclear parameters and characteristics of the subcritical assembly throughout its life cycle. These analyses show that the system is inherently stable during both steady-state and transient operations.

4a2.6.1 NORMAL OPERATING CONDITIONS

The normal operating conditions for the subcritical assembly are most significantly affected by four factors:

- uranium concentration in the target solution;
- fill height of the TSV;
- target solution temperature; and
- neutron driver neutron generation rate.

The SCAS is designed to remain in the subcritical operating region in all operating modes. The five modes that are used to describe the subcritical assembly status:

- Mode 0 – Solution Removed: No target solution in the SCAS
- Mode 1 – Startup: Filling the TSV
- Mode 2 – Irradiation: Operating mode (neutron driver active)
- Mode 3 – Post-Irradiation: TSV dump valves open
- Mode 4 – Transfer to radioisotope production facility (RPF): Dump tank drain valve~~s~~ opens to permit solution transfer

Modes 1, 2, and 3 are relevant to the nuclear design and are discussed in this section. Figure 4a2.1-2 provides the configuration of the SHINE subcritical assembly and is a useful reference in understanding this subsection and the relationship between components in the different operating modes. These modes are also described in Section 7.3.

Mode 1: Startup Mode

Prior to entering startup mode (filling the TSV), the TSV dump tank is empty and the target solution hold tank is filled with target solution (see Figure 4a2.2-1). Chemical and physical properties of the target solution are described in Subsection 4a2.2.1. The target solution uranium concentration, catalyst concentration, and pH are measured and adjusted as necessary to ensure parameters are within the prescribed technical specification limits. At a minimum, sampling is performed after preparation of a new batch and after making adjustments to an existing batch, prior to transferring the batch to the TSV.

The difference between the weighted average k_{eff} and 1 is the bias. The bias is calculated using the methodology in Section 2.4.1 of NUREG/CR-6698, Guide for Validation of Nuclear Criticality Safety Calculational Methodology (NRC, 2001b).

For conservatism, positive bias (i.e., where MCNP is found on average to over-predict k_{eff}) is assumed to be zero for the purposes of determining TSV dump tank and TOGS reactivity.

Bias uncertainty is calculated based on the pooled variance of the data used to calculate the bias and a one-sided tolerance factor. The bias uncertainty is calculated using the methodology described in Section 2.4.1 of NUREG/CR-6698 (NRC, 2001b).

MCNP statistical uncertainty is accounted for in the calculation by adding two times the standard deviation in k_{eff} reported by MCNP ($\sigma_{keff,MCNP}$) to the k_{eff} reported by MCNP ($k_{eff,MCNP}$).

The TSV dump tank and TOGS are designed to a k_{eff} value of less than 0.95 at the most reactive uranium concentration and at cold conditions. Reactivity analysis for the TSV dump tank and TOGS satisfies the following inequality:

$$k_{eff,\,MCNP} + 2\,\sigma_{keff,\,MCNP} \le K_L - 0.05 - \Delta A0A$$

Where:

- K_L is the weighted single-sided lower tolerance limit.
- $\Delta A0A$ is an additional margin of subcriticality that may be necessary as a result of extensions to the area of applicability.

Both of these values are determined following the methodology of Section 2.4.4 of NUREG/CR-6698 (NRC, 2001b). K_L includes the effects of bias and bias uncertainty.

The methodology ensures with a high degree of confidence that the target solution is safely shut down by appropriately accounting for uncertainty in MCNP and providing margin to criticality.

See Subsection 4a2.6.3.4 for detailed discussion on TSV dump tank subcriticality.

See Section 4a2.8 for detailed discussion on TOGS subcriticality.

4a2.6.2.7 Trip Requirements to Limit Reactivity in Mode 1

In conjunction with the additional engineered and administrative controls described below, the limiting trip setpoint for TRPS high source range neutron flux signal is designed such that during normal operation and anticipated transients, the subcritical assembly k_{eff} remains below 1.0.

Anticipated transients in the subcritical assembly are described in Subsection 4a2.6.3.3. Postulated accidents that could add reactivity to the system are described in Subsection 13a2.1.2.

The trip setpoint is set to ensure a trip occurs prior to exceeding a percentage above the normal startup flux as measured by the neutron detection system, per the equation below:

Figure 4a2.8-1 – Subcritical Assembly System and TSV Off-Gas System Flow Diagram

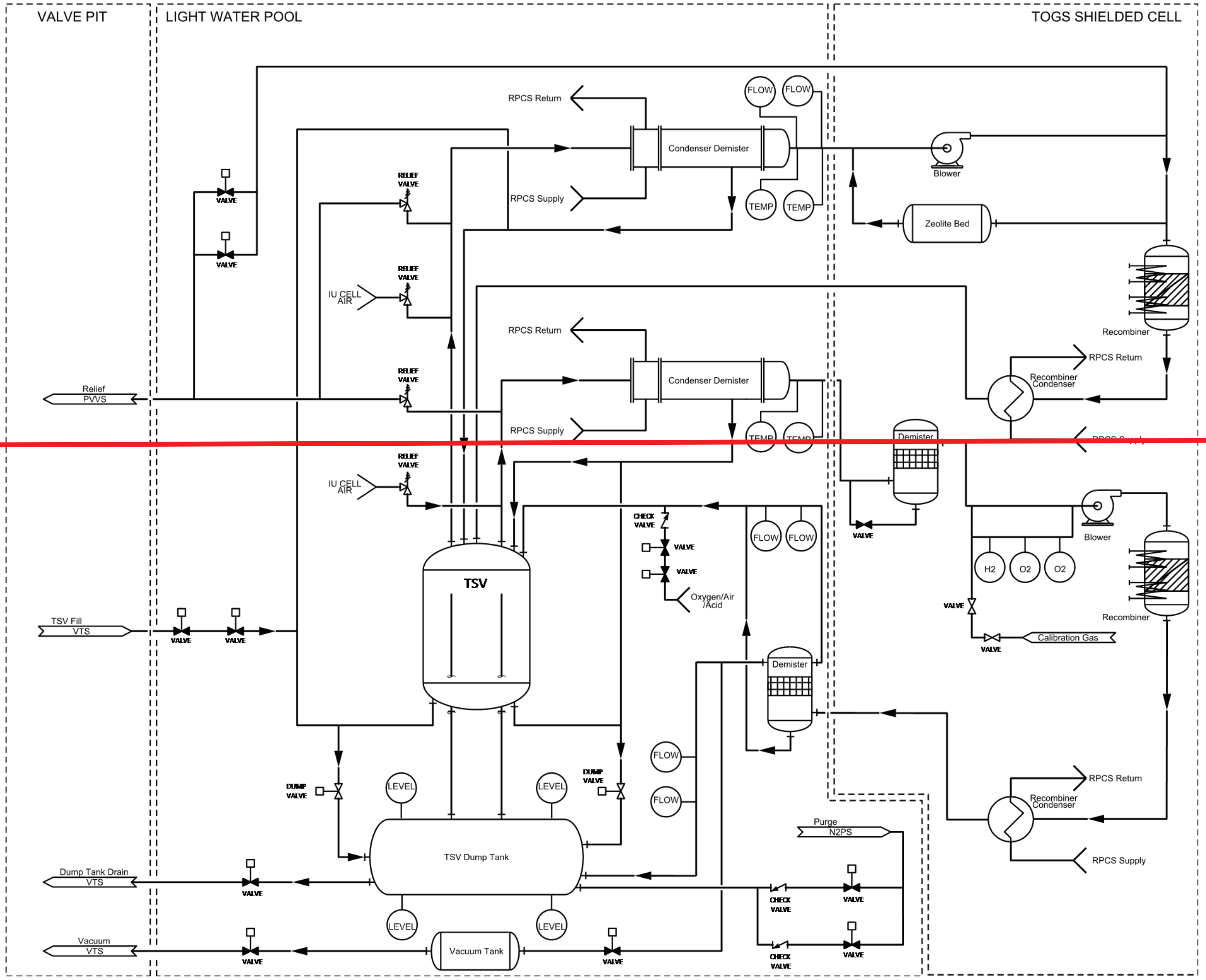
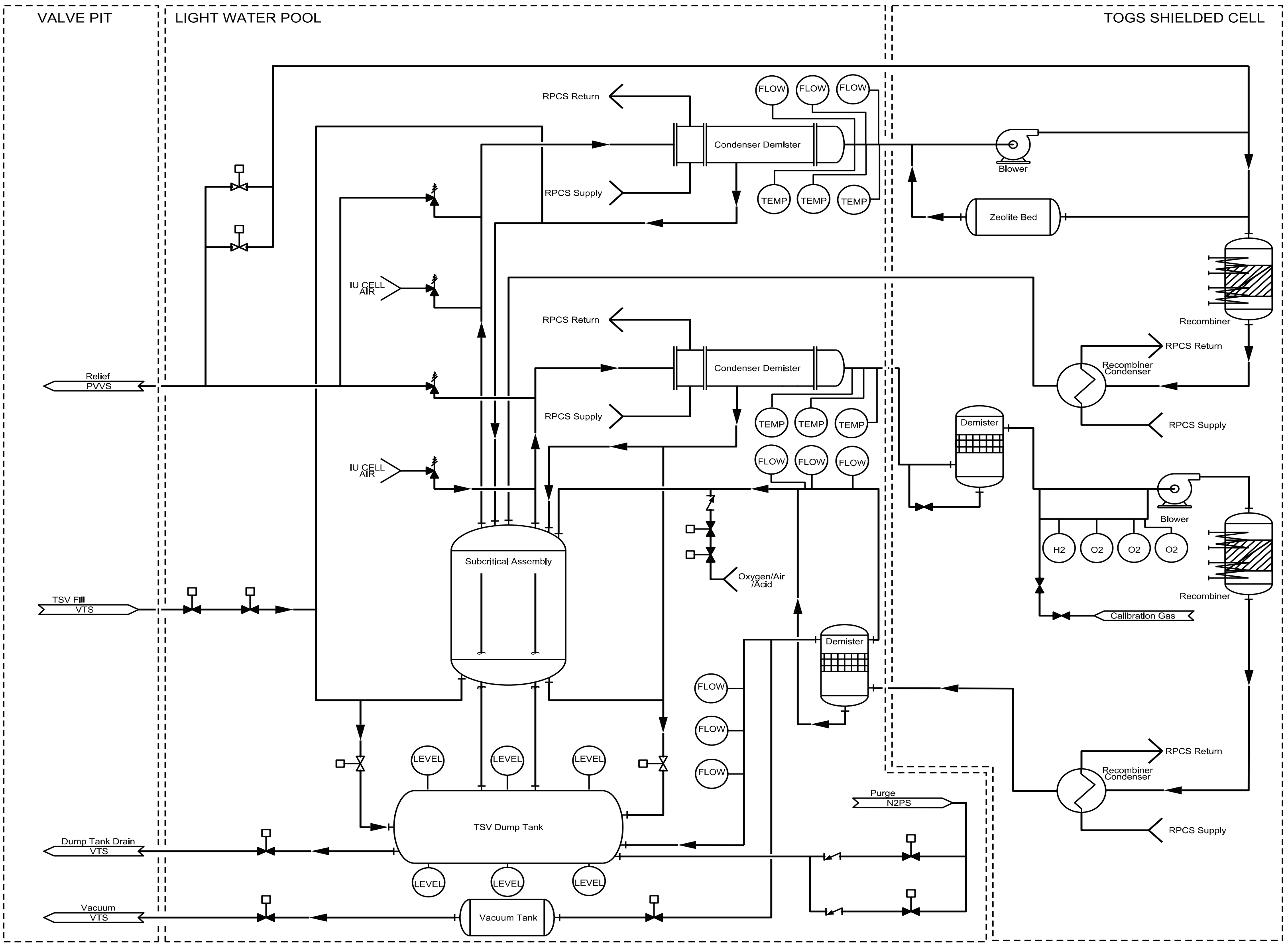


Figure 4a2.8-1 – Subcritical Assembly System and TSV Off-Gas System Flow Diagram



4a2.9 REFERENCES

~~**ACI, 2007a.** Building Code Requirements for Structural Concrete and Commentary, ACI 318-08, American Concrete Institute, 2007.~~

ACI, 2007~~b~~. Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, ACI 349-06, American Concrete Institute, 2007.

ACI, 2008. Building Code Requirements for Structural Concrete and Commentary, ACI 318-08, American Concrete Institute, 2008.

ACI, 2014. Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, ACI 349-13, American Concrete Institute, 2014.

ANSI/ANS, 2006. Nuclear Analysis and Design of Concrete Radiation Shielding for Nuclear Power Plants, ANSI/ANS-6.4-2006, American National Standards Institute, 2006.

ANSI/ANS, 2015. Program for Testing Radiation Shields in Light Water Reactors (LWR), ANSI/ANS-6.3.1-1987 (R2015), American National Standards Institute, 2015.

ASME, 2010. Boiler & Pressure Vessel Code - Rules for Construction of Pressure Vessels, Section VIII, American Society of Mechanical Engineers, July 1, 2010.

ASME, 2013. Code for Pressure Piping, B31.3-2012, American Society of Mechanical Engineers, January 10, 2013.

Baker, 1944. Water Boiler, LA Report 134, Los Alamos National Laboratory, Baker, C., et al., September 4, 1944.

Barbry Francis, 2007. French CEA Experience on Homogeneous Aqueous Solution Nuclear Reactors, Commissariat a l' Energie Atomique CEA/France, June 2007.

Beall, 1954. The Homogeneous Reactor Experiment – A Chemical Engineering Pilot Plant, Chemical Engineering Progress, Vol. 50, No. 5, Beall, S., et al., May 1954.

BNL, 2010. Aqueous Homogenous Reactor Technical Panel Report, BNL-94462-2010, Brookhaven National Laboratory, December 10, 2010.

Bull, 2014. Effects of Gas Bubble Production on Heat Transfer from a Volumetrically Heated Liquid Pool, University of Wisconsin-Madison, Bull, G., 2014.

Clayton, 1985. Neutron Source Multiplication Method, Pacific Northwest National Laboratory, Proceedings of the Workshop on Subcritical Reactivity Measurements, Clayton, E.D., 1985.

Gamble, 1959. A Proposed Model of Bubble Growth during Fast Transients in the KEWB Reactor, Paper 25-3, American Nuclear Society, Gamble, D., June 15, 1959.

IAEA, 2008. Homogeneous Aqueous Solution Nuclear Reactors for the Production of Mo-99 and Other Short Lived Radioisotopes, TECDOC-1601, International Atomic Energy Agency, September 2008.

Lane, 1958. Fluid Fuel Reactors, Part 1, Aqueous Homogeneous Reactors, Oak Ridge National Laboratory, Lane, J., June 1958.

LANL, 2011. Monte-Carlo N-Particle Transport Code MCNP5-1.60 Release & Verification, LA-UR-11-00230, Los Alamos National Laboratory, F.B. Brown, B.C. Kiedrowski, J.S. Bull, M.A. Gonzales, N.A. Gibson, 2011.

LANL, 2013a. A Generic System Model for a Fissile Solution Fueled Assembly, LA-UR-13-22033, Los Alamos National Laboratory, Kimpland, R., Klein, S., 2013.

LANL, 2013b. A Generic System Model for a Fissile Solution Fueled Assembly – Part II, LA-UR-13-28572, Los Alamos National Laboratory, Kimpland, R., Klein, S., November 2013.

LANL, 2014a. Aqueous Homogeneous Reactor (AHR) Benchmarks, LA-UR-14-21529, Los Alamos National Laboratory, Kimpland, R., Klein, S., March 2014.

LANL, 2014b. Discussion Regarding Aqueous Homogeneous Reactor (AHR) Benchmarks, LA-UR-14-23768, Los Alamos National Laboratory, Kimpland, R., Klein, S., May 2014.

Lee, 1952. The Density of Uranyl Sulfate Solutions and the Determination of Uranium Concentration by Density Measurements, ORNL-1332, Oak Ridge National Laboratory, Lee, J., et al., June 18, 1952.

NCSU, 1955. Raleigh Research Reactor Critical on September 1953, NCSCR-1, North Carolina State University, June 1955.

NEA, 2014a. International Handbook of Evaluated Reactor Physics Benchmark Experiments, Nuclear Energy Agency, NEA/NSC/DOC(2006)1, March 2014.

NEA, 2014b. International Handbook of Evaluated Criticality Safety Benchmark Experiments, Nuclear Energy Agency, NEA/NSC/DOC(95)03, September 2014.

NRC, 1979. Hydrodynamics and Heat Transfer Characteristics of Liquid Pools with Bubble Agitation, NUREG/CR-0944, United States Nuclear Regulatory Commission, Blottner, F., November 1979.

NRC, 2001a. Safety-Related Concrete Structures for Nuclear Power Plants (Other Than Reactor Vessels and Containments), Regulatory Guide 1.142, Revision 2, United States Nuclear Regulatory Commission, November 2001.

NRC, 2001b. Guide for Validation of Nuclear Criticality Safety Calculational Methodology, NUCREG/CR-6698, United States Nuclear Regulatory Commission, Dean, J., Tayloe, R., January 2001.

NRC, 2009. Concrete Radiation Shields and Generic Shield Testing for Nuclear Power Plants, Regulatory Guide 1.69, United States Nuclear Regulatory Commission, May 2009.

4b.2.4.1.4 Load and Strength Reduction Factors

Load and strength reduction factors for the structural design of concrete shield structures and related members shall be based on those prescribed in ACI 349-13, Sections 9.2 and 9.3, respectively (ACI, 2014).

4b.2.4.1.5 Design of Concrete for Shielding Structures

The design of the concrete for shielding structures, including materials selection, durability requirements, quality control, mixing, placement, formwork, embedded pipes, construction joints, reinforcement, analysis, and design, shall conform to provisions outlined in Chapters 3 through 8 of ACI 349-13 (ACI, 2014).

4b.2.4.2 Exceptions for Use of ACI 349-13

Regulatory Guide 1.69, Revision 1 (NRC, 2009) includes exceptions to the use of ACI 349-06. SHINE utilizes the revision to ACI 349-06 (ACI, 2007) and ACI 349-13 (ACI, 2014), and has identified the following exceptions to align with the intent of the exceptions listed in Regulatory Guide 1.69, Revision 1. ACI 349-13, Section 1.2.2, states that input and output data shall be retained as documentation when software is used for the calculation. The software itself and other related documentation is retained as well.

SHINE does not utilize the following sections of ACI 349-13:

- Section 3.3.1: The exception portion of the section is not followed.
- Section 3.3.2 references ACI 318-08, Section 3.3.2~~:~~ (ACI, 2008). The text in ACI 318-08, Section 3.3.2 stating, “These limitations ~~may be waived~~shall not apply if, in the judgment of the ~~engineer~~licensed design professional, workability and methods of consolidation are such that concrete can be placed without honeycombs or voids,” is not followed.
- Section 5.4.1~~:~~ references ACI 318-08, Section 5.4.1 (ACI, 2008). The text in ACI 318-08, Section 5.4.1 stating, “If data required by 5.3 are not available, concrete proportions shall be based upon other experience or information, if approved by the licensed design professional. The required average compressive strength f'c~~′~~r of concrete produced with materials similar to those proposed for use shall be at least 1200 psi greater than f'c~~′~~. This alternative shall not be used if f'c~~′~~ is greater than 5000 psi,” is not followed.
- Section 5.6.2.3: “When total quantity of a given class of concrete is less than 50 yd^3, strength tests are not required when evidence of satisfactory strength is submitted to and approved by the licensed design professional” is not followed. Instead, the provisions of Regulatory Position 5 of Regulatory Guide 1.142 for strength testing are utilized (NRC, 2001).
- Section 7.10~~.3:~~ references ACI 318-08, Section 7.10 (ACI, 2008). The text in ACI 318-08, Section 7.10.3 stating, “It shall be permitted to waive the lateral reinforcement requirements of 7.10, 10.13, and 18.11 where tests and structural analysis show adequate strength and feasibility of construction,” is not followed.

4b.2.5 TEST PROGRAM

ANSI/ANS-6.3.1-1987 (R2015) (ANSI/ANS, 2015), Program for Testing Radiation Shields in Light Water Reactors (LWR), is used as a guide in the development of a test program to be used

3. The irradiated target solution flows through the extraction column, where Mo is adsorbed. The Mo extraction column contains a fixed bed of [ ]$^{\text{PROP/ECI}}$. Extraction of the Mo from the irradiated target solution takes approximately [ ]$^{\text{PROP/ECI}}$ per target solution batch.
4. After the irradiated target solution passes through the extraction column [ ]$^{\text{PROP/ECI}}$, it is directed to the target solution storage system (TSSS), IXP, or radioactive liquid waste storage (RLWS).
5. The column is washed with sulfuric acid. As small amounts of target solution are contained in the interstitial column spaces and piping, uranium is recovered in the initial sulfuric acid wash. This recovered uranium solution can be directed to follow the target solution batch or be sent to RLWS. The remainder of the wash is directed to RLWS.
6. The column is then washed with water to remove acid remaining on the column. The water wash is drained to the RLWS.
7. The extraction column is eluted with the extraction column eluent, sodium hydroxide, to extract the Mo-99. The eluate associated with this process is transferred to the Mo-99 eluate hold tank.
8. The extraction column is washed with deionized water. The water is drained to the Mo-99 eluate hold tank or RLWS.
9. The collected Mo-bearing solution is re-acidified with nitric acid.
10. The Mo-bearing solution [ ]$^{\text{PROP/ECI}}$.
11. [ ]$^{\text{PROP/ECI}}$
12. If replacement is required for product purity or product yield purposes, the Mo-99 extraction column [ ]$^{\text{PROP/ECI}}$ disconnected and removed from service. The extraction column [ ]$^{\text{PROP/ECI}}$ placed on a decay storage rack prior to being transferred into the waste export drum. The solid radioactive waste packaging (SRWP) system is described in Subsection 9b.7.5. A new Mo extraction column [ ]$^{\text{PROP/ECI}}$ then installed.

The radioactive inventory in the extraction and concentration process is evaluated for release in the ~~integrated~~ safety analysis~~ (ISA) process~~. The engineered safety features actuation system (ESFAS) detects unacceptable releases from the extraction cell, if they were to occur, and provides confinement functions to maintain doses within acceptable levels. Section 7.5 provides a detailed description of ESFAS. See Section 6b.2 for a description of confinement.

4b.3.1.4.2 Molybdenum Radioisotope Purification Process Sequence

The purification process for the Mo occurs in the Mo-99 purification hot cell, which is a portion of the supercell.

The Mo-99 purification process does not involve any significant quantities of special nuclear material (SNM). The radioisotopes involved are the Mo isotopes and any impurities that have followed the Mo through the extraction process. Radioactive material inventories are described in Subsection 4b.3.2 and Section 11.1.

First, solution received from the extraction process is collected in an evaporator. The volume of solution is decreased to match the input requirements of the subsequent purification steps. The evaporator condensate is collected and directed towards the RLWS.

The subsequent purification steps use a laboratory scale process, which was derived from the low enriched uranium (LEU)-modified Cintichem process (ANL, 2016). The purification process consists of precipitation of contaminants, chelation of the Mo, and filtering of the product solution. The resulting product is a Mo-99, sodium hydroxide solution, with a volume of [ ]PROP. Small samples are taken from the purification process and transported to the analytical laboratories to verify product specifications are met. The product bottle is transferred to the Mo isotope product packaging system (MIPS) to prepare for shipment.

The radioactive inventory in the purification process is evaluated for release in the ~~ISA process~~safety analysis. The ESFAS system detects unacceptable releases from the purification cell, if they were to occur, and provides confinement functions to maintain doses within acceptable levels. Section 7.5 provides a detailed description of ESFAS. See Section 6b.2 for a description of confinement.

4b.3.1.4.3 Iodine and Xenon Radioisotope Extraction and Purification Process Sequence

The IXP separates the iodine from acidic solution and purifies it [ ]PROP/ECI. The separation and purification of the iodine from the solution occurs in the IXP hot cell. [ ]PROP/ECI There is one IXP hot cell in the radioisotope production facility (RPF).

The following steps are used for extracting the radioisotopes I-131 and Xe-133:

1. Acidic solution is transferred from MEPS for iodine removal using the pumps provided in the MEPS system. The solution can be target solution [ ]PROP/ECI Figure 4b.3-1 identifies the MEPS transfer points to the IXP system.
2. Solution is pumped through the iodine recovery column to separate iodine from the bulk solution. [ ]PROP/ECI
3. The effluent from the adsorption process is directed to TSSS or RLWS.
4. The iodine recovery column is then washed to prepare for subsequent processing steps. [ ]PROP/ECI The washes are directed to TSSS as needed for uranium recovery, and the remainder is directed to RLWS.
5. The iodine recovery column is eluted [ ]PROP/ECI and drained to the IXP elution tank. Any required adjustments to the solution are made in this tank.
6. [ ]PROP/ECI

7. The resulting product is an iodine-131, sodium hydroxide solution.
8. [ ]$^{\text{PROP/ECI}}$ The cryotrap is reheated to desorb the xenon and allow it to be packaged.
9. Xenon is transferred to a xenon product gas bottle meeting customer requirements and shipping requirements. The resulting product is xenon-133 gas, with a volume of [ ]$^{\text{PROP/ECI}}$.
10. The iodine product bottle is transferred to the MIPS system to prepare for shipment.
11. The xenon product bottle is transferred to the MIPS system to prepare for shipment.
12. If replacement is required for product purity or product yield purposes, the iodine recovery, [ ]$^{\text{PROP/ECI}}$ disconnected and removed from service. The columns are placed on a decay storage rack prior to being transferred into the waste export drum. The SRWP system is described in Subsection 9b.7.5. New columns are then installed to replace the spent columns.

The radioactive inventory in the IXP process is evaluated for release in the ~~ISA process~~safety analysis. The ESFAS system detects unacceptable releases from the hot cell, if they were to occur, and provides confinement functions to maintain doses within acceptable levels. Section 7.5 provides a detailed description of ESFAS.

4b.3.1.4.4 Process Equipment

The following is process equipment associated with the Mo-99 extraction system.

Components within the extraction cell are typically replaceable with the manipulators. Materials of construction for the below listed components are principally stainless steel. Materials of construction for extraction components are chemically compatible with the process fluids (including target solution for relevant components) to ensure corrosion resistance, designed to prevent galvanic coupling concerns, and perform acceptably under the radiation environment. Alloys that meet these criteria include type 316/316L stainless steel, type 347 stainless steel, type 304/304L stainless steel, and Alloy 20.

Nonsafety-related monitoring and control of MEPS is provided by the process integrated control system (PICS), which is described in Section 7.3. PICS monitors valve position, process temperature, pressure, and pump operation in MEPS. PICS also provides interlocks to minimize process errors.

Safety-related monitoring and control of MEPS is provided by ESFAS. ESFAS monitors positions of valves performing a safety-related function in MEPS, conductivity in the MEPS [ ]$^{\text{PROP/ECI}}$ radiation in the hot cell ventilation ducts, and level detection in the radioactive drain system (RDS). In the event ESFAS detects an abnormal condition in any of these parameters, ESFAS actuates to isolate the MEPS hot cell and place MEPS equipment in a safe condition. Details on each ESFAS operation and actuation are described in Section 7.5.

MEPS isolation valves and conductivity instrumentation are the only components within the MEPS that are required to function during an accident to ensure doses to the public and workers

4b.5 REFERENCES

ACI, 2007. Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, ACI 349-06, American Concrete Institute, 2007.

ACI, 2008. Building Code Requirements for Structural Concrete and Commentary, ACI 318-08, American Concrete Institute, 2008.

ACI, 2014. Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, ACI 349-13, American Concrete Institute, 2014.

AGS, 2007. Guideline for Gloveboxes, AGS-G001-2007, American Glovebox Society, 2007.

ANL, 2016. Compendium of Phase-1 Mini-SHINE Experiments, ANL/NE-16/39, Argonne National Laboratory, 2016.

ANSI/ANS, 2006a. Nuclear Analysis and Design of Concrete Radiation Shielding for Nuclear Power Plants, ANSI/ANS 6.4-2006, American National Standards Institute, 2006.

ANSI/ANS, 2015. Program for Testing Radiation Shield in Light Water Reactors (LWR), ANSI/ANS 6.3.1-1987 (R2015), American National Standards Institute, 2015.

LANL, 2011. Monte Carlo N-Particle Transport Code MCNP5-1.60 Release & Verification, LA-UR-11-00230, Los Alamos National Laboratory, F.B. Brown, B.C. Kiedrowski, J.S. Bull, M.A. Gonzales, N.A. Gibson, 2011.

USNRC, 2001. Safety-Related Concrete Structures for Nuclear Power Plants (Other Than Reactor Vessels and Containments), Regulatory Guide 1.142, Revision 2, U.S. Nuclear Regulatory Commission, November 2001.

USNRC, 2009. Concrete Radiation Shields and Generic Shield Testing for Nuclear Power Plants, Regulatory Guide 1.69, Revision 1, U.S. Nuclear Regulatory Commission, 2009.

USNRC, 2013. A Review of the Effects of Radiation on Microstructure and Properties of Concretes Used in Nuclear Power Plants, NUREG/CR-7171, U.S. Nuclear Regulatory Commission, 2013.

target solution prevents boiling of the solution during the draining process. Once the target solution has drained to the TSV dump tank, the light water pool prevents the solution from boiling by natural convection heat transfer. See Subsection 4a2.7.3.8 for further discussion on the transition from forced to natural convection.

Voiding of the SCAS cooling channels caused by loss of primary cooling water causes reactivity insertions as discussed in Subsection 13a2.1.2. To prevent the drainage of primary cooling water from the SCAS, the SCAS is located below grade in the light water pool. Portions of the PCLS located outside of the light water pool are above grade to prevent gravity drainage of the SCAS cooling channels.

The PCLS pumps draw cooling water from a line connected to the PCLS expansion tank. Because the expansion tank is vented, a leak of the PCLS pressure boundary would result in the PCLS expansion tank level reducing until the PCLS return line breaks vacuum. Once the PCLS return line breaks vacuum, the PCLS pumps cannot draw more water out of the SCAS. This arrangement ensures that the PCLS pumps cannot draw the water out of the SCAS cooling channels.

The use of centrifugal pumps and an air separator prevents the PCLS from effectively voiding the cooling channels by pumping air into the SCAS.

Malfunctions or leaks in the PCLS do not cause uncontrolled release of primary cooling water outside the radiologically controlled area (RCA). The facility structure (FSTR) provides barriers at exits from the RCA to prevent the release of potentially contaminated water to the uncontrolled environment.

The PCLS piping penetrating confinement boundaries are provided with redundant isolation capabilities as shown in Figure 5a2.2-1. ~~Piping systems that pass between confinement boundaries are equipped with either:~~

- ~~a locked closed manual isolation valve, or~~
- ~~an automatic isolation valve that takes the position that provides greater safety upon loss of actuating power.~~

~~Manual isolation valves are maintained locked-shut for any conditions requiring confinement boundary integrity.~~ The automatic isolation valves are closed as part of an IU Cell Safety Actuation if the TSV reactivity protection system (TRPS) detects a malfunction of PCLS, inleakage of primary cooling water into the PSB, or outleakage of target solution into the primary cooling water. PCLS automatic isolation valves take a closed position upon loss of actuating power as described in Section 7.4.4.7.

5a2.2.3 INSTRUMENTATION AND CONTROL

Pressure, flow, temperature, conductivity, and level instrumentation monitor the operating parameters of the PCLS.

Temperature instrumentation is provided to ensure the cooling water supply temperature remains within allowable limits despite variations in TSV power. Output from the temperature instrumentation is used for controlling the flow of RPCS water through the PCLS heat exchanger to regulate the cooling water supply temperature at the SCAS cooling water inlet.

Figure 5a2.2-1 – Primary Closed Loop Cooling System Flow Diagram

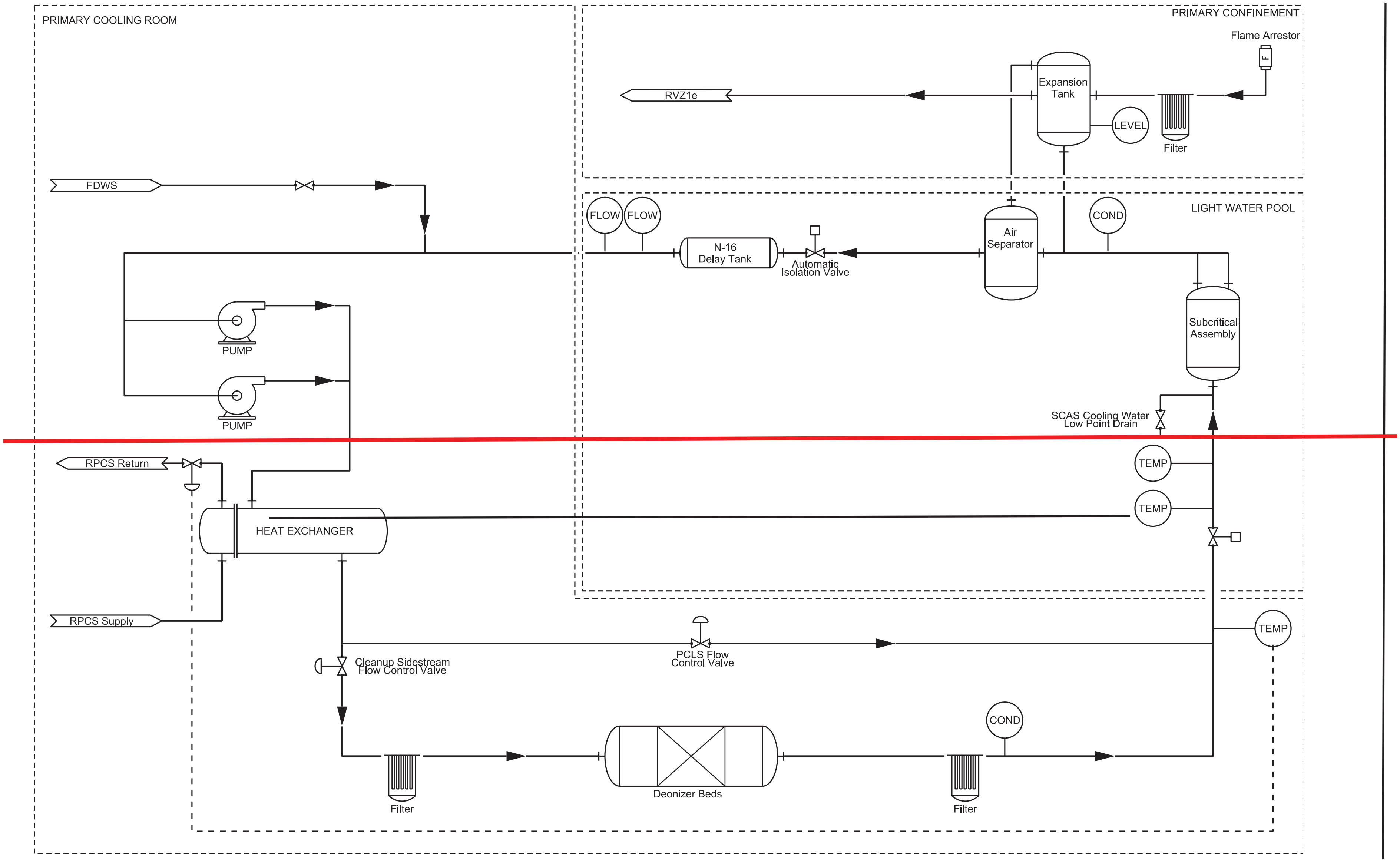
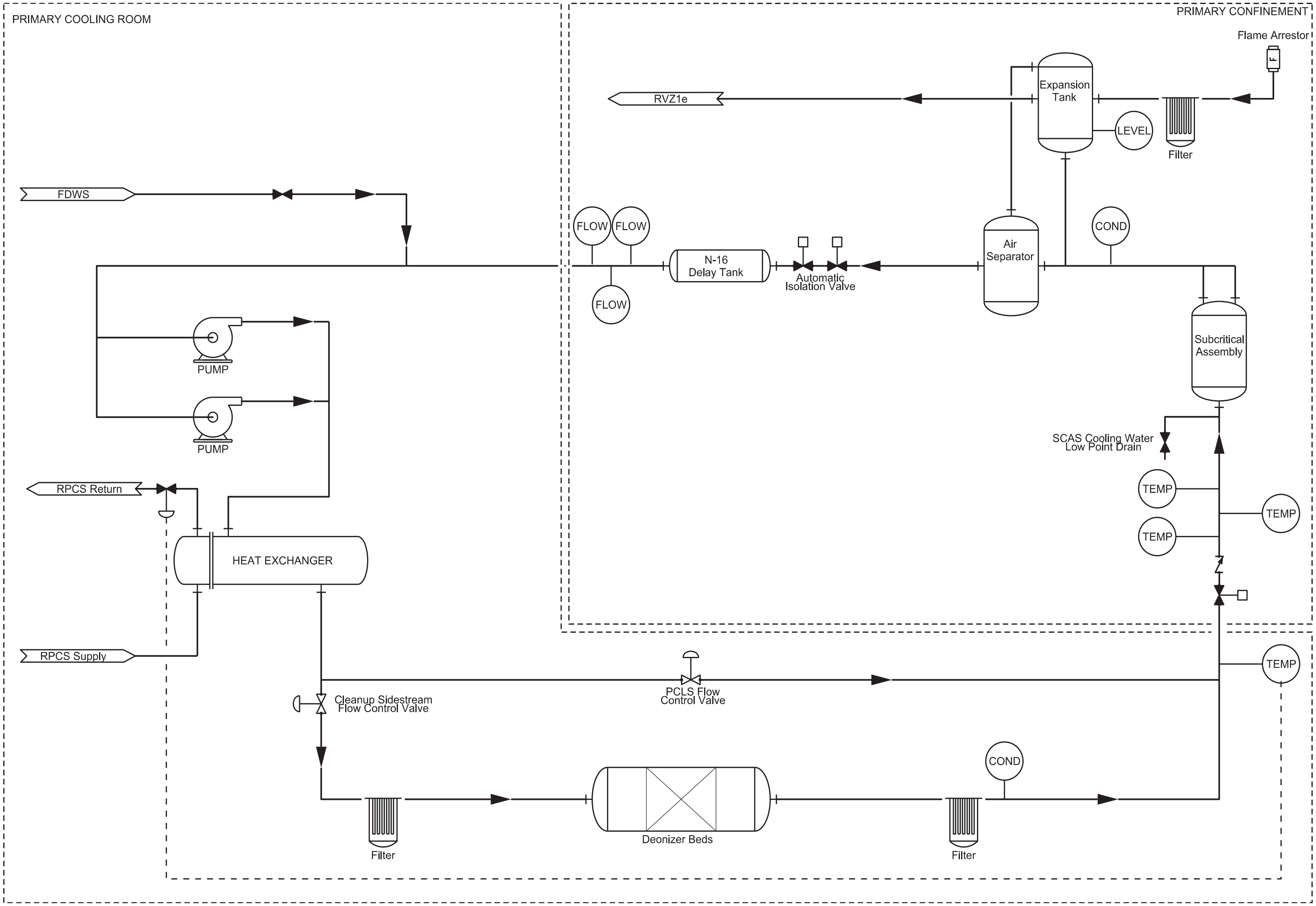


Figure 5a2.2-1 – Primary Closed Loop Cooling System Flow Diagram



ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
ANS	American Nuclear Society
ANSI	American National Standards Institute
CAAS	criticality accident alarm system
CSP	criticality safety program
DBA	design basis accident
DCP	double contingency principle
ESF	engineered safety feature
ESFAS	engineered safety features actuation system
FCRS	facility chemical reagent system
FMO	fissionable material operation
~~GBSS~~	~~glovebox stripper system~~
gU/L	grams of uranium per liter
HEPA	high efficiency particulate air
HVAC	heating, ventilation, and air conditioning
ICBS	irradiation cell biological shield
IF	irradiation facility

6a2 IRRADIATION FACILITY ENGINEERED SAFETY FEATURES

6a2.1 SUMMARY DESCRIPTION

This section provides a summary of the engineered safety features (ESFs) installed in the irradiation facility (IF). Table 6a2.1-1 contains a summary of the ESFs and the IF design basis accidents (DBAs) they are designed to mitigate. Table 6a2.1-2 provides unmitigated and mitigated doses for the public and the worker, with one DBA selected per confinement system, to demonstrate the mitigative effects of the confinements. The same methods described in Section 13a2.2 were used to calculate the unmitigated doses, but with a leak path factor of 1 for both the worker and public. A block diagram for the IF ESFs is provided as Figure 6a2.1-1. This block diagram shows the location and basic function of the structures, systems, and components (SSCs) providing the ESFs in the IF portion of the SHINE facility.

Confinement Systems

Confinement systems are provided for protection against the potential release of radioactive material to the IF and the environment during normal conditions of operation and during and after DBAs. Passive confinement is performed by physical barriers such as concrete or steel boundaries, sealed access plugs, and sealed doors. The confinement systems provide active isolation of penetrations during and after certain DBAs that include process piping and heating, ventilation, and air conditioning (HVAC) systems penetrating confinement boundaries. The IF uses two confinement systems: (1) the primary confinement barrier for the irradiation unit (IU) cells, target solution vessel (TSV) off-gas system (TOGS) shielded cells, and the IU cell and TOGS cell HVAC enclosures; and (2) the tritium confinement barrier for the tritium purification system (TPS). A detailed description of these confinement systems is provided in Subsection 6a2.2.1.

The accidents for which IF confinement systems are credited are described in detail in Section 13a2.1 and listed in Table 6a2.1-1. The accident sequences in the IF which require confinement are related to the release of irradiated target solution, radioactive off-gas from TOGS, or the release of tritium from the TPS.

The IF confinement systems remain operational during and following any of the DBAs, including seismic events and loss of off-site power. Active components which comprise portions of the confinement boundary are designed to fail safe on a loss of control or actuating power and maintain the integrity of the confinement boundary.

A listing of the automatic isolation valves included in the confinement boundaries is provided in Section 7.4 and Section 7.5.

Combustible Gas Management

The combustible gas management systems perform mitigation functions for the primary system boundary (PSB). The combustible gas management system uses the nitrogen purge system (N2PS), PSB piping, and the process vessel vent system (PVVS) to establish an inert gas flow through the IUs.

One of the functions of the TOGS is to maintain PSB hydrogen concentrations below values which could result in a hydrogen explosion overpressure capable of rupturing the PSB during

Table 6a2.1-2 – Comparison of Unmitigated and Mitigated Radiological Doses for Select Irradiation Facility DBAs

	Unmitigated Public Dose (rem)			Mitigated Public Dose (rem)		
Representative DBA	**Public TEDE**	**Worker TEDE**	**Worker Limiting Organ**	**Public TEDE**	**Worker TEDE**	**Worker Limiting Organ**
Mishandling or Malfunction of Target Solution *(Primary Confinement Boundary – IU Cell)*	5.0E+00	4.1E+02	2.4E+03	6.5E-02	1.5E+00	3.0E+00
Mishandling or Malfunction of Equipment *(Primary Confinement Boundary – TOGS Cell)*	4.9E+00	4.0E+02	2.3E+03	2.3E-01	4.8E+00	2.8E+01
Facility-Specific Events *(Tritium Confinement Boundary)*	~~2.1~~2.7E+00	~~2.5~~3.1E+02	~~2.4~~3.0E+02	~~3.4~~4.8E-01	~~7.1E-02~~2.5E-01	~~6.9E-02~~2.4E-01

Figure 6a2.1-1 – Irradiation Facility Engineered Safety Features Block Diagram

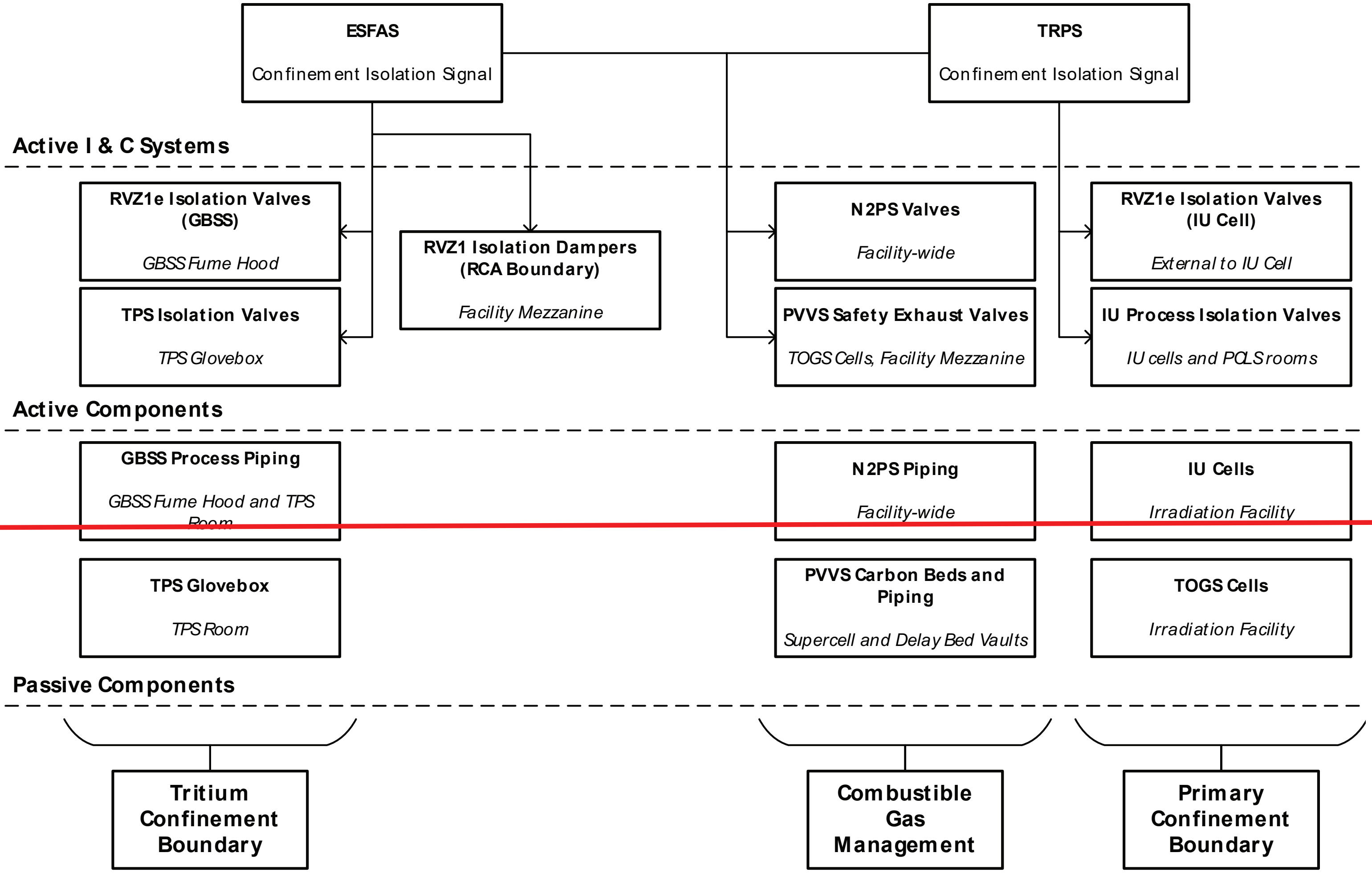
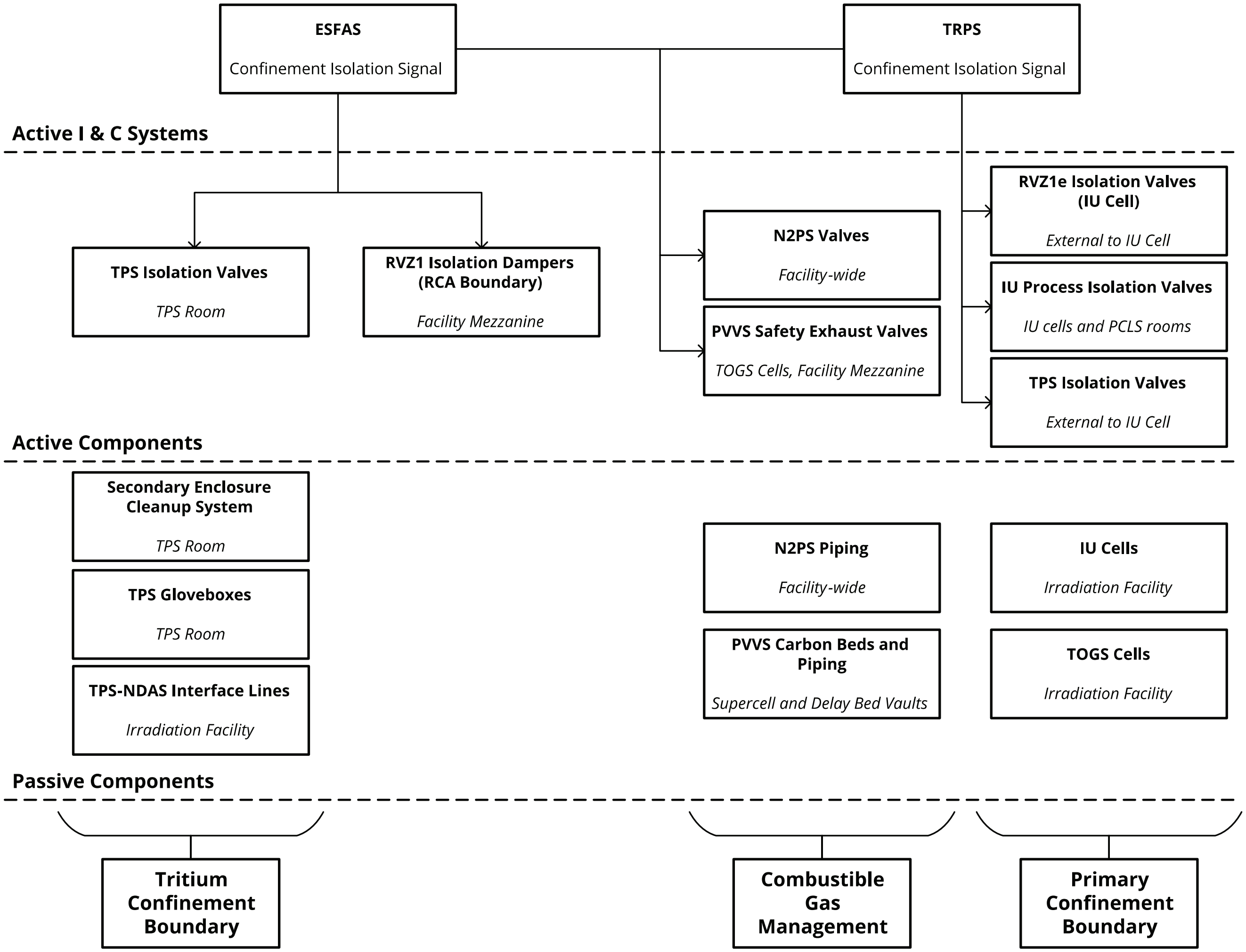


Figure 6a2.1-1 – Irradiation Facility Engineered Safety Features Block Diagram



6a2.2 DETAILED DESCRIPTIONS

This section provides the details of the design, initiation, and operation of engineered safety features (ESFs) that are provided to mitigate design basis accidents (DBAs) in the irradiation facility (IF). The IF DBAs, the ESFs required to mitigate the DBAs, and the location of the bases for these determinations are listed in Table 6a2.1-1.

6a2.2.1 CONFINEMENT

The confinement systems are designed to limit the release of radioactive material to occupied or uncontrolled areas during and after DBAs to mitigate the consequences to facility staff, the public, and the environment. The principal objective of the confinement systems is to protect on-site personnel, the public, and the environment. The second objective is to minimize the reliance on administrative or active engineering controls to provide a confinement system that is as simple and fail-safe as reasonably possible. See Figure 6a2.1-1 for an overview of the structures, systems, and components (SSCs) that provide IF confinement safety functions.

6a2.2.1.1 Primary Confinement Boundary

The primary confinement boundary consists predominantly of the ~~concrete structure of the~~ irradiation unit (IU) cell, the target solution vessel (TSV) off-gas system (TOGS) shielded cell, and the IU cell and TOGS cell heating, ventilation, and air conditioning (HVAC) enclosures. The IU and TOGS shielded cells are equipped with removable shield plugs which allow entry into the confined area. The primary confinement boundary is primarily passive, and the boundary for each IU is independent from the other IUs. In the event of a DBA that results in a release within the primary confinement boundary, radioactive material is confined primarily by the structural components of the boundary and process isolation valves which actuate to isolate the confinement. Gaskets and other non-structural features are used, as necessary, to provide sealing where separate structural components meet (e.g., shield plugs). Portions of the confinement are included as part of the irradiation cell biological shield (ICBS) and their shielding functions are described in Section 4a2.5.

The IU cell portion of the primary confinement boundary holds the TSV, TSV dump tank, portions of the TOGS, portions of the primary closed loop cooling system (PCLS), associated primary system boundary (PSB) piping, the light water pool, and the neutron driver. The balance of the TOGS is located in the TOGS shielded cell. The TSV, TSV dump tank, TOGS, and primary system piping comprise the PSB which contains the target solution, fission products, and off-gas byproducts associated with the irradiation process. The neutron driver is independent from the PSB and contains an inventory of tritium gas. Figure 6a2.2-1 provides a block diagram of the primary confinement boundary.

A number of process systems penetrate the primary confinement boundary as shown on Figure 6a2.2-1. Each piping system capable of excessive leakage that penetrates the primary confinement boundary is equipped with one or more isolation valves which serve as active confinement components except for the N2PS supply and PVVS connections, which may remain open to provide combustible gas mitigation. Actuation of the isolation valves is controlled by the TSV reactivity protection system (TRPS). A detailed description of the TRPS is provided in Section 7.4.

The primary confinement boundary has a normally-closed atmosphere without connections to the facility ventilation system, except through the PCLS expansion tank. Closed loop ventilation units (i.e., radiological ventilation zone 1 recirculating subsystem [RVZ1r]) circulate and cool the air within the IU cell and the TOGS cell. Each subsystem is equipped with a cooling coil and high efficiency particulate air (HEPA) and carbon filters to remove contaminants in the circulated air. The cooling coil is supplied by the radioisotope process facility cooling system (RPCS). The closed loop ventilation units are entirely located in the ~~HVAC enclosures~~primary cooling rooms. There are no normally-open external connections between the RVZ1r subsystem and the main RVZ1 system. A detailed discussion of RVZ1r is provided in Section 9a2.1.

The PCLS expansion tank has a connection to radiological ventilation zone 1 exhaust subsystem (RVZ1e) which provides a vent path for radiolysis gases produced in the PCLS and light water pool, to avoid the buildup of hydrogen gas. The PCLS expansion tank is located in the IU cell but draws air from the TOGS cell atmosphere. A small line connecting the IU cell and TOGS cell atmospheres creates a flow path from the IU cell, into the TOGS cell, and out through the PCLS expansion tank to RVZ1e. This flow path normally maintains the cells at a slightly negative pressure. The connection to RVZ1e is equipped with redundant dampers or valves that close on a confinement actuation signal, isolating the cells from RVZ1. A detailed discussion of RVZ1e is provided in Section 9a2.1.

The complete listing of variables within the TRPS that can cause the initiation of an IU Cell Safety Actuation is provided in Subsection 7.4.3.2. The parameters indicating a release of radioactive material into the primary confinement boundary are high RVZ1e IU cell radiation (indicating a release of fission products)~~ and high ATIS mixed-gas return line pressure~~, high tritium purification system (TPS) target chamber supply pressure, and high TPS target chamber exhaust pressure (indicating a release from the neutron driver assembly system [NDAS]).

Following an IU Cell Safety Actuation, PSB and primary confinement boundary isolation valves transition to their deenergized (safe) states. The normal flow of materials passes through the mezzanine RVZ1 exhaust filter banks before being released to the environment. RVZ filtration is not credited in the accident analysis. If sufficient radioactive material reaches the radiation monitors in the RVZ1 exhaust duct, the engineered safety features actuation system (ESFAS) will isolate the RVZ building supply and exhaust.

Following cell isolation, three mechanisms by which the primary confinement boundary exchanges air with the IF are considered in the accident analysis: pressure-driven flow, counter-current flow, and barometric breathing. The facility accident analysis models the combined effect of these mechanisms as a minor outflow of radioactive material from the primary confinement boundary directly to the IF and then to the environment under accident conditions. The evaluated accident sequences for which the primary confinement boundary is necessary are listed in Table 6a2.1-1 and discussed further in Chapter 13a2.

The requirements for the ICBS and TRPS needed for system operability, periodic surveillance, setpoints, and other specific requirements needed to ensure the functionality of the primary confinement boundary are located in the technical specifications.

6a2.2.1.2 Tritium Confinement Boundary

Portions of the TPS serve as the tritium confinement boundary. The TPS is described in detail in Section 9a2.7. A functional block diagram of the tritium confinement is provided in Figure 6a2.2-2.

Tritium in the IF is confined using active and passive features of the TPS. The TPS glovebox~~ is a~~es and secondary enclosure cleanup subsystems are credited passive confinement barrier~~ that~~s. The TPS gloveboxes enclose~~s the isotope separation subsystem~~ TPS process equipment. The process equipment of the secondary enclosure cleanup subsystem is a credited passive confinement barrier. The TPS glovebox~~ is~~es are maintained at negative pressure relative to the TPS room and ha~~s~~ve a ~~nitrogen~~helium atmosphere. The TPS gloveboxes provide~~s~~ confinement in the event of a breach in the TPS process equipment that results in a release of tritium from the isotope separation process equipment.

~~The ATIS header jacket and ATIS gloveboxes are a credited passive confinement barrier that encloses the ATIS header tritium lines and ATIS subsystem process equipment. The ATIS gloveboxes are maintained at negative pressure relative to the IF and have a nitrogen atmosphere. The ATIS header jacket and ATIS gloveboxes provide confinement in the event of a breach in the ATIS process equipment or ATIS header tritium lines that results in a release of tritium from the ATIS process equipment or ATIS header tritium lines.~~

~~The TPS glovebox is equipped with the glovebox stripper system (GBSS) which strips tritium from the nitrogen atmosphere during normal operation and from the process lines during maintenance. The GBSS process equipment exhausts to RVZ1e and is located in an air hood adjacent to the glovebox. The GBSS process equipment is part of the credited passive confinement boundary. The TPS process equipment other than the GBSS is not credited with confinement functions under accident conditions.~~

The TPS gloveboxes include~~s~~ isolation valves on the ~~nitrogen~~helium supply~~ for the nitrogen atmosphere~~, the glovebox pressure control exhaust, and the vacuum/impurity treatment subsystem process vents.

The TPS ~~process equipment within the TPS glovebox~~ has isolation valves on the process connections to the ~~tritium supply header, the deuterium supply header, and the mixed gas return header. The TPS process equipment within the TPS glovebox also has isolation valves on the process evacuation lines that connect to the GBSS and the instrument nitrogen supply line. The GBSS process equipment has isolation valves on the connection to the ATIS glovebox exhaust and the exhaust to RVZ1e. These valves close automatically upon loss of power or receipt of a confinement isolation signal generated by the ESFAS~~NDAS target chamber supply and exhaust lines. The TPS-NDAS interface lines themselves are part of the credited tritium confinement boundary up to the interface with the primary confinement boundary.~~.~~

When the isolation valves for a process line or glovebox close, the spread of radioactive material is limited to the glovebox plus the small amount between the glovebox and its isolation valves. The liquid nitrogen supply and exhaust lines and the gaseous nitrogen pneumatic lines for the TPS equipment are credited to remain intact during a DBA and the internal interface between the gloveboxes and nitrogen lines serves as a passive section of the tritium confinement boundary.~~ Process piping outside the glovebox other than the GBSS piping to the isolation valves are not credited to remain intact during accident conditions to achieve confinement of tritium.~~

Upon detection of high TPS exhaust to facility stack tritium concentration or high TPS glovebox tritium concentration, the ESFAS automatically initiates a TPS isolation. The active components required to function to maintain the confinement barrier are transitioned to their deenergized (safe) state by the ESFAS. ~~This includes process isolation valves, the GBSS RVZ1e isolation valves, and the RVZ2 dampers that isolate the TPS room from the IF general area.~~ A description of the ESFAS and a complete listing of the active components that transition state with a TPS isolation are provided in Section 7.5.

In the event of a break in the process piping within the TPS glovebox, the release of tritium from the glovebox is uncontrolled for up to 20 seconds until the isolation valves close. Long-term leakage and permeation of the confinement barrier result in migration of tritium out of the confinement and into the TPS room, IF, and environment. The facility accident analysis considers the effect of this air exchange in its evaluation of radiological consequences. The evaluated accident sequences for which the tritium confinement boundary is necessary are listed in Table 6a2.1-1 and further discussed in Chapter 13a2.

The requirements for the TPS and ESFAS needed for system operability, periodic surveillance, setpoints, and other specific requirements needed to ensure the functionality of the tritium confinement boundary are located in the technical specifications.

6a2.2.2 COMBUSTIBLE GAS MANAGEMENT

Hydrogen gas is produced by radiolysis in the target solution during and after irradiation. During normal operation the concentration of hydrogen gas is monitored and maintained below the lower flammability limit (LFL) using the TOGS. The management of combustible gases during normal operation and the TOGS is described in detail in Section 4a2.8. If TOGS becomes unavailable, the buildup of hydrogen gas is limited using the combustible gas management system, which uses the N2PS, PSB piping, and the process vessel vent system (PVVS) to establish an inert gas flow through the IUs.

The principal objective of the combustible gas management system is to prevent the conditions required for a hydrogen deflagration within the PSB that results in an explosion overpressure exceeding the pressure safety limit of the PSB.

The N2PS provides back-up nitrogen sweep gas to each IU upon a loss of power or loss of normal sweep gas flow to maintain hydrogen concentrations in these systems below the values which could result in a hydrogen explosion overpressure capable of rupturing the PSB. A functional block diagram of the combustible gas management system is provided in Figure 6a2.2-3.

High pressure nitrogen gas is stored in pressurized vessels which are located in an above-grade reinforced concrete structure adjacent to the main production facility. On a loss of power or receipt of an appropriate TRPS or ESFAS actuation signal, solenoid-operated isolation valves on the nitrogen discharge manifold open and supply nitrogen to the IU cell supply header. The nitrogen is regulated to a lower pressure and supplied to each TSV dump tank (as necessary) and flows through the TSV dump tank, the TSV, and the TOGS equipment and piping before being discharged to the PVVS. The nitrogen flows through the PVVS guard, delay beds, and HEPA filter before being discharged to the environment via a safety-related vent path. The nitrogen purge system is described in detail in Section 9b6.2.

Figure 6a2.2-1 – Primary Confinement Boundary

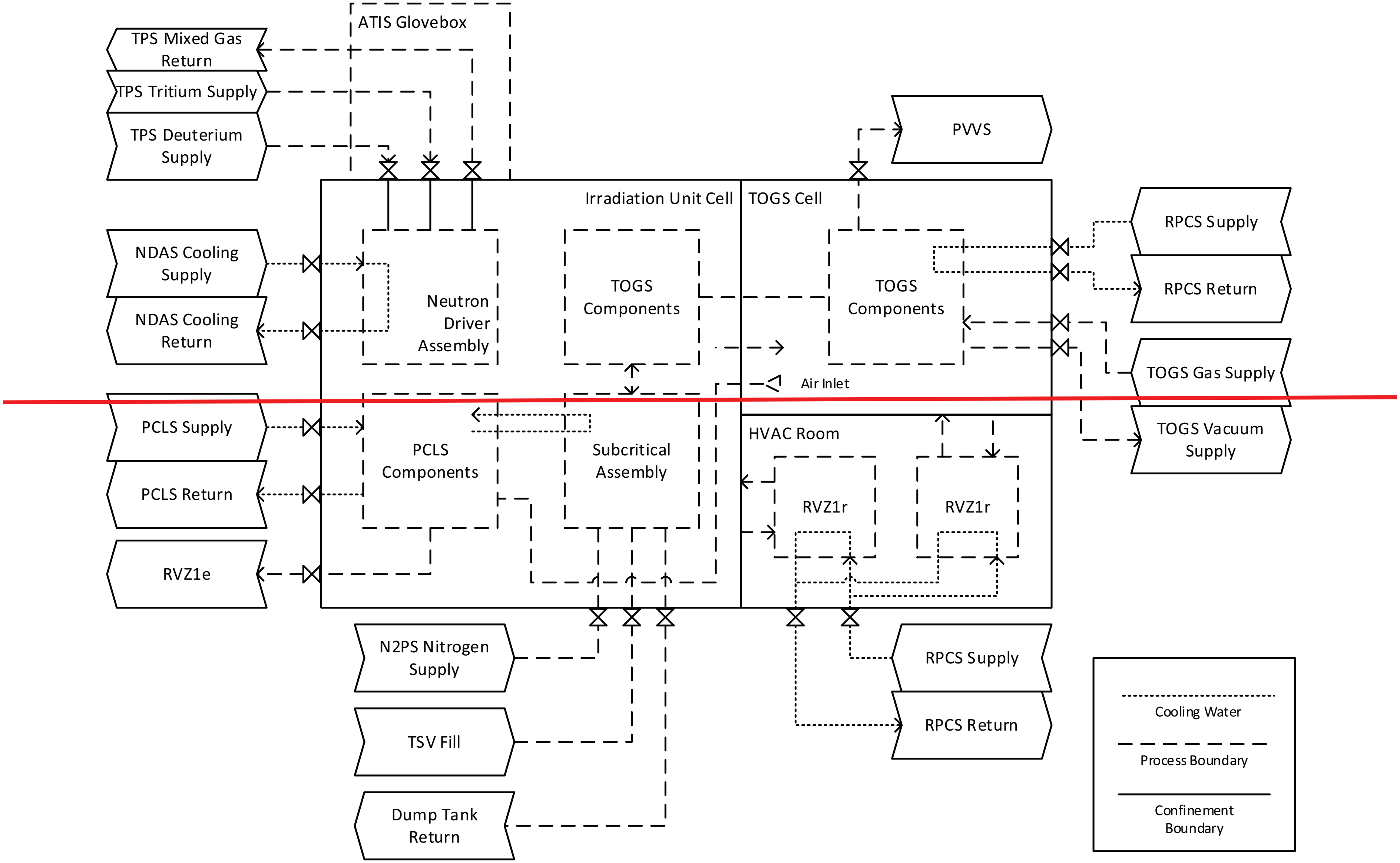


Figure 6a2.2-1 – Primary Confinement Boundary

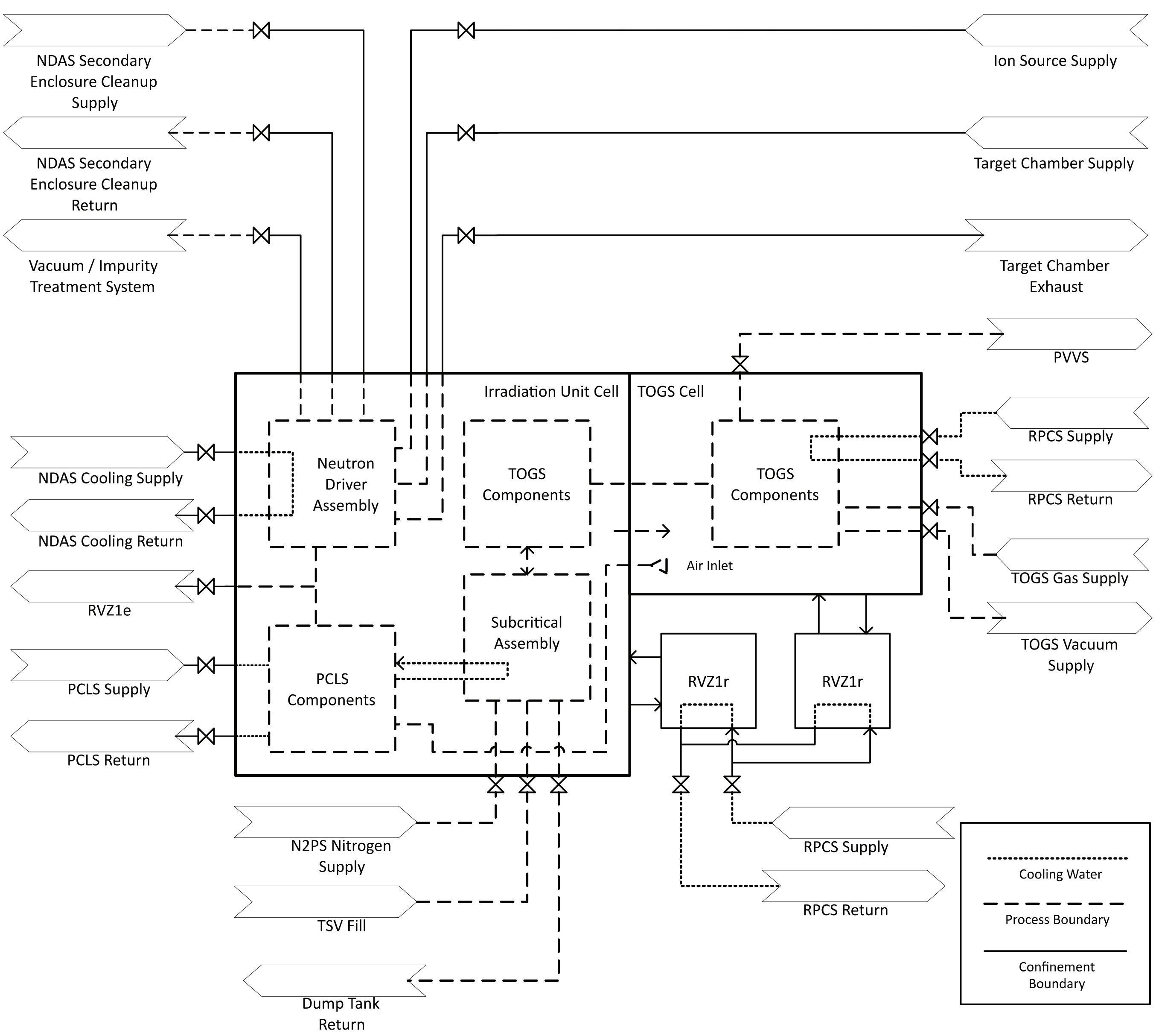


Figure 6a2.2-2 – Tritium Confinement Boundary

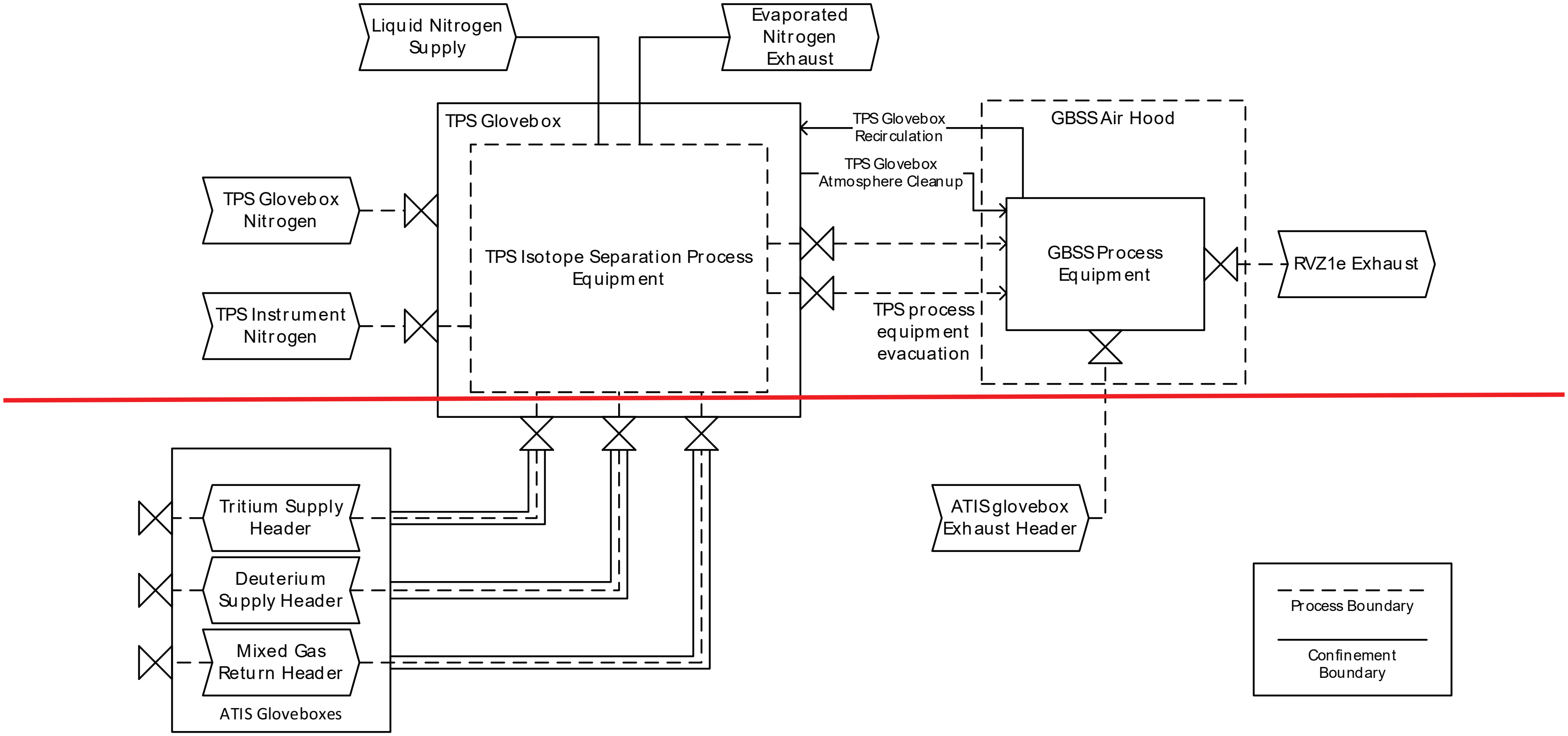


Figure 6a2.2-2 – Tritium Confinement Boundary

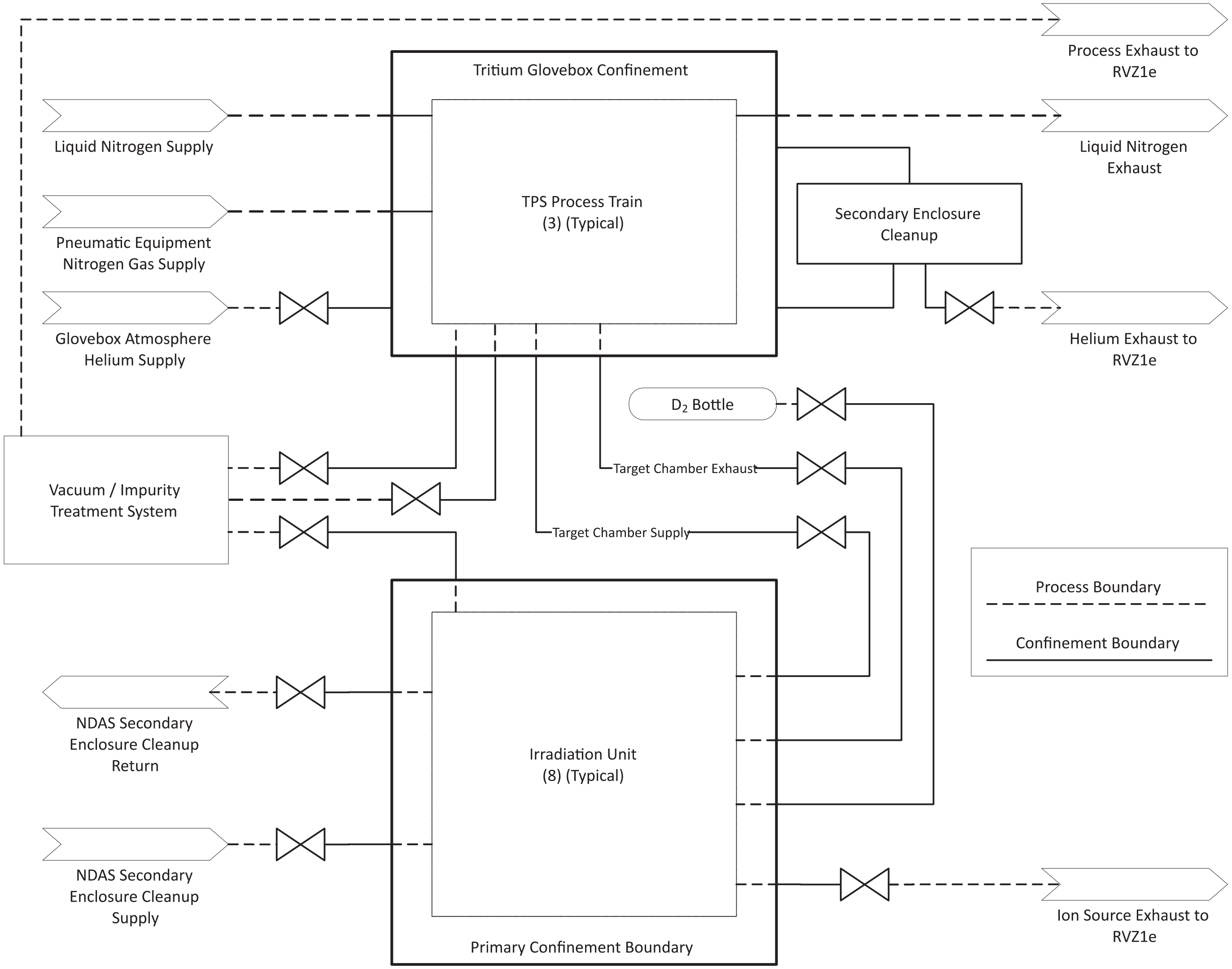


Table 6b.1-1 – Summary of Engineered Safety Features and Design Basis Accidents Mitigated

Credited Engineered Safety Feature (ESF)	~~Irradiation~~ Radioisotope Production Facility Design Basis Accidents Mitigated by ESF	Detailed Description Subsection
Supercell Confinement	Critical Equipment Malfunction (Subsection 13b.2.4)	6b.2.1.1
Below Grade Confinement	Critical Equipment Malfunction (Subsection 13b.2.4)	6b.2.1.2
Process Vessel Ventilation Isolation	Radioisotope Production Facility Fire (Subsection 13b.2.6)	6b.2.2
Combustible Gas Management	Loss of Electrical Power (Subsection 13b.2.2) Critical Equipment Malfunction (Subsection 13b.2.4)	6b.2.3
None	External Events (Subsection 13b.2.3)	N/A

6b.2 DETAILED DESCRIPTIONS

This section provides the details of the design, initiation, and operation of engineered safety features (ESFs) that are provided to mitigate the design basis accidents (DBAs) in the radioisotope production facility (RPF). The RPF DBAs, the ESFs required to mitigate the DBAs, and the location of the bases for these determinations are listed in Table 6b.1-1.

6b.2.1 CONFINEMENT

The confinement systems are designed to limit the release of radioactive material to uncontrolled areas during and after DBAs to mitigate the consequences to workers, the public, and the environment. The principal objective of the confinement systems is to protect on-site personnel, the public, and the environment. The second objective is to minimize the reliance on administrative or active engineering controls to provide a confinement system that is as simple and fail-safe as reasonably possible. Figure 6b.1-1 provides an overview of the structures, systems, and components that provide RPF confinement safety functions.

A listing of the automatic isolation valves included in the confinement boundaries is in Section 7.5.

6b.2.1.1 Supercell Confinement

The supercell is a set of hot cells in which isotope extraction, purification, and packaging is performed, and gaseous waste is handled. The supercell provides shielding and confinement to protect the workers, members of the public, and the environment by confining the airborne radioactive materials during normal operation and in the event of a release. The supercell includes features to allow the import of target solution, consumables, and process equipment; transfer between adjacent cells; and export of final products, waste, spent process equipment, and samples for analysis in the laboratory. The export features of the supercell are integrated into the confinement boundary to allow export operations while maintaining confinement. The supercell is described in detail in Section 4b.2.

Figure 6b.2-1 provides a block diagram of the supercell confinement boundary. [ ]PROP/ECI

The hot cells are fitted with stainless steel boxes for confinement of materials and process equipment. The radiological ventilation zone 1 (RVZ1) draws air through each individual confinement box, drawing air from the general RPF area, to maintain negative pressure inside the confinement, minimizing release of radiological material to the facility. Filters and carbon adsorbers on the ventilation inlets and outlets control release of radioactive material to workers and the public. RVZ1 is described in Section 9a2.1.

The supercell ventilation exhaust ductwork is fitted with radiation monitoring instrumentation to detect off-normal releases to the confinement boxes. Upon indication of a release exceeding setpoints, isolation dampers or valves on both the inlet and outlet ducts isolate the hot cells from the ventilation system. Additionally, the actuation signal closes isolation valves on the molybdenum extraction and purification system (MEPS) heating loops and conducts a vacuum transfer system (VTS) safety actuation. As part of VTS safety actuation, connections to the supercell from the facility chemical reagent system (FCRS) skid isolate, closing the MEPS and iodine and xenon purification and packaging (IXP) supply valves as described in

Subsection 7.5.3.1.17. The active components required to function to maintain the confinement barrier are actuated by the engineered safety features actuation system (ESFAS). A description of the ESFAS is provided in Section 7.5.

Contaminated air is confined to the supercell by the confinement boxes, the ventilation exhaust dampers or valves, and the process isolation valves.

The facility accident analysis considers the effect of air exchange from the confinement to the general areas in its evaluation of radiological consequences. This outflow of radioactive material from the confined area to the RPF and the environment is based on the leak rate of the supercell. If sufficient radioactive material reaches the radiation monitors in the RVZ1 exhaust duct, ESFAS will isolate the RVZ building supply and exhaust. The evaluated accident sequence for which the supercell is necessary is listed in Table 6b.1-1 and discussed further in Section 13b.2.

The requirements needed for supercell confinement system operability, periodic surveillance, setpoints, and other specific requirements needed to ensure the functionality of the supercell are located in technical specifications.

6b.2.1.2 Below Grade Confinement

The below grade confinement provides a barrier to protect workers, members of the public, and the environment by reducing radiation exposure. The below grade confinement includes the RPF tank vaults, valve pits, pipe trench, and carbon delay bed vault. Portions of the below grade confinement are identified as part of the production facility biological shield (PFBS), which is described in detail in Section 4b.2.

Figure 6b.2-2 provides a block diagram of the below grade confinement.

In the event of a DBA that results in a release within the process confinement boundary, radioactive material is confined primarily by the structural components of the boundary. Gaskets and other non-structural features are used, as necessary, to provide sealing where components meet (e.g., shield plugs and inspection ports). Each vault is equipped with a concrete cover plug fabricated in multiple sections with one or more inspection ports which allow remote inspection of the confined areas without personnel access. Each valve pit is equipped with a concrete cover plug fabricated in multiple sections with one inspection port. The pipe trench is equipped with concrete cover plugs fabricated in multiple sections with some having inspection ports. The pipe trench, vaults, and valve pits with equipment containing fissile material are equipped with drip pans and drains to the radioactive drain system (RDS).

The below grade confinement is primarily passive. Most process piping that passes through the confinement boundary is entering or exiting another confinement boundary. Process piping for auxiliary systems entering the boundary from outside confinement is provided with appropriate manual or automatic isolation capabilities. The confinement boundary includes cover plugs and inspection ports for access to the confined areas. Contaminated air is confined to the vaults, valve pits, and pipe trench.

The facility accident analysis considers the effect of air exchange from the confinement to the general areas in its evaluation of radiological consequences. Three mechanisms by which the process confinement boundary exchanges air with the RPF are considered: pressure-driven flow, counter-current flow, and barometric breathing. The combined effect of these mechanisms

Figure 6b.2-1 – Supercell Confinement Boundary

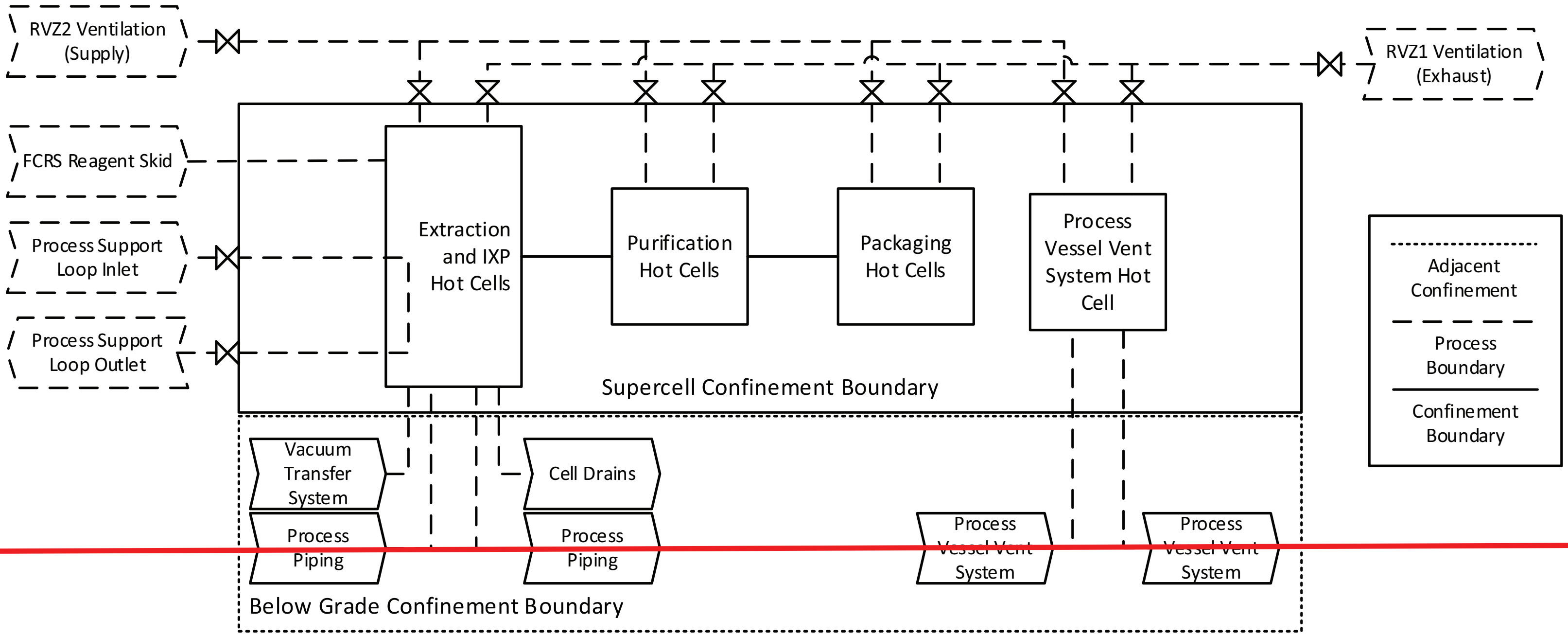
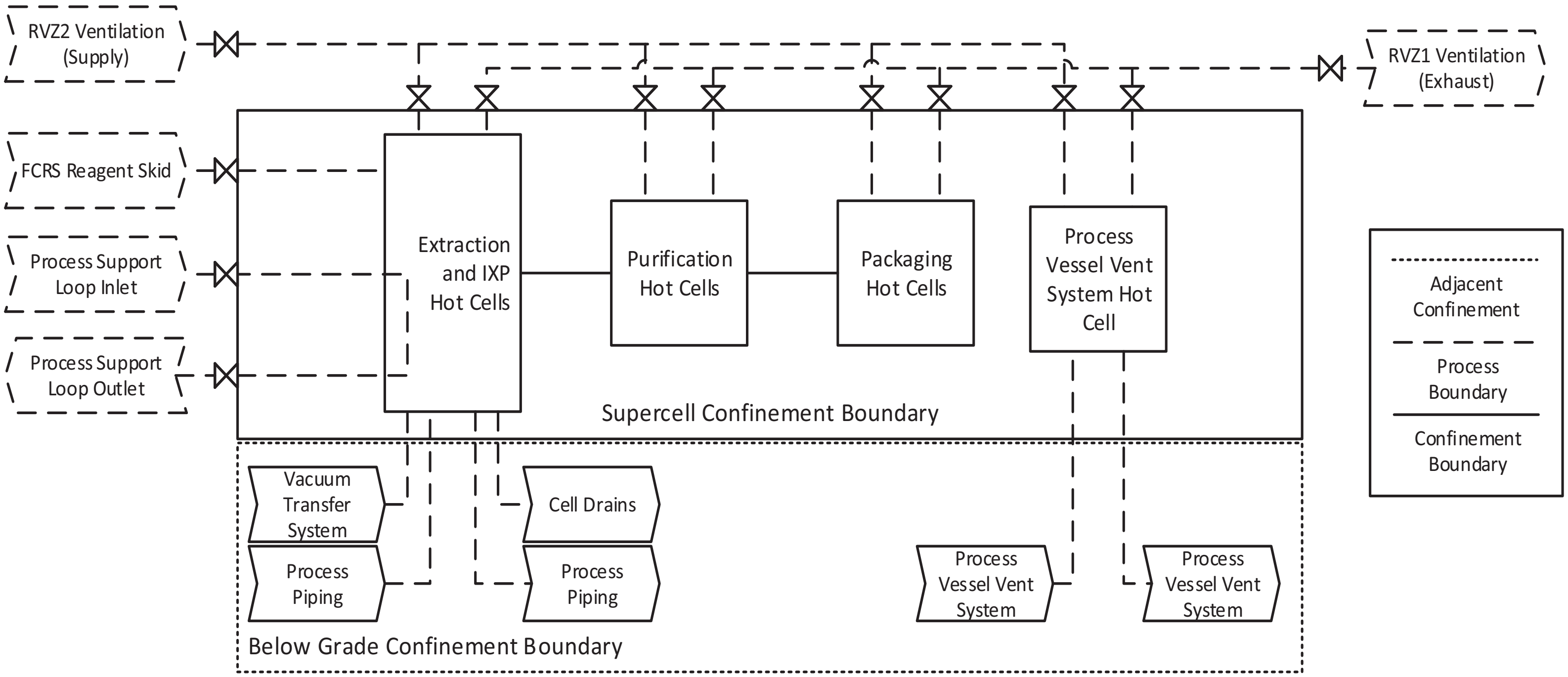


Figure 6b.2-1 – Supercell Confinement Boundary



ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
ALARA	as low as reasonably achievable
ANS	American Nuclear Society
ANSI	American National Standards Institute
AOV	air operated valve
APL	actuation and priority logic
~~ATIS~~	~~accelerator tritium interface system~~
BIST	built-in self-test
CAAS	criticality accident alarm system
CAMS	continuous air monitoring system
cc	cubic centimeter
CCF	common cause failure
CDA	critical digital asset
CDBEM	carbon delay bed effluent monitor
Ci	curie
CM	communication modules
COTS	commercial off-the-shelf

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
CRC	cyclic redundancy checks
CTB	calibration and test bus
DC	direct current
EIM	equipment interface module
EMI	electromagnetic interference
ESFAS	engineered safety features actuation system
FAT	factory acceptance test
FCHS	facility chilled water system
FCR	facility control room
FDCS	facility data and communications system
FDWS	facility demineralized water system
FHWS	facility heating water system
FNHS	facility nitrogen handling system
FPGA	field programmable gate array
~~GBSS~~	~~glovebox stripper system~~

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
HIPS	highly integrated protection system
HRS	hardware requirements specification
HSI	human system interfaces
HVAC	heating, ventilation, and air conditioning
HVPS	high voltage power supply
HWM	hardwired module
I&C	instrumentation and control
IDE	integrated development environment
IDN	isolated development network
IEEE	Institute of Electrical and Electronic Engineers
IF	irradiation facility
ISG	interim staff guidance
ISM	input submodule
ITS	impurity treatment subsystem
IU	irradiation unit
IXP	iodine and xenon purification

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
RVZ3	radiological ventilation zone 3
SASS	subcritical assembly support structure
SBM	scheduling and bypass modules
SCAS	subcritical assembly system
SDB1	safety data bus 1
SDB2	safety data bus 2
SDB3	safety data bus 3
SDE	secure development environment
SFM	safety function module
SGS	standby generator system
SOV	solenoid operated valve
SRM	stack release monitor
SRMS	stack release monitoring system
SVM	scheduling and voting module
SyRS	system requirements specification
TID	total integrated dose

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
TPS	tritium purification system
TRPS	target solution vessel reactivity protection system
TSPS	target solution preparation system
TSSS	target solution storage system
TSV	target solution vessel
UPSS	uninterruptible electrical power supply system
URSS	uranium receipt and storage system
V&V	verification & validation
VAC/ITS	vacuum/impurity treatment subsystem
VTS	vacuum transfer system

7.3.1.5 Operational Bypass

PICS Criterion 7 - Bypasses of PICS interlocks, including provisions for testing, shall be under the direct control of a control room operator and shall be indicated on control room displays.

7.3.1.6 Surveillance

PICS Criterion 8 - Subsystems of and equipment in the PICS shall be designed to allow testing, calibration, and inspection to ensure functionality.

PICS Criterion 9 - Testing, calibration, and inspections of the PICS shall be sufficient to confirm that surveillance test and self-test features address failure detection, self-test capabilities, and actions taken upon failure detection.

7.3.2 DESIGN BASIS

The PICS is designed to allow the operator to perform irradiation cycles, transfer target solution to and from the irradiation unit (IU) as well as through the production facility, and interface with the tritium purification system (TPS), supercell, waste handling, and auxiliary systems.

The modes of operation for the functions of the PICS that interface with individual IUs correspond to the mode of that IU (see Subsection 7.3.3). Portions of the PICS that monitor or control common or facility-wide systems are not mode-dependent.

The PICS control cabinets are located in the non-radiologically controlled areas of the main production facility and PICS components are in various plant areas with varying environmental conditions. The PICS is designed for the normal environmental and radiological conditions provided in Tables 7.2-1 through 7.2-6.

7.3.3 DESCRIPTION

The PICS is a collection of instrumentation and control equipment located throughout the facility to support monitoring, indication, and control of various systems. Decentralized implementation of the PICS functions allows subsets of the system to perform functions independent of each other. A portion of the PICS supports the main control board and operator workstations in the facility control room by receiving operator commands and collecting and transmitting facility information to the operators, as described in Section 7.6. A summary of the PICS facility system interfaces is provided in Figure 7.3-1.

7.3.3.1 Irradiation Unit Systems

The PICS is used to monitor parameters and perform manual and automatic actions during each of the operational modes of a subcritical assembly system (SCAS):

Mode 0 - Solution Removed: No target solution in the SCAS
Mode 1 - Startup: Filling the TSV
Mode 2 - Irradiation: Operating mode (neutron driver active)
Mode 3 - Post-Irradiation: TSV dump valves open
Mode 4 - Transfer to RPF: Dump tank drain valve~~s~~ opens to permit solution transfer

7.4 TARGET SOLUTION VESSEL REACTIVITY PROTECTION SYSTEM

7.4.1 SYSTEM DESCRIPTION

The target solution vessel (TSV) reactivity protection system (TRPS) performs various design basis safety functions for accelerator-based irradiation processes taking place within each irradiation unit (IU) cell of the SHINE production facility. While operating, the TRPS performs various detection, logic processing, control, and actuation functions associated with the SHINE irradiation process. The TRPS includes input/output capabilities necessary to interface with various indications and control components located within the facility control room. The TRPS also provides nonsafety-related system status and measured process variable values to the facility process integrated control system (PICS) for viewing, recording, and trending.

The TRPS monitors variables important to the safety functions of the irradiation process during each operating mode of the IU to perform one or more of the following safety functions:

- IU Cell Safety Actuation
- IU Cell Nitrogen Purge
- IU Cell TPS Actuation
- Driver Dropout

The TRPS also performs the nonsafety defense-in-depth Fill Stop function.

The TRPS monitors the IU cell from filling of the TSV through irradiation of the target solution, dumping of the target solution, and transfer of the target solution to the radioisotope production facility (RPF). All advances to the modes of operation throughout the irradiation process are manually initiated by the operator and the TRPS implements the required mode-specific system interlocks and bypasses; however, the TRPS does not automatically determine the mode of operation. If at any point during the irradiation process a monitored variable indicating unsafe conditions exceeds its setpoint, the TRPS automatically places the IU into a safe state. The TRPS logic diagrams are shown in Figure 7.4-1.

The TRPS uses redundant and independent sensors through three divisions to complete the logical decisions necessary to initiate the required protective trips and actuations. When a TRPS input channel exceeds a predetermined limit, the trip determinations from each division of the TRPS are sent to voting logic where a two-out-of-three coincident logic vote is performed to initiate a trip or actuation. The general architecture of the TRPS is shown in Figure 7.1-2.

When a TRPS output is in its normal, energized state, it does not control the position of the actuation component. Instead, the TRPS and the PICS are arranged in a series configuration for the PICS to control the component normally, and deenergizing the output of the TRPS forces the component to its safe state via the physical design of the valve or breaker. The only exception to this control configuration is for the nitrogen purge system inerting gas valves, TSV off-gas system (TOGS) radioisotope process facility cooling system (RPCS) supply and return isolation valves, TOGS nitrogen vent isolation valves, and the radiological ventilation IU cell dampers. For these components, the TRPS assumes normal control, and PICS only has control of the component when appropriate permissives are active.

TRPS Criterion 11 – Validation testing shall test all portions of TRPS programmable logic necessary to accomplish its safety functions and shall exercise those portions whose operation or failure could impair safety functions during testing.

TRPS Criterion 12 – The TRPS software development life cycle shall include a software risk management program which addresses vulnerabilities throughout the software life cycle.

TRPS Criterion 13 – TRPS equipment not designed under SHINE approved quality assurance (QA) program shall be accepted under the SHINE commercial-grade dedication program.

7.4.2.3 General Instrumentation and Control Requirements

TRPS Criterion 14 – The TRPS safety function shall perform and remain functional during normal operation and during and following a design basis event.

TRPS Criterion 15 – Manual controls of TRPS actuation components shall be implemented downstream of the digital I&C portions of the safety system.

7.4.2.4 Single Failure

TRPS Criterion 16 – The TRPS shall be designed to perform its protective functions after experiencing a single random active failure in nonsafety control systems or in the TRPS, and such failure shall not prevent the TRPS and credited passive redundant control components from performing its intended functions or prevent safe shutdown of an IU cell.

TRPS Criterion 17 – The TRPS shall be designed such that no single failure can cause the failure of more than one redundant component.

7.4.2.5 Independence

TRPS Criterion 18 – Interconnections among TRPS safety divisions shall not adversely affect the functions of the TRPS.

TRPS Criterion 19 – A logical or software malfunction of any interfacing non-safety systems shall not affect the functions of the TRPS.

TRPS Criterion 20 – The TRPS shall be designed with physical, electrical, and communications independence of the TRPS both between the TRPS channels and between the TRPS and nonsafety-related systems to ensure that the safety functions required during and following any design basis event can be accomplished.

TRPS Criterion 21 – Physical separation and electrical isolation shall be used to maintain the independence of TRPS circuits and equipment among redundant safety divisions or with nonsafety systems so that the safety functions required during and following any design basis event can be accomplished.

TRPS Criterion 22 – The TRPS shall be designed such that no communication – within a single safety channel, between safety channels, and between safety and nonsafety systems – adversely affects the performance of required safety functions.

7.4.3 DESIGN BASIS

The TRPS is used to initiate protective actions of the IU in response to monitored variables exceeding predetermined limits. Modes of operation are used within the TRPS to set interlocks on the applicable variables for each operating mode in the IU and to create permissives for allowing the operator to perform certain actions with the safety-related TRPS components.

7.4.3.1 Mode Transition

IU operating modes are described in Subsection 7.3.3.1.

Each mode transition in the TRPS is initiated manually through the PICS, except for transition to Mode 3 via an IU Cell Safety Actuation or use of the control key to deactivate the facility master operating permissive. Before an operator is able to transition to a different mode, the transition criteria conditions must be met. Figure 7.4-2 shows a state diagram of the mode transitions.

Mode 0 to Mode 1 Transition Criteria

The TRPS permissives prevent transitioning from Mode 0 to Mode 1 until the TSV dump valves and TSV fill isolation valves have been confirmed to be closed and ~~TSV off-gas system (~~TOGS~~)~~ mainstream flow is at or above the low flow limit. Normal control of actuation component positions when going from Mode 0 to Mode 1 is manual and independent from TRPS mode transition.

Mode 0 to Mode 3 Transition Criteria

Transition from Mode 0 to Mode 3 is initiated automatically by TRPS or manually by an operator via manual actuation or the facility master operating permissive. Initiation of this transition generates an IU Cell Safety Actuation.

Mode 1 to Mode 2 Transition Criteria

The TRPS permissives prevent transitioning from Mode 1 to Mode 2 until the TSV fill isolation valves indicate fully closed ~~and the [~~ ~~]PROP/ECI~~. Normal control of actuation component positions when going from Mode 1 to Mode 2 is manual and independent from TRPS mode transition.

Mode 1 to Mode 3 Transition Criteria

Transition from Mode 1 to Mode 3 is initiated automatically by TRPS or manually by an operator via manual actuation or the facility master operating permissive. Initiation of this transition generates IU Cell Safety Actuation.

Mode 2 to Mode 3 Transition Criteria

The TRPS permissives prevent transitioning from Mode 2 to Mode 3 until the neutron driver assembly system (NDAS) high voltage power supply (HVPS) breakers have been confirmed opened. Normal control of the HVPS breakers from closed to open is manual and independent from TRPS mode transition. Normal transition of the dump valves to the open position is

Mode 3 Transition Components

- TSV dump valves
- NDAS HVPS breakers

Primary System Boundary Components

- TSV fill isolation valves
- TSV dump tank drain isolation valve
- TOGS gas supply isolation valves
- TOGS vacuum tank isolation valves
- Vacuum transfer system (VTS) lower lift tank target solution valve(s)

The VTS lower lift tank target solution valves are redundant to the TSV dump tank drain isolation valve for an IU Cell Safety Actuation.

Primary Confinement Boundary Components

- Primary closed loop cooling system (PCLS) supply isolation valve~~s~~
- PCLS return isolation valves
- TPS target chamber supply isolation valves
- ~~ATIS~~TPS deuterium supply ~~line~~ isolation valves
- ~~ATIS tritium supply line~~TPS target chamber exhaust isolation valves
- ~~ATIS mixed-gas return line isolation valves~~
- ~~ATIS~~TPS neutron driver evacuation ~~line~~ isolation valves
- Radiological ventilation zone 1 exhaust subsystem (RVZ1e) IU cell ventilation dampers
- TOGS ~~radioisotope process facility cooling system (~~RPCS~~)~~ supply isolation valves
- TOGS RPCS return isolation valve
- Radiological ventilation zone 1 recirculation subsystem (RVZ1r) RPCS supply isolation valve
- RVZ1r RPCS return isolation valve

The TRPS initiates an IU Cell Safety Actuation based on the following variables:

- High source range neutron flux signal
- High wide range neutron flux
- High time-averaged neutron flux
- High RVZ1e IU cell radiation
- Low TOGS oxygen concentration
- Low TOGS mainstream flow (Train A)
- Low TOGS mainstream flow (Train B)
- Low TOGS dump tank flow
- High TOGS condenser demister outlet temperature (Train A)
- High TOGS condenser demister outlet temperature (Train B)
- Low PCLS flow (180 second delay)
- High PCLS temperature (180 second delay)
- Low PCLS temperature
- ~~High ATIS mixed-gas return line pressure~~
- Low-high TSV dump tank level signal
- High-high TSV dump tank level signal

- TSV fill isolation valves not fully closed
- Facility master operating permissive

7.4.3.2.2 IU Cell Nitrogen Purge

An IU Cell Nitrogen Purge is initiated when monitored variables indicate a loss of hydrogen recombination capability in the IU. An IU Cell Nitrogen Purge results in purging the primary system boundary with nitrogen.

An IU Cell Nitrogen Purge consists of an automatically or manually initiated transition of each of the following components to their deenergized state and providing a signal to the engineered safety features actuation system (ESFAS) to initiate an ESFAS IU Cell Nitrogen Purge (see Section 7.5).

- Nitrogen purge system (N2PS) inerting gas isolation valves
- TOGS nitrogen vent isolation valves
- TOGS RPCS supply isolation valves
- TOGS RPCS return isolation valve

The TRPS initiates an IU Cell Nitrogen Purge based on the following variables:

- Low-high TSV dump tank level
- High-high TSV dump tank level
- Low TOGS oxygen concentration
- Low TOGS mainstream flow (Train A)
- Low TOGS mainstream flow (Train B)
- Low TOGS dump tank flow
- High TOGS upstream condenser demister outlet temperature (Train A)
- High TOGS upstream condenser demister outlet temperature (Train B)
- ESFAS loss of external power

7.4.3.2.3 IU Cell TPS Actuation

An IU Cell TPS Actuation is initiated when monitored variables indicate a release of tritium in a TPS glovebox. An IU Cell TPS Actuation results in isolating the TPS lines into and out of the IU cell, isolating the RVZ1 exhaust out of the IU cell, and deenergizing the neutron driver.

An IU Cell TPS Actuation consists of an automatically or manually initiated transition of each of the following components to their deenergized state and initiating a Driver Dropout (see Section 7.4.3.2.4):

- TPS target chamber supply isolation valves
- TPS deuterium supply isolation valves
- TPS target chamber exhaust isolation valves
- TPS neutron driver evacuation isolation valves
- RVZ1e IU cell ventilation dampers

The TRPS initiates an IU Cell TPS Actuation based on the following variables:

- ESFAS IU Cell TPS Actuation
- ESFAS TPS Process Vent Actuation

7.4.3.2.4 Driver Dropout

A Driver Dropout responds to monitored variables that indicate a loss of neutron driver output or a loss of cooling to allow the SCAS to recover from NDAS or PCLS transients. A Driver Dropout functions differently depending on whether it was initiated based on loss of neutron driver output or loss of cooling.

The TRPS initiates a Driver Dropout based on:

- Low power range neutron flux
- Low PCLS flow
- High PCLS temperature
- IU Cell TPS Actuation

The TRPS initiates a loss of neutron driver Driver Dropout on low power range neutron flux by opening the NDAS HVPS breakers with a timed delay. ~~The breakers are then interlocked open until the [ ]$^{\text{PROP/ECI}}$. This action prevents the neutron driver from restarting in situations when a restart may exceed analyzed conditions for the SCAS.~~ Driver Dropout on low power range neutron flux is bypassed until the power range neutron flux has reached the power range driver dropout permissive. After the bypass of Driver Dropout on low power range neutron flux has been removed, it remains removed until a mode transition~~, the [ ]$^{\text{PROP/ECI}}$~~ or both HVPS breakers are open. The TRPS implements a timed delay of [ ]$^{\text{PROP/ECI}}$ from the time the low power range neutron flux signal is initiated, indicating that the neutron flux has exceeded its lower limits, to when the TRPS output to the HVPS breakers is deenergized. If fewer than two-out-of-three low power range neutron flux actuation signals are present before the timer has expired, then the low power range neutron flux timer resets. This delay allows the neutron driver to be restarted or to restart automatically within analyzed conditions.

The TRPS initiates a loss of cooling Driver Dropout on low PCLS cooling water flow or high PCLS cooling water supply temperature to open the NDAS HVPS breakers without a timed delay. This shuts down the neutron driver to prevent overheating of the target solution, while allowing the target solution to remain within the TSV. The breakers are then interlocked open until the PCLS flow and temperature are in the allowable range. If PCLS flow and temperature are not in the allowable range within 180 seconds, an IU Cell Safety Actuation is initiated, as described in Subsection 7.4.3.2.1.

7.4.3.2.5 Fill Stop

The nonsafety-related Fill Stop function aids in controlling the rate of fill of the TSV. If Fill Stop parameters are not met, then the Fill Stop deenergizes the TSV fill isolation valves blocking the fill path into the TSV.

7.4.4.3 General Instrumentation and Control Design

The TRPS is powered from the uninterruptible electrical power supply system (UPSS), which provides a reliable source of power to maintain the TRPS functional during normal operation and during and following a design basis event. The UPSS is designed to provide power to the TRPS for two hours after a loss of off-site power. The UPSS is described in Section 8a2.2.

The actuation and priority logic (APL) portions within an equipment interface module (EIM) support the implementation of different actuation methods. The APL is implemented using discrete components and is not vulnerable to a software common cause failure (CCF). Having the capability for hardwired signals into each EIM supports the capability for additional and diverse actuation means from automated actuation. As an example, a division of APL circuits may receive inputs automatically from the programmable logic portion of the TRPS, inputs from manual controls in the facility control room, and input signals from a nonsafety control system. Both the manual controls and nonsafety control system inputs come individually into the APL and are downstream of the programmable logic portion of the TRPS architecture as shown in Figure 7.1-2.

7.4.4.4 Single Failure

The TRPS consists of three divisions of input processing and trip determination and two divisions of actuation logic (see Figure 7.1-2), arranged such that no single failure ~~can prevent a safety actuation when required~~within the TRPS results in the loss of the protective function, and no single failure in a single measurement channel can generate an unnecessary safety actuation.

The only nonsafety inputs into the TRPS are those from the PICS for control, the discrete mode input, and monitoring and indication only variables. The nonsafety control signals from the PICS are implemented through a hardwired parallel interface that requires the PICS to send a binary address associated to the output state of the EIM along with a mirrored complement address. The mirrored complement address prevents any single incorrectly presented bit from addressing the wrong EIM output state. To prevent the PICS from inadvertently presenting a valid address, the TRPS contains a safety-related enable nonsafety switch that controls when the hardwired parallel interface within the APL is active, thus controlling when the PICS inputs are allowed to pass through the input circuitry and for use in the priority logic within the APL. When the enable nonsafety switch is not active, the nonsafety-related control signal is ignored. If the enable nonsafety is active, and no automatic or manual safety actuation command is present, the nonsafety-related control signal can control the TRPS output. The hardwired module (HWM) provides isolation for the nonsafety-related signal path.

The discrete mode input has a unique input for each of Division A and Division B. The HWM provides isolation of the signal path into the TRPS. As a discrete input, the three failure modes that are addressed are stuck high, stuck low, or oscillating. Because the TRPS only clocks in a new mode on the rising edge of the mode input, an input stuck low or high would maintain the TRPS in the same mode and continue monitoring the variables important to the safe operation of that mode. If the mode input began oscillating continuously between a logic high and low, the TRPS would only allow the mode to change if permissive conditions for the current mode are met. If the permissive conditions place the IU into a state that within the transitioned mode are outside of the predetermined operating limits, then the TRPS would initiate an IU Cell Safety Actuation and transition to and maintain Mode 3, ignoring any further input from the discrete mode input.

Each input variable to the TRPS for monitoring and indication only is processed on independent input submodules that are unique to that input. If the variable is not used for a safety function (i.e., no trip determination is performed with the variable), then the variable is not connected to the safety data buses and is only placed onto the monitoring and indication bus. The monitoring and indication bus is used by the monitoring and indication communication module (MI-CM) without interacting with any of the safety data paths.

7.4.4.5 Independence

See Subsection 7.2.2 for independence applied to the TRPS.

7.4.4.6 Prioritization of Functions

The APL (which is constructed of discrete components and part of the EIM) is designed to provide priority to safety-related signals over nonsafety-related signals. Division A and Division B priority logic of the TRPS prioritizes the following TRPS inputs, with the first input listed having the highest priority and each successive input in the list having a lower priority than the previous.

1) Automatic Safety Actuation, Manual Safety Actuation
2) PICS nonsafety control signals

7.4.4.7 Fail Safe

Safety actuations result in deenergizing one or more control outputs, and the controlled components are designed such that they go to their safe state when deenergized. On a loss of power to the TRPS, the TRPS deenergizes actuation components to the positions defined below:

Mode 3 Transition Components

- NDAS HVPS breakers
  - Open
- TSV dump valves
  - Open

Primary System Boundary Components

- TSV fill isolation valves
  - Closed
- TSV dump tank drain isolation valve
  - Closed
- TOGS gas supply isolation valves
  - Closed
- TOGS vacuum tank isolation valves
  - Closed
- VTS lower lift tank target solution valves
  - Closed

Primary Confinement Components

- N2PS inerting gas isolation valves
  - Open

- TOGS nitrogen vent isolation valves
  - Open
- TOGS RPCS supply isolation valves
  - Closed
- TOGS RPCS return isolation valve
  - Closed
- RVZ1e IU cell ventilation dampers
  - Closed
- RVZ1r RPCS supply isolation valve
  - Closed
- RVZ1r RPCS return isolation valve
  - Closed
- PCLS supply isolation valve~~s~~
  - Closed
- PCLS return isolation valves
  - Closed
- ~~ATIS deuterium~~TPS target chamber supply ~~line~~isolation valves
  - Closed
- ~~ATIS tritium~~TPS deuterium supply ~~line~~isolation valves
  - Closed
- ~~ATIS mixed gas return line~~TPS target chamber exhaust isolation valves
  - Closed
- ~~ATIS~~TPS neutron driver evacuation ~~line~~isolation valves
  - Closed

7.4.4.8 Setpoints

Setpoints in the TRPS are based on a documented methodology that identifies each of the assumptions and accounts for the uncertainties in each instrument channel. The setpoint methodology is further described in Subsection 7.2.3.

7.4.4.9 Operational Bypass, Permissives, and Interlocks

Maintenance bypasses are described in Subsection 7.1.4.

Permissive conditions, bypasses, and interlocks are created in each mode of operation specific to that mode to allow the operator to progress the TRPS to the next mode of operation. The TRPS implements logic associated with each mode of operation to prevent an operator from activating a bypass through changing the IU cell mode out of sequential order. Each mode of operation is achieved through manual input from the operator when permissive conditions for the next mode in the sequence have been met. See the TRPS mode state diagram in the TRPS logic diagrams (Figure 7.4-1~~, Sheet 7~~) for the transitional sequence of the TRPS. Below are the required conditions that must be satisfied before a transition to the following mode in the sequence can be initiated.

- The TRPS shall only transition from Mode 0 to Mode 1 if all TSV dump valve position indications and all TSV fill isolation valve indications indicate valves are fully closed and the TOGS mainstream flow is above the minimum flow rate.
- The TRPS shall only transition from Mode 1 to Mode 2 if the TSV fill isolation valve position indications indicate both valves are fully closed ~~and the [ ]PROP/ECI~~.

- The TRPS shall only transition from Mode 2 to Mode 3 if all HVPS breaker position indications indicate the breakers are open.
- The TRPS shall only transition from Mode 3 to Mode 4 if an IU Cell Safety Actuation is not present.
- The TRPS shall only transition from Mode 4 to Mode 0 if the TSV dump tank level is below the low-high TSV dump tank level.

In each mode of operation, the TRPS bypasses different actuation channels when the actuation channel is not needed for initiation of an IU Cell Safety Actuation, an IU Cell Nitrogen Purge, or Driver Dropout. The lists below identify each variable that is bypassed during the different modes of operation.

Safety actuations based on the following instrumentation channels are bypassed in Mode 0:

- Low power range neutron flux
- Low PCLS temperature
- High PCLS temperature
- Low PCLS flow
- ~~High ATIS mixed-gas return line pressure~~
- Low TOGS mainstream flow
- Low TOGS dump tank flow
- High TOGS condenser demister outlet temperature
- ESFAS loss of external power

Safety actuations based on the following instrumentation channels are bypassed in Mode 1:

- Low power range neutron flux
- ~~High ATIS mixed-gas return line pressure~~
- TSV fill isolation valve not fully closed

Safety actuations and interlocks based on the following instrumentation channels are bypassed in Mode 2:

- High source range neutron flux signal

The TRPS bypasses Driver Dropout on the low power range neutron flux signal until the power range neutron flux is above the driver dropout permissive setpoint. The bypass is reapplied if there has been a change in mode of operation~~, the ATIS mixed-gas return line [ ]$^{\text{PROP/ECI}}$,~~ or if both HVPS breaker position indications indicate in Mode 2 that they are open.

When the low power range neutron flux signal becomes active, a timer is started to create a [ ]$^{\text{PROP/ECI}}$ delay before a Driver Dropout is initiated. If fewer than two-out-of-three low power range neutron flux actuation signals are present before the timer has expired, then the low power range neutron flux timer resets.

Low PCLS flow and high PCLS temperature do not initiate an IU Cell Safety Actuation until after a time delay of 180 seconds from the start of the low PCLS flow or high PCLS temperature signal. If fewer than two-out-of-three Low PCLS flow or high PCLS temperature signals are present before the timer has expired, then the 180 second timer resets.

Safety actuations and interlocks based on the following instrumentation channels are bypassed in Mode 3:

- High source range neutron flux signal
- Low power range neutron flux
- High PCLS temperature
- Low PCLS temperature
- Low PCLS flow
- Low-high TSV dump tank level signal
- ~~High ATIS mixed gas return line pressure~~
- TSV fill isolation valve not fully closed

The TRPS includes the ability for the operator to transition the system from Mode 3 operation to a secure state of operation. While in the secure state, an interlock is maintained preventing the TRPS from transitioning to the next sequential mode. The control key, via use of a facility master operating permissive, is used to place the TRPS into and out of the secure state.

Safety actuations and interlocks based on the following instrumentation channels are bypassed in Mode 4:

- High source range neutron flux signal
- Low power range neutron flux
- High PCLS temperature
- Low PCLS temperature
- Low PCLS flow
- Low-high TSV dump tank level signal
- ~~High ATIS mixed gas return line pressure~~
- TSV fill isolation valve not fully closed

When the mode of operation changes, the bypasses are removed from the previous mode where they are no longer appropriate. The status of each bypass is provided to the operator through the monitoring and indication bus to the PICS, which allows the operator to confirm that a function has been bypassed or returned to service.

The manual actuation signals input from the operators in the facility control room are brought directly into the discrete actuation and priority logic. The manual actuation input into the priority logic does not have the ability to be bypassed and will always have equal priority to the automated actuation signal over any other signals that are present.

7.4.4.10 Completion of Protective Actions

The TRPS is designed so that once initiated, protective actions will continue to completion. Only deliberate operator action can be taken to reset the TRPS following a protective action. Figure 7.4-1~~, Sheet 11 and Sheet 12,~~ shows how the TRPS latches in a protective action and maintains the state of a protective action until operator input is initiated to reset the output of the TRPS.

The output of the TRPS is designed so that actuation through automatic or manual means of a safety function can only deenergize the output. If there is no signal present from the automatic safety actuation or manual safety actuation, then the output of the EIM remains in its current

7.4.4.15 Quality

The following codes and standards are applied to the TRPS design:

1) Section 8 of IEEE Standard 344-2013, IEEE Standard for Seismic Qualification of Equipment for Nuclear Power Generating Stations (IEEE, 2013); invoked as guidance to meet SHINE Design Criterion 2, Natural phenomena hazards.
2) IEEE Standard 379-2000, IEEE Standard Application of Single-Failure Criterion to Nuclear Power Generating Station Safety Systems (IEEE, 2000); invoked to meet SHINE Design Criterion 1~~3~~5, ~~Instrumentation and controls~~Protection system reliability and testability.
3) IEEE Standard 384-2008, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits (IEEE, 2008); invoked for separation of safety-related and nonsafety-related cables and raceways, as described in Subsection 8a2.1.3 and Subsection 8a2.1.5.
4) IEEE Standard 1023-2004, IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities (IEEE, 2004c); invoked as a guidance to support implementation of human factors into the design of I&C systems.
5) Section 5.2.1 of IEEE Standard 1050-2004, IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations (IEEE, 2004b); invoked as guidance to support electromagnetic compatibility qualification for digital I&C equipment.
6) Regulatory Guide 1.152, Revision 3, Criteria for Use of Computers in Safety Systems of Nuclear Power Plants (USNRC, 2011); invoked to demonstrate secure development and operating environment.
7) The guidance of ANSI/ANS 15.8-1995, Quality Assurance Program Requirements for Research Reactors (R2013) (ANSI/ANS, 1995), as endorsed by Regulatory Guide 2.5, Quality Assurance Program Requirements for Research and Test Reactors (USNRC, 2010), is applied as part of the SHINE Quality Assurance Program for complying with the programmatic requirements of 10 CFR 50.34(b)(6)(ii).

7.4.5 OPERATION AND PERFORMANCE

7.4.5.1 High Source Range Neutron Flux

The high source range neutron flux signal protects against an insertion of excess reactivity during the filling process. The TRPS bypasses safety actuations based on the high source range neutron flux signal when filling activities cannot be in progress (i.e., Mode 2 and Mode 3), because the fill isolation valves are closed. The signal is transmitted as a discrete input to the TRPS from the NFDS through three independent and redundant channels, one for each division of TRPS. When two-out-of-three or more high source range neutron flux signals are active, an IU Cell Safety Actuation is initiated.

7.4.5.2 Low Power Range Neutron Flux

The low power range neutron flux signal protects against loss of the neutron beam followed by a restart of the neutron beam outside of analyzed conditions. The low power range neutron flux is only used during the irradiation process (Mode 2) and is bypassed in the other modes of operation. Safety actuations based on the low power range neutron flux are bypassed until the power range neutron flux has reached the power range driver dropout permissive. Once power channels, one for each division of TRPS. Safety actuations based on the low TOGS mainstream flow are bypassed when no target solution is present in the IU. When two-out-of-three or more TOGS mainstream flow inputs drop below the allowable limit, an IU Cell Safety Actuation and an IU Cell Nitrogen Purge are initiated.

7.4.5.12 Low TOGS Dump Tank Flow

The low TOGS dump tank flow signal protects against a deflagration in the TSV dump tank caused by an inability to remove accumulated hydrogen from that tank. The TOGS dump tank flow is measured with an analog interface on three different channels, one for each division of TRPS. Safety actuations based on the low TOGS dump tank flow are bypassed when no target solution is present in the IU. When two-out-of-three or more TOGS dump tank flow inputs drop below the allowable limit, an IU Cell Safety Actuation and an IU Cell Nitrogen Purge are initiated.

7.4.5.13 High TOGS Condenser Demister Outlet Temperature

The high TOGS condenser demister outlet temperature signal protects against adverse effects on TOGS instrumentation and zeolite beds, causing them to fail to perform their safety functions. The TOGS condenser demister outlet temperature signal is measured with a temperature interface on three different channels, one for each TRPS division. When two-out-of-three or more TOGS condenser demister outlet temperature inputs exceed the allowable limit, an IU Cell Safety Actuation and an IU Cell Nitrogen Purge are initiated.

7.4.5.14 ESFAS Loss of External Power

The ESFAS loss of external power signal is an anticipatory protection against the impending loss of TOGS blowers and recombiners after the runtime of that equipment on the UPSS has been exceeded. TRPS does not receive the loss of external power signal from ESFAS until three minutes after the external power loss. The ESFAS loss of external power signal is measured with a discrete input signal on two different channels, one for each Division A and Division B of TRPS. When an ESFAS loss of external power signal is active, the division receiving the discrete signal initiates an IU Cell Nitrogen Purge.

7.4.5.15 ~~High ATIS Gas Return Line Pressure~~

~~The high ATIS gas return line pressure signal protects against a break in the tritium lines in the IU cell. The ATIS gas return line pressure is measured with an analog interface on three different channels, one for each division of TRPS. Safety actuations based on high ATIS gas return line pressure are bypassed except for when the IU is in irradiation (Mode 2). When two-out-of-three or more ATIS gas return line pressure inputs exceed the allowable limit, an IU Cell Safety Actuation is initiated.~~

7.4.5.16 High RVZ1e IU Cell Radiation

The high RVZ1 radiation signal protects against a breach in the primary system boundary. The RVZ1 radiation is measured with an analog interface on three different channels, one for each division of TRPS. When two-out-of-three or more RVZ1 radiation channels exceed the allowable limit, an IU Cell Safety Actuation is initiated.

7.4.5.17 TSV Fill Isolation Valves Open

A TSV fill isolation valve open signal protects against the inadvertent addition of target solution to the TSV. The TSV valve open position indication is measured with a discrete input on two different channels for each valve. When one-out-of-two or more TSV fill isolation valve open signals are active for both of the TSV fill isolation valves, an IU Cell Safety Actuation is initiated. IU Cell Safety Actuation on TSV valves open is only active when the IU cell is undergoing irradiation (Mode 2).

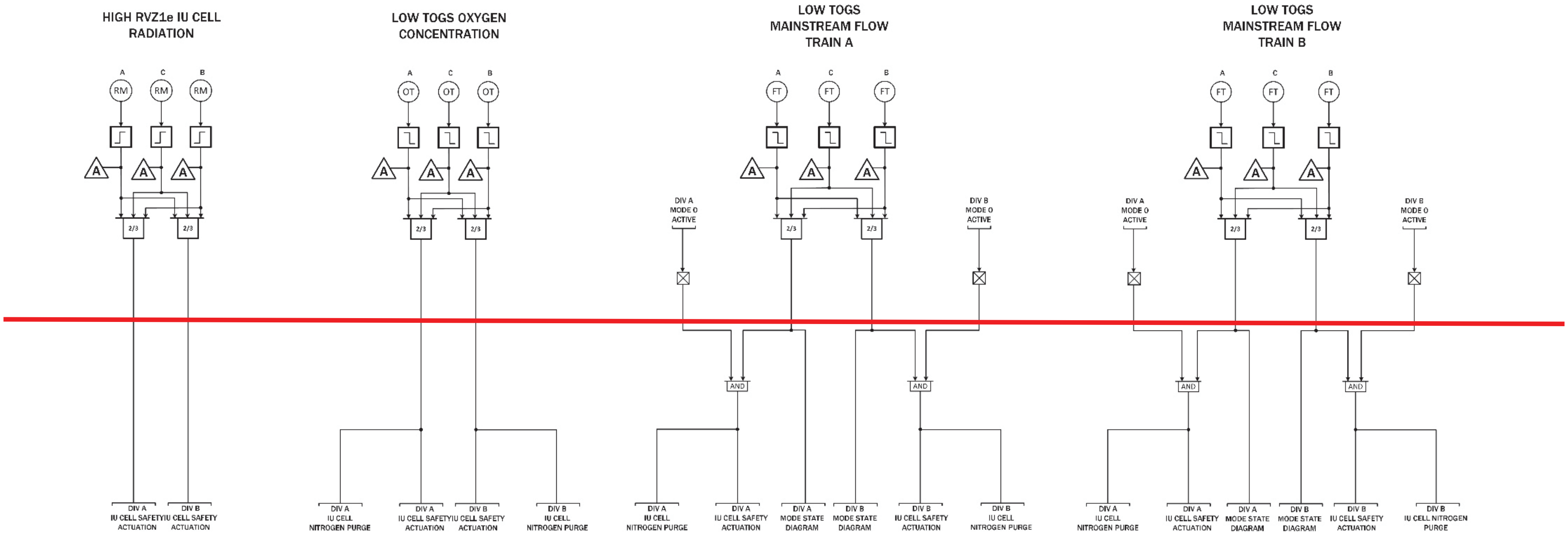
7.4.5.18 ESFAS IU Cell TPS Actuation

An ESFAS IU Cell TPS Actuation protects against release of tritium events in the TPS. The ESFAS IU Cell TPS Actuation is measured with a discrete input signal on two different channels, one for each Division A and Division B of TRPS. When an ESFAS IU Cell TPS Actuation is active, the division receiving the discrete signal initiates an IU Cell TPS Actuation.

Table 7.4-1 – TRPS Monitored Variables
(Sheet 1 of 2)

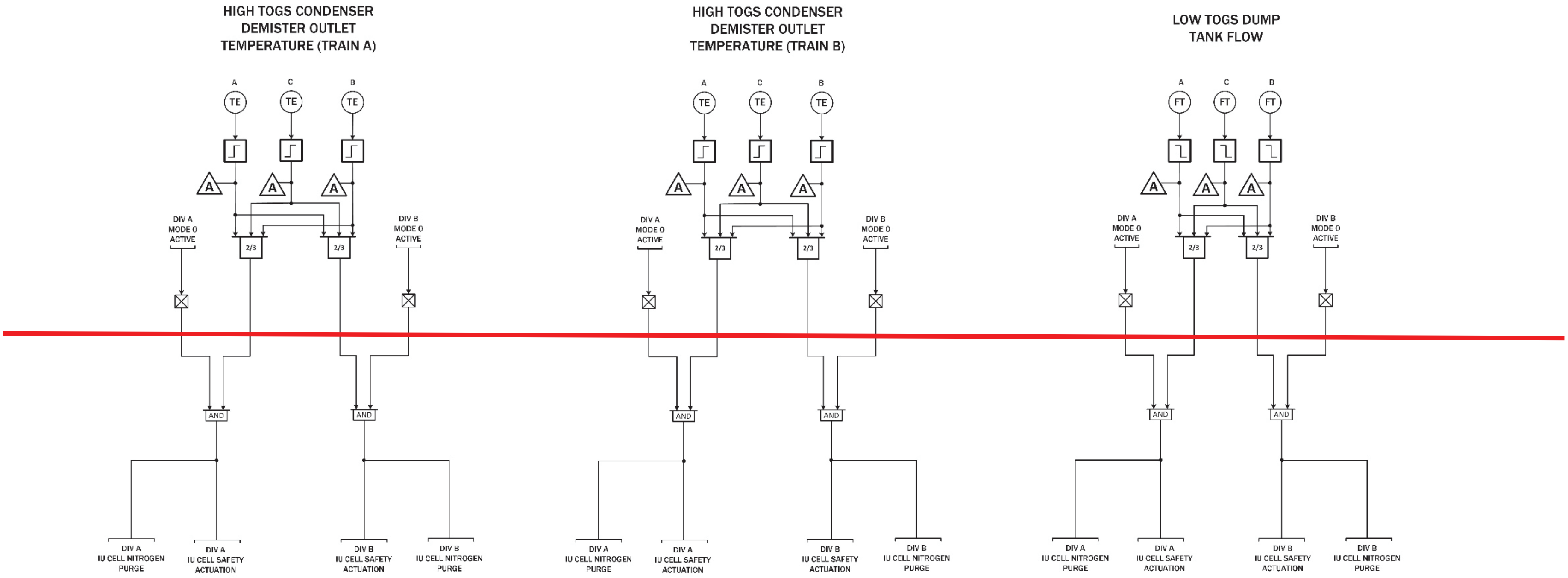
Variable	Analytical Limit	Logic	Range	Accuracy	Instrument Response Time
Source range neutron flux signal	1.5 times the nominal flux at 95 percent volume of the critical fill height	2/3↑	1 to 1.0E+05 cps	2 percent	450 milliseconds
Wide range neutron flux	240 percent	2/3↑	1.0E-8 to 250 percent	2 percent	450 milliseconds
Power range neutron flux	[ ]$^{PROP/ECI}$	2/3↓	0 to 125 percent	1 percent	1 second
	25 percent	2/3↑			
	104 percent	2/3↑			
RVZ1e IU cell radiation	5x background radiation	2/3↑	10^{-7} to 10^{-1} μCi/cc	20 percent	15 seconds
~~ATIS mixed gas return line tritium concentration~~	~~[ ]~~$^{PROP/ECI}$	~~2/3↑~~	~~1 to 200 kCi/m~~^{3}	~~1 percent~~	~~5 seconds~~
~~ATIS gas return line pressure~~	~~8 psia~~	~~2/3↑~~	~~0 to 19.5 psia~~	~~1 percent~~	~~10 seconds~~
TOGS oxygen concentration	10 percent	2/3↓	0 to 25 percent	1 percent	120 seconds
TOGS mainstream flow	[ ]$^{PROP/ECI}$	2/3↓	[ ]$^{PROP/ECI}$	3 percent	0.5 seconds
TOGS dump tank flow	[ ]$^{PROP/ECI}$	2/3↓	[ ]$^{PROP/ECI}$	3 percent	0.5 seconds
TOGS upstream condenser demister outlet temperature	25°C	2/3↑	0 to 100°C	0.65 percent	10 seconds
Low-high TSV dump tank level signal	Active	2/3↑	Active/inactive	Discrete input signal	1.5 seconds
High-high TSV dump tank level signal	Active	2/3↑	Active/inactive	Discrete input signal	1.5 seconds

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 1 of 13)



Trip Determination and Bypasses

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 2 of 13)

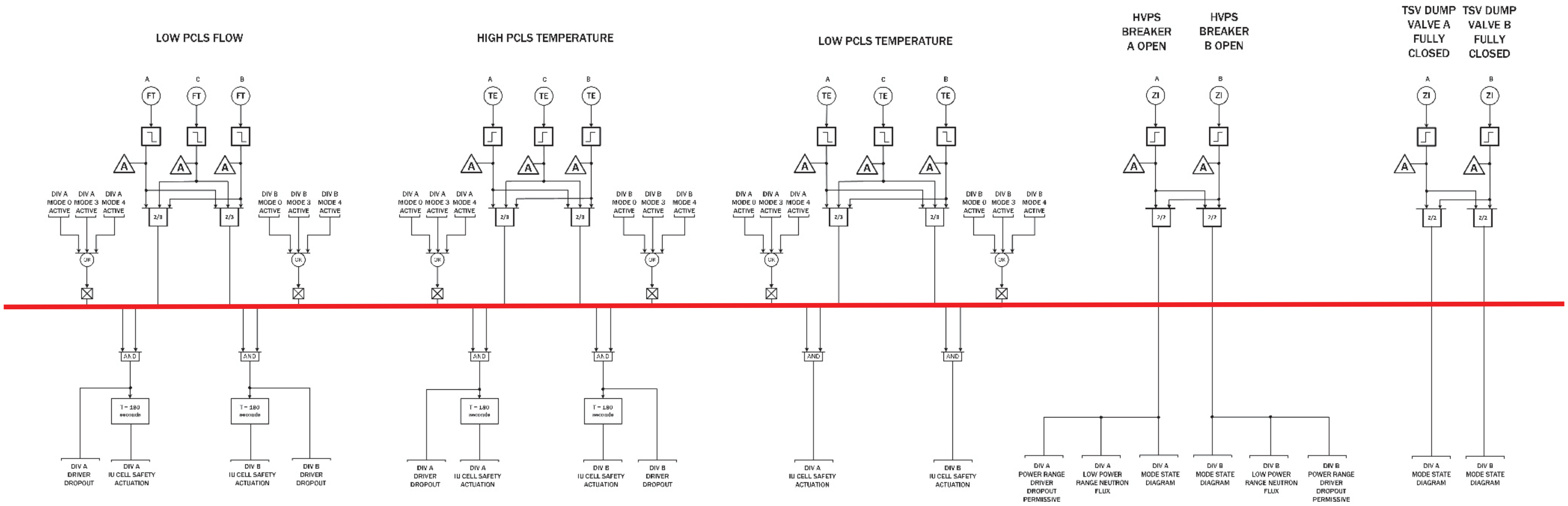


Trip Determination and Bypasses

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 3 of 13)

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 4 of 13)

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 5 of 13)

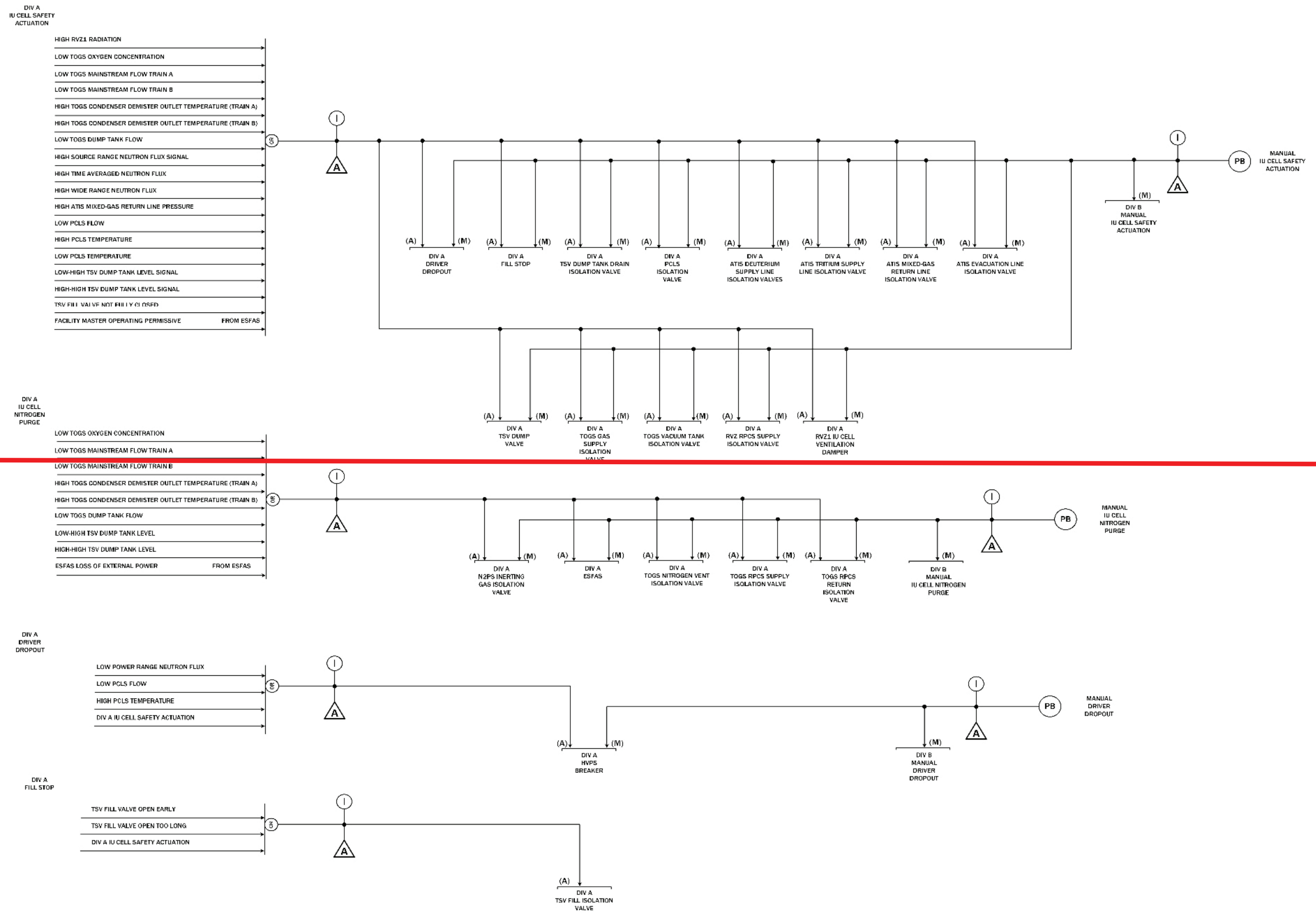


Trip Determination and Bypasses

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 6 of 13)

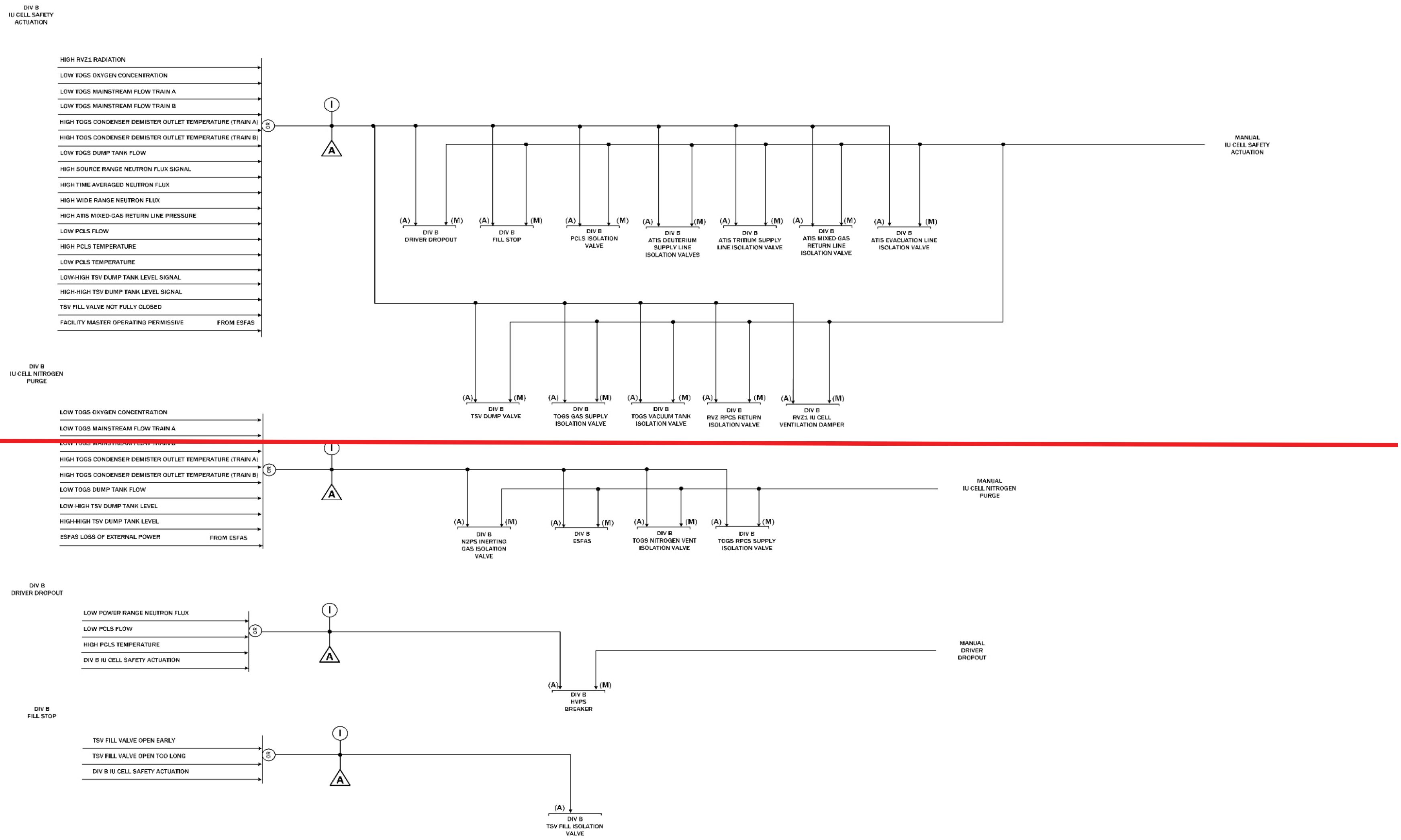
Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 7 of 13)

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 8 of 13)



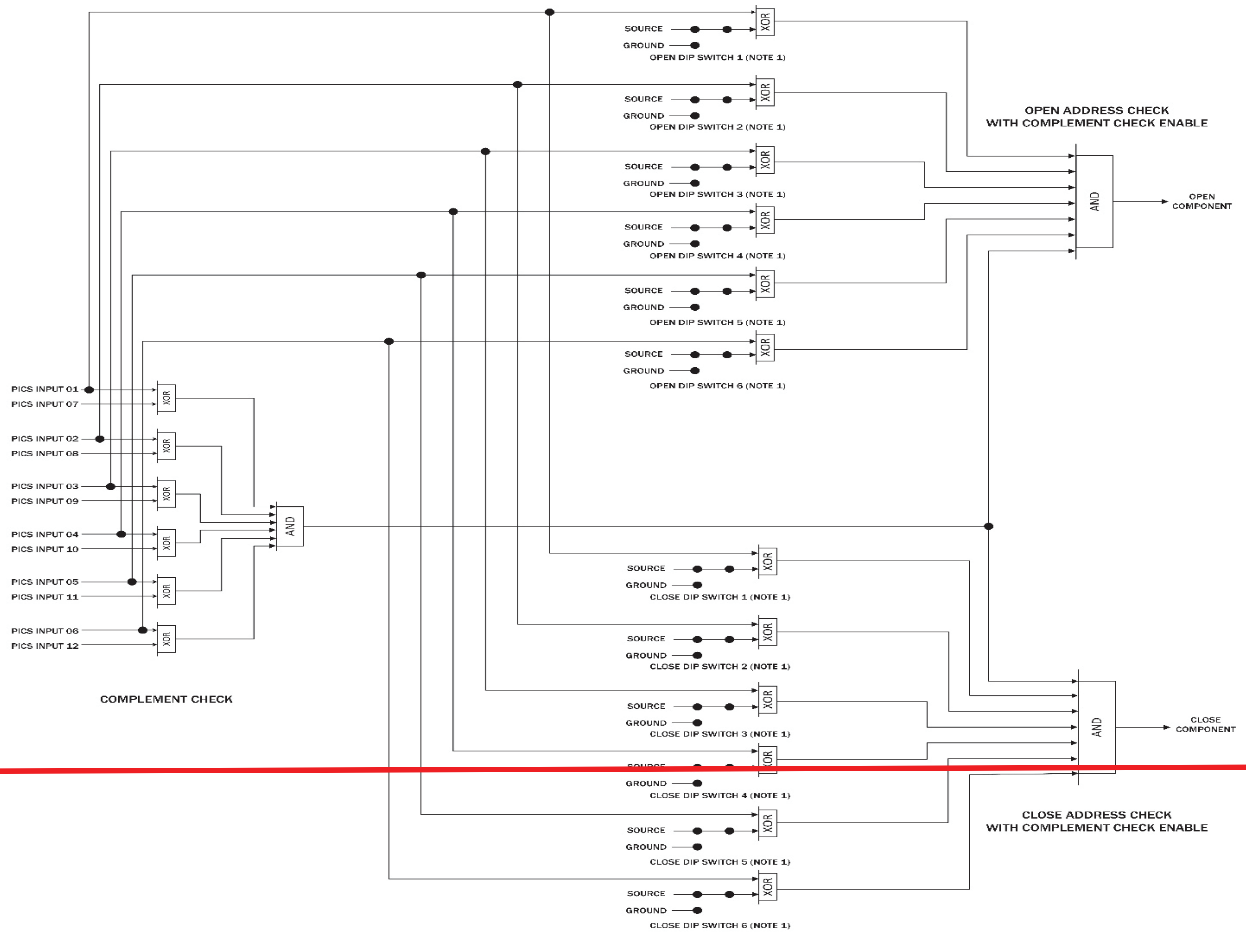
Safety Function

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 9 of 13)



Safety Function

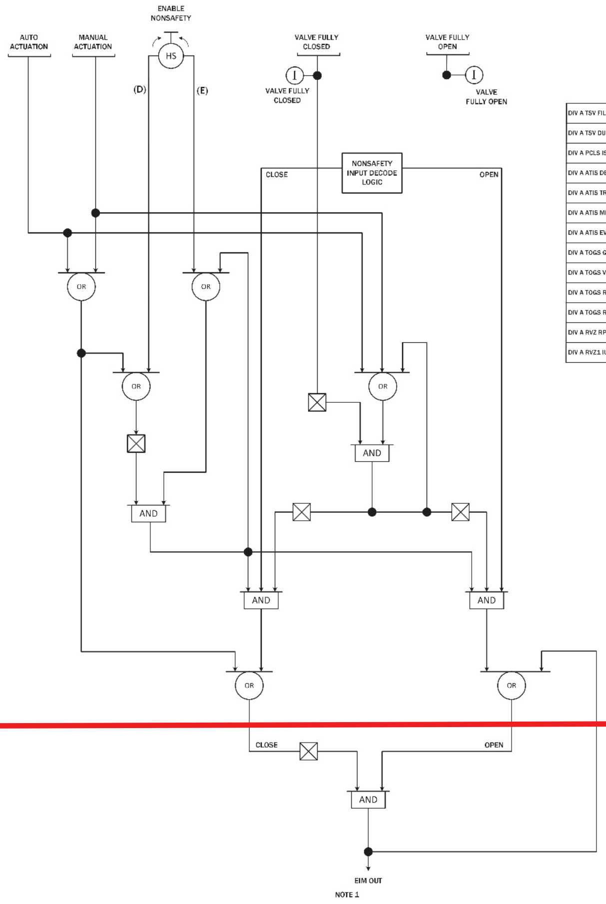
Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 10 of 13)



NOTE 1: CONNECTIONS TO BE CONFIGURED WITH SWITCHES FOR EACH SPECIFIC EIM APPLICATION

Nonsafety Interface Decode

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 11 of 13)

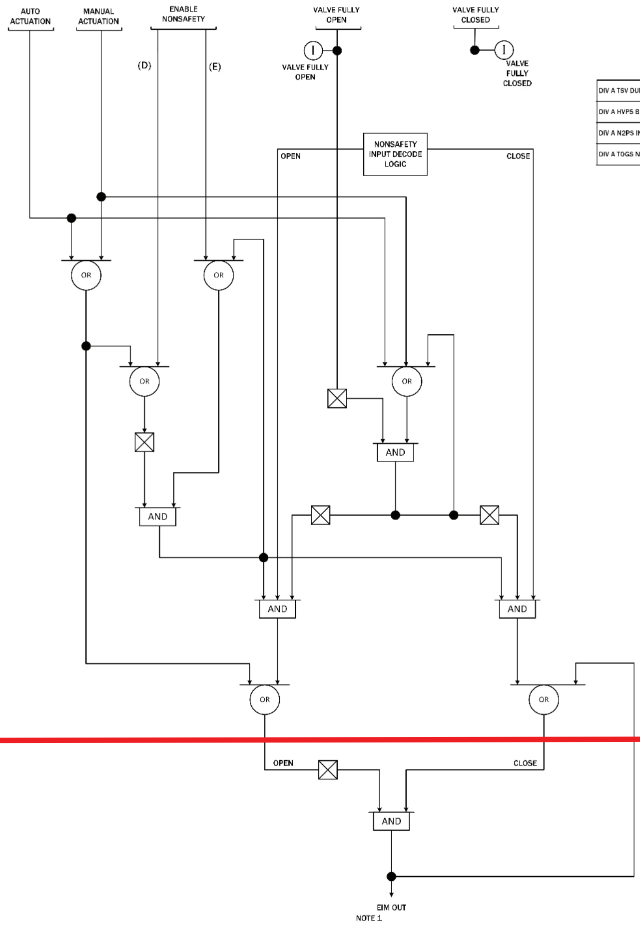


DIV A TSV FILL ISOLATION VALVE	DIV B TSV FILL ISOLATION VALVE
DIV A TSV DUMP TANK DRAIN ISOLATION VALVE	DIV B PCLS ISOLATION VALVE
DIV A PCLS ISOLATION VALVE	DIV B ATIS DEUTERIUM SUPPLY LINE ISOLATION VALVE
DIV A ATIS DEUTERIUM SUPPLY LINE ISOLATION VALVE	DIV B ATIS TRITIUM SUPPLY LINE ISOLATION VALVE
DIV A ATIS TRITIUM SUPPLY LINE ISOLATION VALVE	DIV B ATIS MIXED-GAS RETURN LINE ISOLATION VALVE
DIV A ATIS MIXED-GAS RETURN LINE ISOLATION VALVE	DIV B ATIS EVACUATION LINE ISOLATION VALVE
DIV A ATIS EVACUATION LINE ISOLATION VALVE	DIV B TOGS GAS SUPPLY LINE ISOLATION VALVE
DIV A TOGS GAS SUPPLY LINE ISOLATION VALVE	DIV B TOGS VACUUM TANK ISOLATION VALVE
DIV A TOGS VACUUM TANK ISOLATION VALVE	DIV B TOGS RPCS SUPPLY ISOLATION VALVE
DIV A TOGS RPCS SUPPLY ISOLATION VALVE	DIV B RVZ RPCS RETURN ISOLATION VALVE
DIV A TOGS RPCS RETURN ISOLATION VALVE	DIV B RVZ1 IU CELL VENTILATION DAMPER
DIV A RVZ RPCS SUPPLY ISOLATION VALVE	
DIV A RVZ1 IU CELL VENTILATION DAMPER	

NOTE 1: OUTPUT OF EIM IS DEENERGIZED TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER
NOTE 2: THIS ACTUATION AND PRIORITY LOGIC IS USED FOR ALL COMPONENTS THAT ARE DEENERGIZE TO CLOSE

Priority Logic

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 12 of 13)

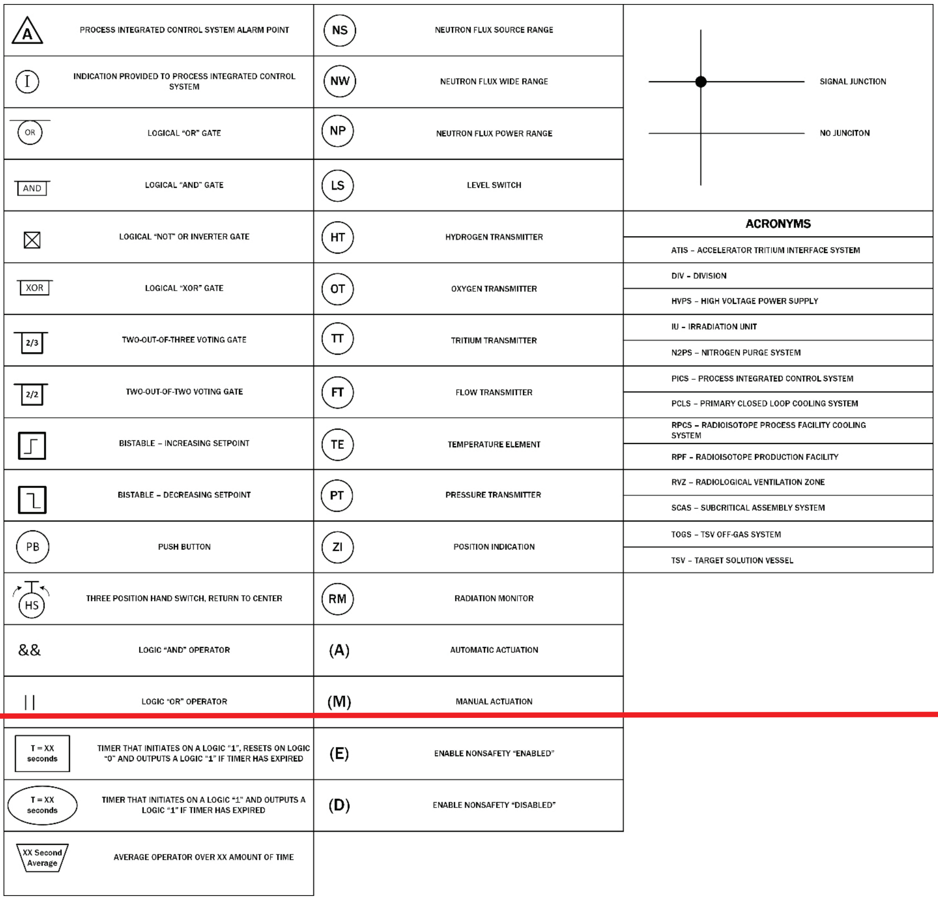


DIV A TSV DUMP VALVE	DIV B TSV DUMP VALVE
DIV A HVPS BREAKER	DIV B HVPS BREAKER
DIV A N2PS INERTING GAS ISOLATION VALVE	DIV B N2PS INERTING GAS ISOLATION VALVE
DIV A TOGS NITROGEN VENT ISOLATION VALVE	DIV B TOGS NITROGEN VENT ISOLATION VALVE

NOTE 1: OUTPUT OF EIM IS DEENERGIZED TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER
NOTE 2: THIS ACTUATION AND PRIORITY LOGIC IS USED FOR ALL COMPONENTS THAT ARE DEENERGIZE TO OPEN

Priority Logic

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 13 of 13)

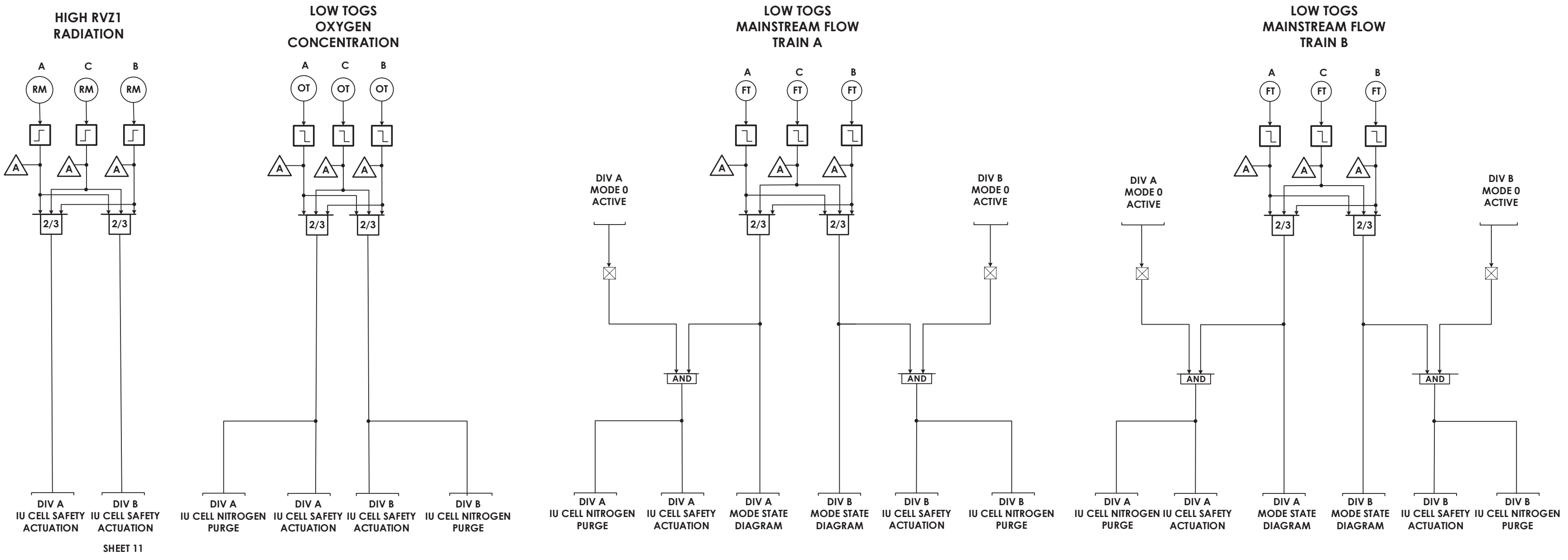


A	PROCESS INTEGRATED CONTROL SYSTEM ALARM POINT	NS	NEUTRON FLUX SOURCE RANGE
I	INDICATION PROVIDED TO PROCESS INTEGRATED CONTROL SYSTEM	NW	NEUTRON FLUX WIDE RANGE
OR	LOGICAL "OR" GATE	NP	NEUTRON FLUX POWER RANGE
AND	LOGICAL "AND" GATE	LS	LEVEL SWITCH
☒	LOGICAL "NOT" OR INVERTER GATE	HT	HYDROGEN TRANSMITTER
XOR	LOGICAL "XOR" GATE	OT	OXYGEN TRANSMITTER
2/3	TWO-OUT-OF-THREE VOTING GATE	TT	TRITIUM TRANSMITTER
2/2	TWO-OUT-OF-TWO VOTING GATE	FT	FLOW TRANSMITTER
	BISTABLE – INCREASING SETPOINT	TE	TEMPERATURE ELEMENT
	BISTABLE – DECREASING SETPOINT	PT	PRESSURE TRANSMITTER
PB	PUSH BUTTON	ZI	POSITION INDICATION
HS	THREE POSITION HAND SWITCH, RETURN TO CENTER	RM	RADIATION MONITOR
&&	LOGIC "AND" OPERATOR	(A)	AUTOMATIC ACTUATION
||	LOGIC "OR" OPERATOR	(M)	MANUAL ACTUATION
T = XX seconds	TIMER THAT INITIATES ON A LOGIC "1", RESETS ON LOGIC "0" AND OUTPUTS A LOGIC "1" IF TIMER HAS EXPIRED	(E)	ENABLE NONSAFETY "ENABLED"
T = XX seconds	TIMER THAT INITIATES ON A LOGIC "1" AND OUTPUTS A LOGIC "1" IF TIMER HAS EXPIRED	(D)	ENABLE NONSAFETY "DISABLED"
XX Second Average	AVERAGE OPERATOR OVER XX AMOUNT OF TIME		

ACRONYMS
ATIS – ACCELERATOR TRITIUM INTERFACE SYSTEM
DIV – DIVISION
HVPS – HIGH VOLTAGE POWER SUPPLY
IU – IRRADIATION UNIT
N2PS – NITROGEN PURGE SYSTEM
PICS – PROCESS INTEGRATED CONTROL SYSTEM
PCLS – PRIMARY CLOSED LOOP COOLING SYSTEM
RPCS – RADIOISOTOPE PROCESS FACILITY COOLING SYSTEM
RPF – RADIOISOTOPE PRODUCTION FACILITY
RVZ – RADIOLOGICAL VENTILATION ZONE
SCAS – SUBCRITICAL ASSEMBLY SYSTEM
TOGS – TSV OFF-GAS SYSTEM
TSV – TARGET SOLUTION VESSEL

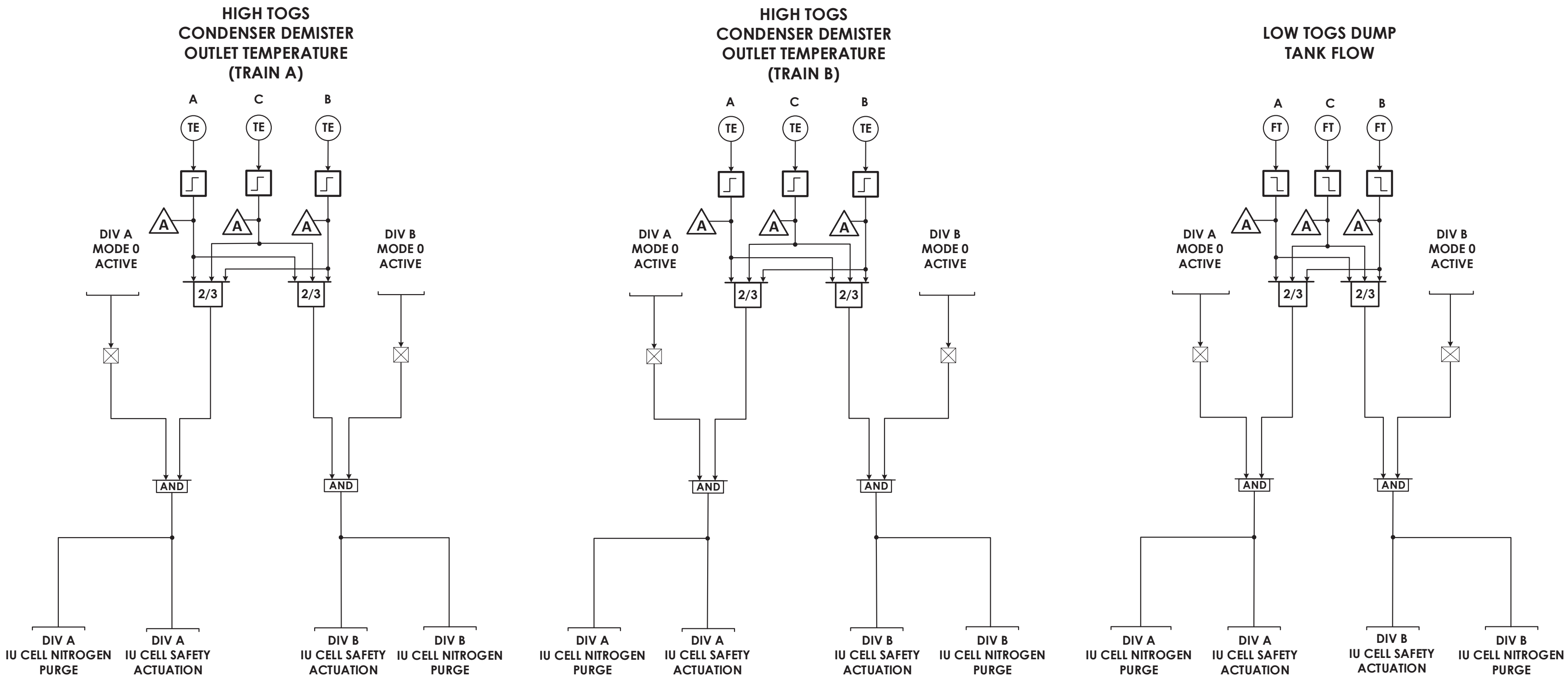
Legend

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 1 of 14)



Trip Determination and Bypasses

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 2 of 14)



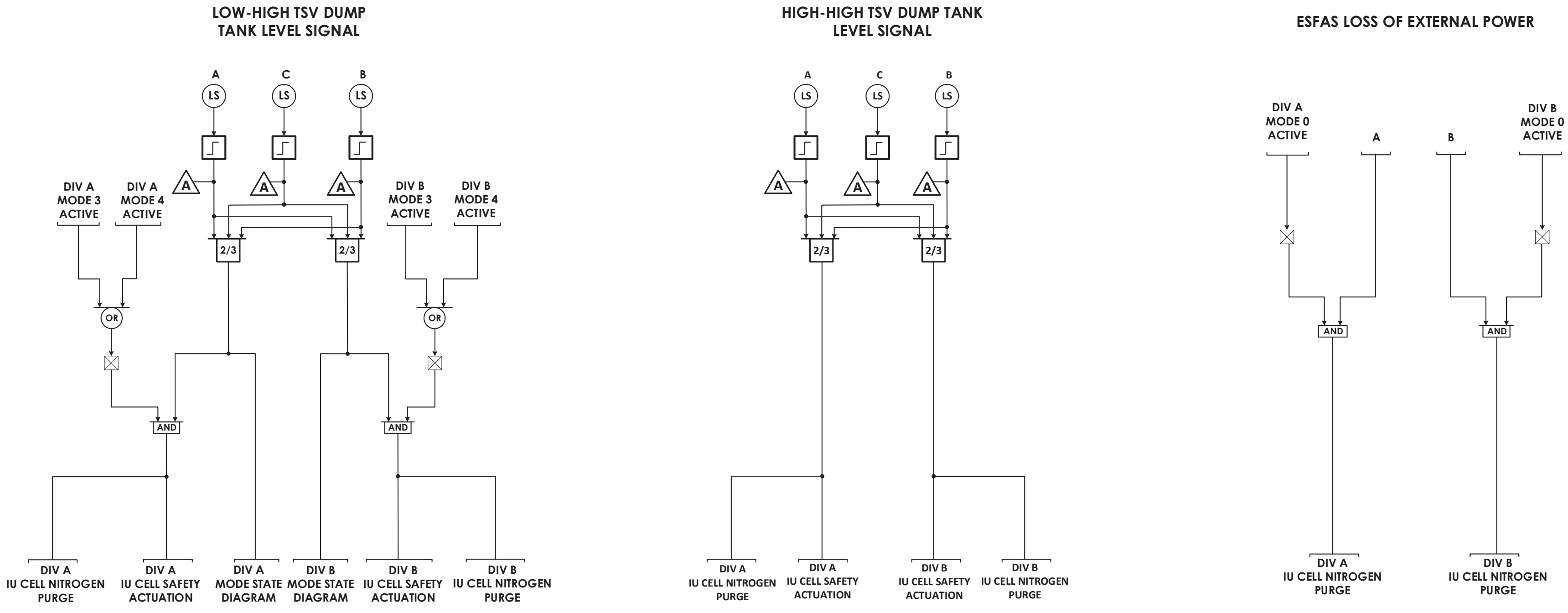
Trip Determination and Bypasses

**Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 3 of 14)**

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 4 of 14)

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 5 of 14)

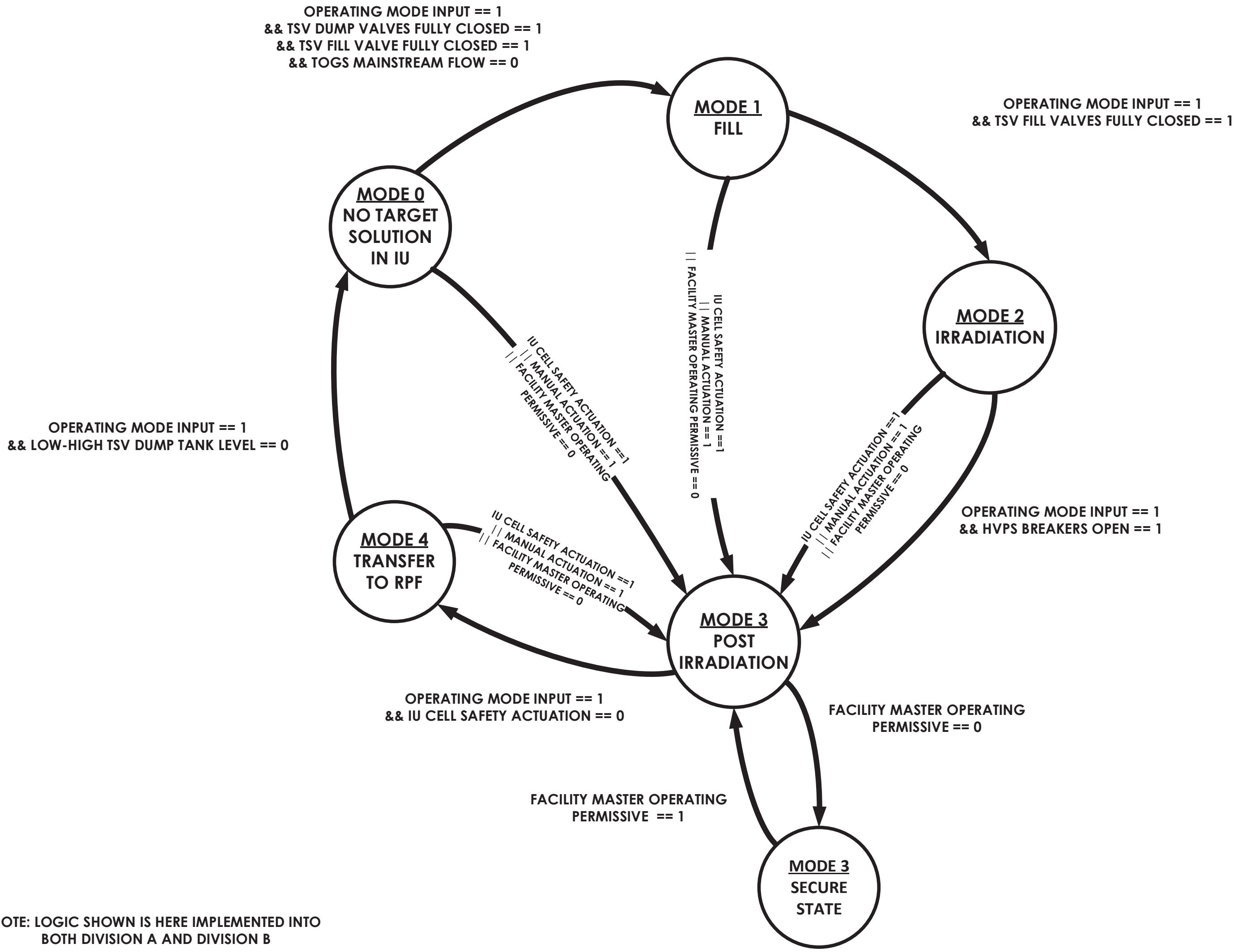
Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 6 of 14)



Trip Determination and Bypasses

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 7 of 14)

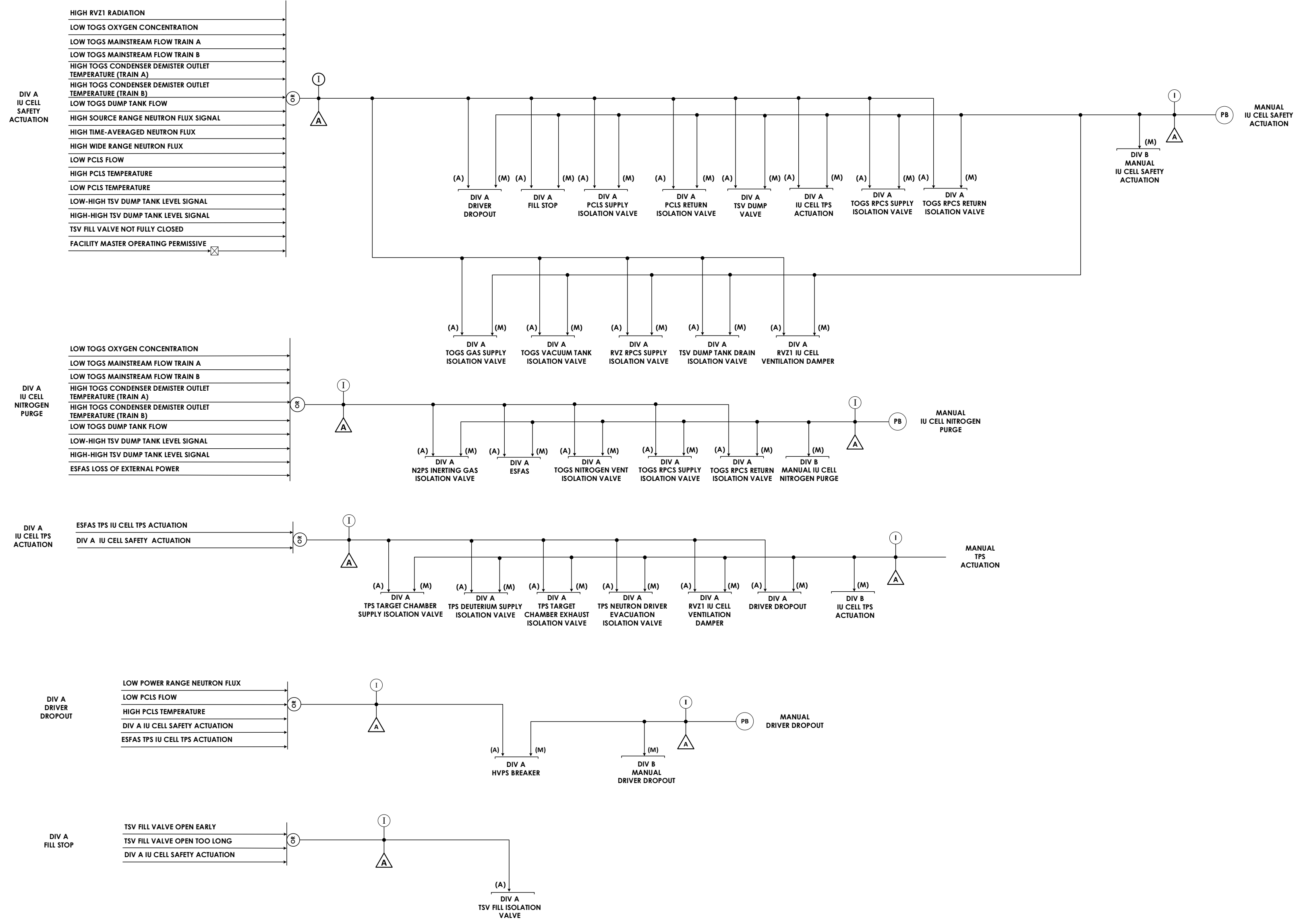
Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 8 of 14)



NOTE: LOGIC SHOWN IS HERE IMPLEMENTED INTO
BOTH DIVISION A AND DIVISION B

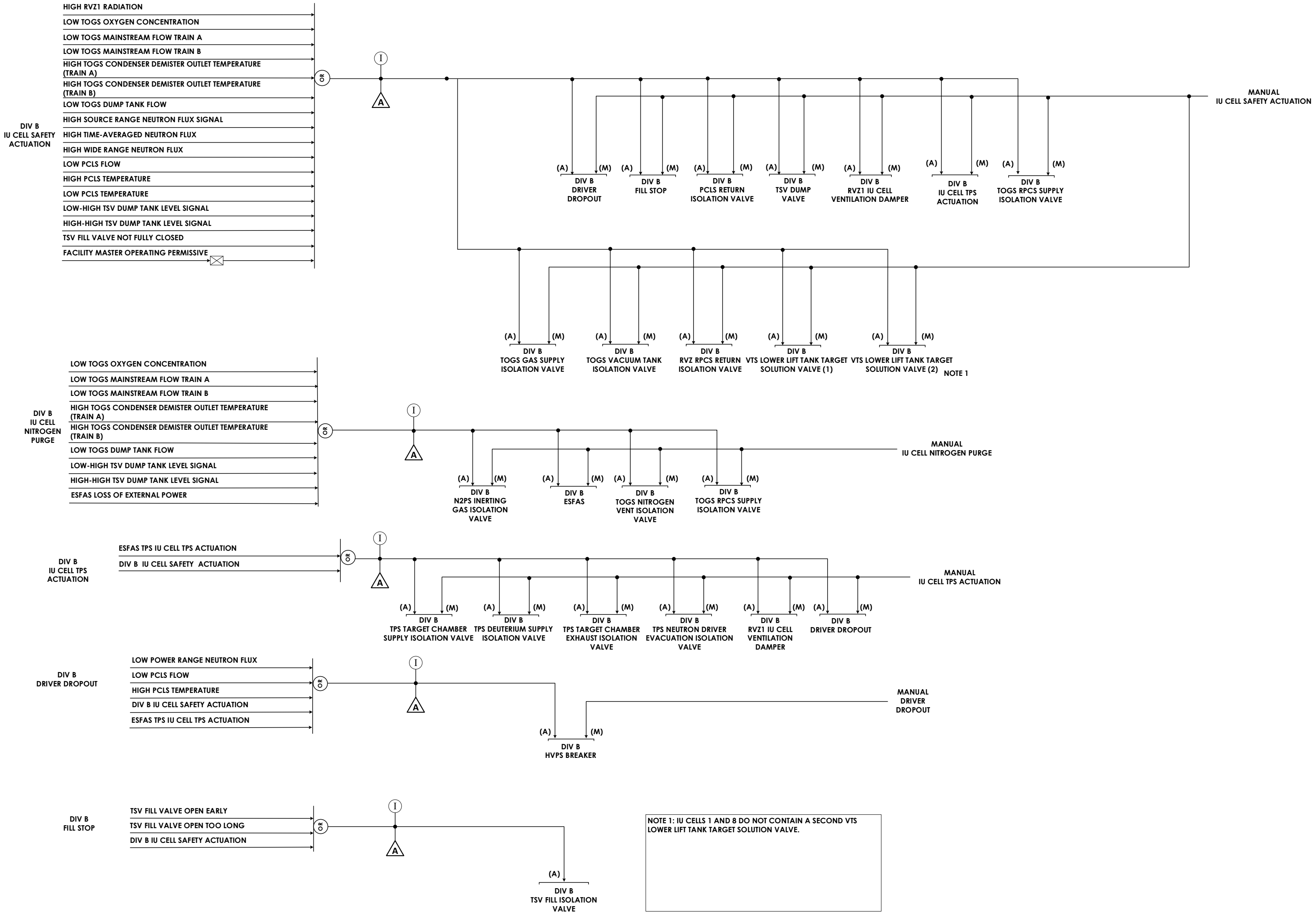
Mode State Machine

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 9 of 14)



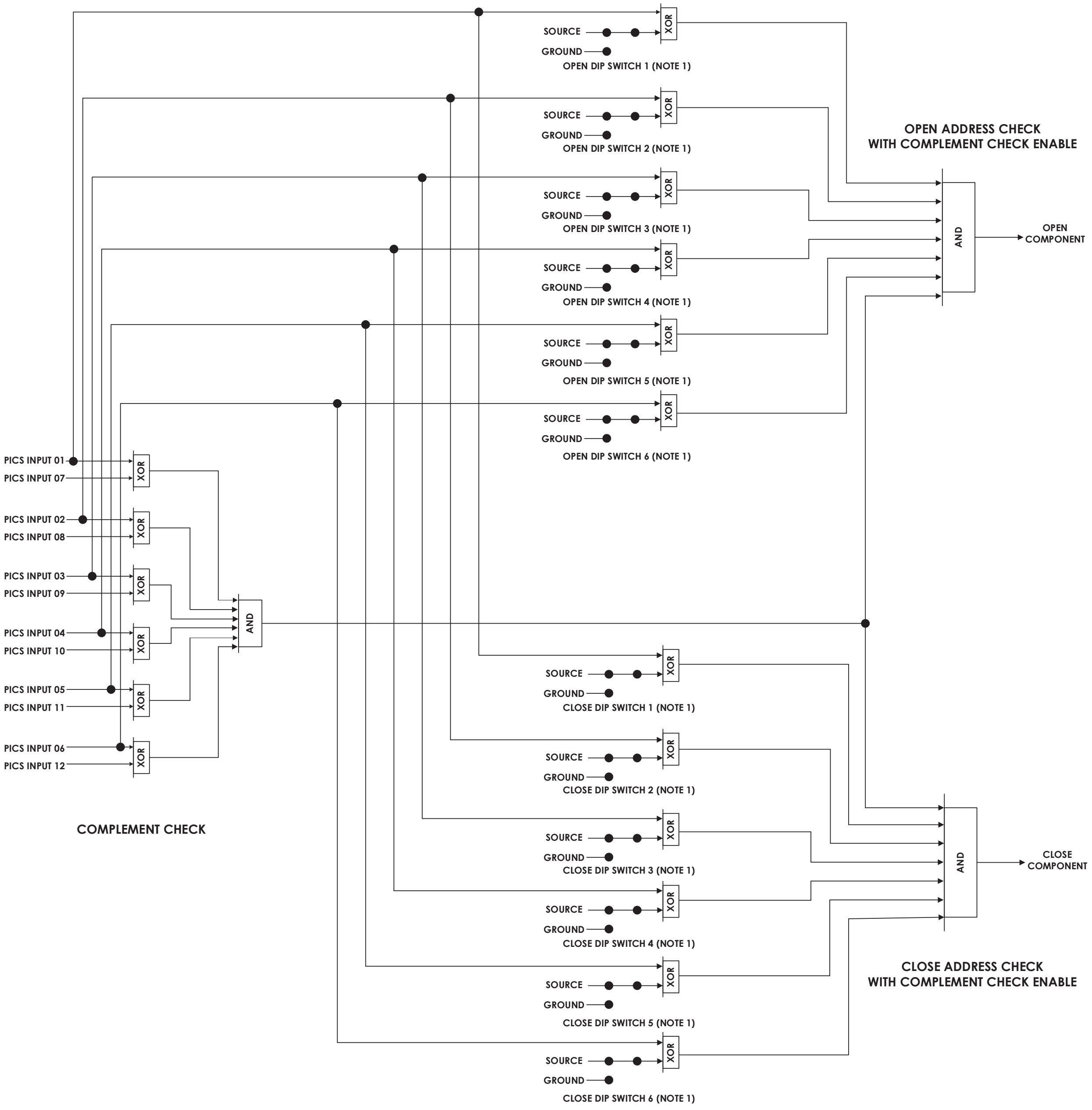
Safety Function

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 10 of 14)



Safety Function

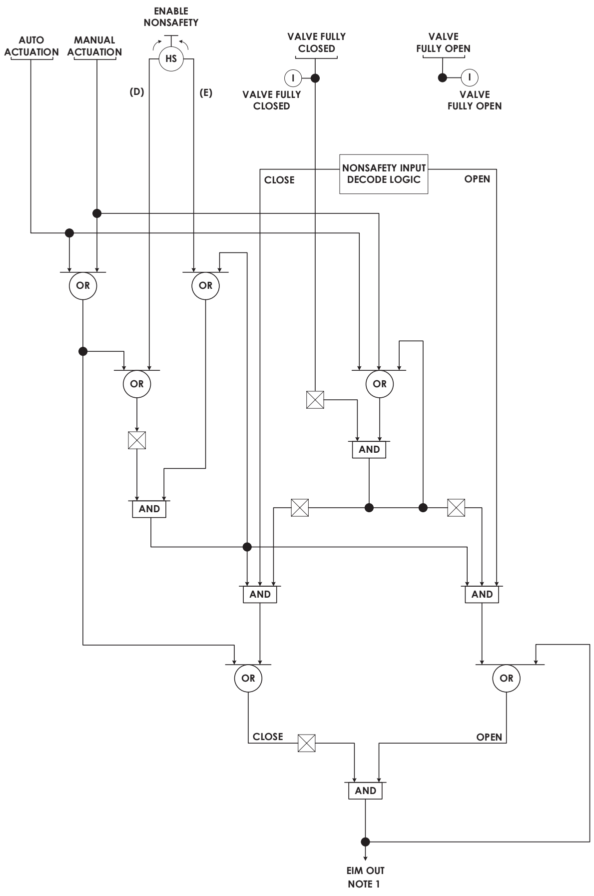
Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 11 of 14)



NOTE 1: CONNECTIONS TO BE CONFIGURED WITH SWITCHES FOR EACH SPECIFIC EIM APPLICATION

Nonsafety Interface Decode

Figure 7.4-1 – TRPS Logic Diagrams (Sheet 12 of 14)

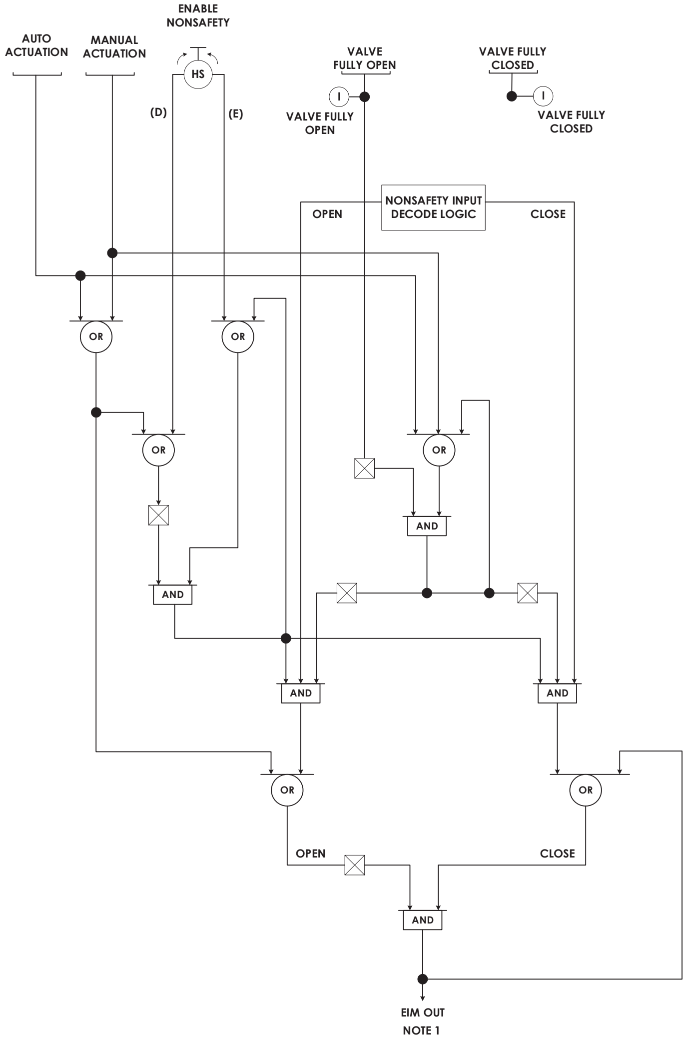


DIV A TSV FILL ISOLATION VALVE	DIV B TSV FILL ISOLATION VALVE
DIV A TSV DUMP TANK DRAIN ISOLATION VALVE	DIV B PCLS RETURN ISOLATION VALVE
DIV A PCLS SUPPLY ISOLATION VALVE	DIV B TPS TARGET CHAMBER SUPPLY ISOLATION VALVE
DIV A PCLS RETURN ISOLATION VALVE	DIV B TPS DEUTERIUM SUPPLY ISOLATION VALVE
DIV A TPS TARGET CHAMBER SUPPLY ISOLATION VALVE	DIV B TPS TARGET CHAMBER EXHAUST ISOLATION VALVE
DIV A TPS DEUTERIUM SUPPLY ISOLATION VALVE	DIV B TPS NEUTRON DRIVER EVACUATION ISOLATION VALVE
DIV A TPS TARGET CHAMBER EXHAUST ISOLATION VALVE	DIV B TOGS GAS SUPPLY LINE ISOLATION VALVE
DIV A TPS NEUTRON DRIVER EVACUATION ISOLATION VALVE	DIV B TOGS VACUUM TANK ISOLATION VALVE
DIV A TOGS GAS SUPPLY LINE ISOLATION VALVE	DIV B TOGS RPCS SUPPLY ISOLATION VALVE
DIV A TOGS VACUUM TANK ISOLATION VALVE	DIV B RVZ RPCS RETURN ISOLATION VALVE
DIV A TOGS RPCS SUPPLY ISOLATION VALVE	DIV B RVZ1 IU CELL VENTILATION DAMPER
DIV A TOGS RPCS RETURN ISOLATION VALVE	DIV B VTS LOWER LIFT TANK TARGET SOLUTION VALVE (1)
DIV A RVZ RPCS SUPPLY ISOLATION VALVE	DIV B VTS LOWER LIFT TANK TARGET SOLUTION VALVE (2)
DIV A RVZ1 IU CELL VENTILATION DAMPER	

NOTE 1: OUTPUT OF EIM IS DEENERGIZE TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER

Priority Logic

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 13 of 14)



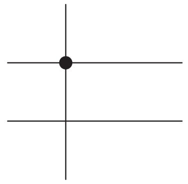
DIV A TSV DUMP VALVE	DIV B TSV DUMP VALVE
DIV A HVPS BREAKER	DIV B HVPS BREAKER
DIV A N2PS INERTING GAS ISOLATION VALVE	DIV B N2PS INERTING GAS ISOLATION VALVE
DIV A TOGS NITROGEN VENT ISOLATION VALVE	DIV B TOGS NITROGEN VENT ISOLATION VALVE

NOTE 1: OUTPUT OF EIM IS DEENERGIZE TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER

Priority Logic

Figure 7.4-1 – TRPS Logic Diagrams
(Sheet 14 of 14)

△ A	PROCESS INTEGRATED CONTROL SYSTEM ALARM POINT	NS	NEUTRON FLUX SOURCE RANGE
I	INDICATION PROVIDED TO PROCESS INTEGRATED CONTROL SYSTEM	NW	NEUTRON FLUX WIDE RANGE
OR	LOGICAL "OR" GATE	NP	NEUTRON FLUX POWER RANGE
AND	LOGICAL "AND" GATE	LS	LEVEL SWITCH
☒	LOGICAL "NOT" OR INVERTER GATE	HT	HYDROGEN TRANSMITTER
XOR	LOGICAL "XOR" GATE	OT	OXYGEN TRANSMITTER
2/3	TWO-OUT-OF-THREE VOTING GATE	TT	TRITIUM TRANSMITTER
2/2	TWO-OUT-OF-TWO VOTING GATE	FT	FLOW TRANSMITTER
_|‾	BISTABLE – INCREASING SETPOINT	TE	TEMPERATURE ELEMENT
‾|_	BISTABLE – DECREASING SETPOINT	PT	PRESSURE TRANSMITTER
PB	PUSH BUTTON	ZI	POSITION INDICATION
HS	THREE POSITION HAND SWITCH, RETURN TO CENTER	RM	RADIATION MONITOR
&&	LOGIC "AND" OPERATOR	DI	DISCRETE INPUT
| |	LOGIC "OR" OPERATOR	(A)	AUTOMATIC ACTUATION
T = XX seconds	TIMER THAT INITIATES ON A LOGIC "1", RESETS ON LOGIC "0" AND OUTPUTS A LOGIC "1" IF TIMER HAS EXPIRED	(M)	MANUAL ACTUATION
T = XX seconds	TIMER THAT INITIATES ON A LOGIC "1" AND OUTPUTS A LOGIC "1" IF TIMER HAS EXPIRED	(E)	ENABLE NONSAFETY "ENABLED"
XX Second Average	AVERAGE OPERATOR OVER XX AMOUNT OF TIME	(D)	ENABLE NONSAFETY "DISABLED"



SIGNAL JUNCTION

NO JUNCTION

ACRONYMS
DIV – DIVISION
HVPS – HIGH VOLTAGE POWER SUPPLY
IU – IRRADIATION UNIT
N2PS – NITROGEN PURGE SYSTEM
PICS – PROCESS INTEGRATED CONTROL SYSTEM
PCLS – PRIMARY CLOSED LOOP COOLING SYSTEM
RPCS – RADIOISOTOPE PROCESS FACILITY COOLING SYSTEM
RPF – RADIOISOTOPE PRODUCTION FACILITY
RVZ – RADIOLOGICAL VENTILATION ZONE
SCAS – SUBCRITICAL ASSEMBLY SYSTEM
TOGS – TSV OFF-GAS SYSTEM
TPS – TRITIUM PURIFICATION SYSTEM
TSV – TARGET SOLUTION VESSEL

Legend

Figure 7.4-2 – TRPS Mode State Diagram

Figure 7.4-2 – TRPS Mode State Diagram

7.5 ENGINEERED SAFETY FEATURES ACTUATION SYSTEM

7.5.1 SYSTEM DESCRIPTION

The engineered safety features actuation system (ESFAS) is a three-division safety-related instrumentation and control (I&C) system that performs various control and actuation functions credited by the SHINE safety analysis as required to prevent the occurrence or mitigate the consequences of design basis events within the SHINE facility. The ESFAS provides sense, command, and execute functions necessary to maintain the facility confinement strategy and provides process actuation functions required to shutdown processes and maintain processes in a safe condition. The ESFAS also provides nonsafety-related system status and measured process variable values to the facility process integrated control system (PICS) for viewing, recording, and trending.

The ESFAS monitors variables important to the safety functions for confinement of radiation and tritium within the irradiation facility (IF) and the radioisotope production facility (RPF) and for criticality safety to perform the following functions:

- Radiologically Controlled Area (RCA) Isolation
- Supercell Isolation
- Carbon Delay Bed Isolation
- Vacuum Transfer System (VTS) Safety Actuation
- Tritium Purification System (TPS) Train Isolation
- TPS Process Vent Actuation
- Irradiation Unit (IU) Cell Nitrogen Purge
- RPF Nitrogen Purge
- Molybdenum Extraction and Purification System (MEPS) [ ]$^{\text{PROP/ECI}}$ Isolation
- Extraction Column Alignment Actuation
- Iodine and Xenon Purification and Packaging (IXP) Alignment Actuation
- Dissolution Tank Isolation

The ESFAS monitors the IF and the RPF continually throughout the operation of processes within the main production facility, via the use of radiation monitoring and other instrumentation. Interlocks and bypass logic necessary for operation are implemented within the ESFAS. If at any point a monitored variable exceeds its predetermined limits, the ESFAS automatically initiates the associated safety function. ESFAS logic diagrams are provided in Figure 7.5-1 and the general architecture of the ESFAS is provided in Figure 7.1-3.

7.5.2 DESIGN CRITERIA

The SHINE design criteria are described in Section 3.1. Table 3.1-1 shows the SHINE design criteria applicable to the ESFAS.

7.5.2.1 Access Control

ESFAS Criterion 1 – The ESFAS shall require a key or combination authentication input at the control console to prevent unauthorized use of the ESFAS.

- MEPS C extraction column wash supply valve
- MEPS C extraction column eluent valve
- MEPS C [ ]$^{PROP/ECI}$ wash supply valve
- MEPS C [ ]$^{PROP/ECI}$ eluent valve
- IXP recovery column wash supply valve
- IXP recovery column eluent valve
- IXP [ ]$^{PROP/ECI}$ wash supply valve
- IXP [ ]$^{PROP/ECI}$ eluent valve
- IXP FNHS supply valve
- IXP liquid nitrogen supply valve

The ESFAS initiates a VTS Safety Actuation based on the following variables or safety actuations:

- VTS vacuum header liquid detection switch signal
- RDS liquid detection switch signal
- Supercell Area 1 Isolation
- Supercell Area 2 Isolation
- Supercell Area 6 Isolation
- Supercell Area 7 Isolation
- RCA Isolation
- Facility master operating permissive

A representation of the VTS Safety Actuation is provided in Figure 7.5-3.

7.5.3.1.18 TPS Train A Isolation

TPS Train A Isolation initiates the following safety functions:

- ~~Deenergize accelerator tritium interface system (ATIS) header glovebox stripper system (GBSS) isolation~~TPS train A glovebox pressure control exhaust isolation valve~~s~~
- ~~Deenergize ATIS header GBSS bypass~~Vacuum/impurity treatment subsystem (VAC/ITS) train A process vent ITS isolation valves (TPS train A ITS isolation valves)
- ~~Deenergize GBSS RVZ isolation~~TPS train A helium air operated valve (AOV) supply valve~~s~~
- ~~Deenergize ATIS header return line isolation valves~~TPS train A helium solenoid operated valve (SOV) supply valve
- ~~Deenergize TPS process evacuation header isolation valves~~RVZ2 TPS ventilation supply dampers
- ~~Deenergize ATIS header deuterium supply isolation valves~~RVZ2 TPS ventilation exhaust dampers
- ~~Deenergize storage and separation system GBSS raffinate~~VAC/ITS train A process vent vacuum isolation valves (TPS train A vacuum isolation valves)
- ~~Deenergize ATIS header tritium supply isolation valves~~IU Cell 1 TPS Actuation
- ~~Deenergize ATIS glovebox exhaust header isolation valves~~IU Cell 2 TPS Actuation
- ~~Deenergize TPS process evacuation GBSS isolation valves~~
- ~~Deenergize TPS glovebox nitrogen supply valves~~
- ~~Deenergize RVZ TPS ventilation dampers~~

The ESFAS initiates a TPS Train A Isolation based on the following variables or safety actuation:

- High TPS IU cell 1 target chamber supply pressure
- High TPS IU cell 2 target chamber supply pressure
- High TPS IU cell 1 target chamber exhaust pressure
- High TPS IU cell 2 target chamber exhaust pressure
- High TPS ~~exhaust to facility stack~~confinement A tritium ~~concentration~~
- ~~High TPS glovebox tritium concentration~~
- RCA Isolation
- Facility master operating permissive

7.5.3.1.19 TPS Train B Isolation

TPS Train B Isolation initiates the following safety functions:

- TPS train B glovebox pressure control exhaust isolation valve
- VAC/ITS train B process vent ITS isolation valves (TPS train B ITS isolation valves)
- TPS train B helium AOV supply valve
- TPS train B helium SOV supply valve
- RVZ2 TPS ventilation supply dampers
- RVZ2 TPS ventilation exhaust dampers
- VAC/ITS train B process vent vacuum isolation valves (TPS train B vacuum isolation valves)
- IU Cell 3 TPS Actuation
- IU Cell 4 TPS Actuation
- IU Cell 5 TPS Actuation

The ESFAS initiates a TPS Train B Isolation based on the following variables or safety actuation:

- High TPS IU cell 3 target chamber supply pressure
- High TPS IU cell 4 target chamber supply pressure
- High TPS IU cell 5 target chamber supply pressure
- High TPS IU cell 3 target chamber exhaust pressure
- High TPS IU cell 4 target chamber exhaust pressure
- High TPS IU cell 5 target chamber exhaust pressure
- High TPS confinement B tritium
- RCA Isolation
- Facility master operating permissive

7.5.3.1.20 TPS Train C Isolation

TPS Train C Isolation initiates the following safety functions:

- TPS train C glovebox pressure control exhaust isolation valve
- VAC/ITS train C process vent ITS isolation valves (TPS train C ITS isolation valves)
- TPS train C helium AOV supply valve
- TPS train C helium SOV supply valve
- RVZ2 TPS ventilation supply dampers
- RVZ2 TPS ventilation exhaust dampers
- VAC/ITS train C process vent vacuum isolation valves (TPS train C vacuum isolation valves)
- IU Cell 6 TPS Actuation

- IU Cell 7 TPS Actuation
- IU Cell 8 TPS Actuation

The ESFAS initiates a TPS Train C Isolation based on the following variables or safety actuation:

- High TPS IU cell 6 target chamber supply pressure
- High TPS IU cell 7 target chamber supply pressure
- High TPS IU cell 8 target chamber supply pressure
- High TPS IU cell 6 target chamber exhaust pressure
- High TPS IU cell 7 target chamber exhaust pressure
- High TPS IU cell 8 target chamber exhaust pressure
- High TPS confinement C tritium
- RCA Isolation
- Facility master operating permissive

7.5.3.1.21 TPS Process Vent Actuation

TPS Process Vent Actuation initiates the following safety functions:

- TPS train A vacuum isolation valves
- TPS train A ITS isolation valves
- TPS train B vacuum isolation valves
- TPS train B ITS isolation valves
- TPS train C vacuum isolation valves
- TPS train C ITS isolation valves
- IU Cell 1 TPS Actuation
- IU Cell 2 TPS Actuation
- IU Cell 3 TPS Actuation
- IU Cell 4 TPS Actuation
- IU Cell 5 TPS Actuation
- IU Cell 6 TPS Actuation
- IU Cell 7 TPS Actuation
- IU Cell 8 TPS Actuation

The ESFAS initiates a TPS Process Vent Actuation based on the following variables or safety actuation:

- High TPS exhaust to facility stack tritium
- RCA Isolation
- Facility master operating permissive

7.5.3.1.22 IU Cell Nitrogen Purge

IU Cell Nitrogen Purge transitions the nitrogen purge system (N2PS) IU cell header valves to their deenergized state.

The ESFAS also provides the target solution vessel (TSV) reactivity protection system (TRPS) for each IU cell with an actuation signal to initiate an IU Cell Nitrogen purge within the TRPS.

- Supercell Area 4 Isolation
- Supercell Area 5 Isolation
- Supercell Area 6 Isolation
- Supercell Area 7 Isolation
- Supercell Area 8 Isolation
- Supercell Area 9 Isolation
- Supercell Area 10 Isolation
- VTS Safety Actuation
- TPS Train A Isolation
- TPS Train B Isolation
- TPS Train C Isolation

The ESFAS initiates an RCA Isolation based on the following variables:

- High RVZ1 RCA exhaust radiation
- High RVZ2 RCA exhaust radiation

A representation of the RCA Isolation is provided in Figure 7.5-4.

7.5.3.1.25 Extraction Column A Alignment Actuation

Extraction Column A Alignment Actuation initiates the following safety functions:

- Deenergize MEPS area A upper three-way valve
- Deenergize MEPS area A lower three-way valve
- Deenergize MEPS A extraction column eluent valve

The ESFAS initiates the Extraction Column A Alignment Actuation based on both of the following inputs being active:

- MEPS area A upper three-way valve supplying position indication
- MEPS area A lower three-way valve supplying position indication

7.5.3.1.26 Extraction Column B Alignment Actuation

Extraction Column B Alignment Actuation initiates the following safety functions:

- Deenergize MEPS area B upper three-way valve
- Deenergize MEPS area B lower three-way valve
- Deenergize MEPS B extraction column eluent valve

The ESFAS initiates the Extraction Column B Alignment Actuation based on both of the following inputs being active:

- MEPS area B upper three-way valve supplying position indication
- MEPS area B lower three-way valve supplying position indication

7.5.3.1.27 Extraction Column C Alignment Actuation

Extraction Column C Alignment Actuation initiates the following safety functions:

be bypassed and will always have equal priority to the automated actuation signals over any other signals that are present.

7.5.4.10 Completion of Protective Actions

The ESFAS is designed so that once initiated, protective actions will continue to completion. Only deliberate operator action can be taken to reset the ESFAS following a protective action. Figure 7.5-1~~, Sheets 19 through 23,~~ shows how the ESFAS latches in a protective action and maintains the state of a protective action until operator input is initiated to reset the output of the ESFAS to normal operating conditions.

The output of the ESFAS is designed so that actuation through automatic or manual means of a safety function can only change when a new position is requested. If there is no signal present from the automatic safety actuation or manual actuation, then the output of the EIM remains in its current state. A safety-related enable nonsafety switch allows an operator, after the switch has been brought to enable, to control the output state of the ESFAS with a hardwired binary control signal from the nonsafety-related controls. The enable nonsafety switch is classified as part of the safety system and is used to prevent spurious nonsafety-related control signals from adversely affecting safety-related components. If the enable nonsafety switch is active, and no automatic safety actuation or manual actuation signals are present, the operator is capable of energizing or deenergizing any EIM outputs using the nonsafety-related hardwired control signals. If the enable nonsafety switch is not active, the nonsafety-related hardwired control signals are ignored.

7.5.4.11 Equipment Qualification

ESFAS rack mounted equipment is installed in a mild operating environment and is designed to meet the environmental conditions described in Subsection 7.4.3.4. Rack mounted ESFAS equipment is tested to appropriate standards to show that the effects of EMI/RFI and power surges are adequately addressed. Appropriate grounding of the ESFAS is performed in accordance with Section 5.2.1 of Institute of Electrical and Electronics Engineers (IEEE) Standard 1050-2004, IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations (IEEE, 2004b).

7.5.4.12 Surveillance

The TRPS supports calibration and testing to ensure operability as described in Subsection 7.2.4.

7.5.4.13 Classification and Identification

Each division of the ESFAS is uniquely labeled and identified in accordance with SHINE identification and classification procedures.

7.5.4.14 Human Factors

The ESFAS provides manual actuation capabilities for each of the safety functions identified in Subsection 7.5.3. To support the use of manual actuations, the ESFAS includes isolated outputs for each safety-related instrument channel to provide monitoring and indication information to the PICS. To facilitate operator indication of ESFAS actuation function status, manual initiation and reset of protective actions, the ESFAS, at the division level, includes isolated input/output for the following:

- Indication of ESFAS variable values
- Indication of ESFAS parameter values
- Indication of ESFAS logic status
- Indication of ESFAS equipment status
- Indication of ESFAS actuation device status

7.5.4.15 Codes and Standards

The following codes and standards are applied to the ESFAS design.

1) Section 8 of IEEE Standard 344-2013, IEEE Standard for Seismic Qualification of Equipment for Nuclear Power Generating Stations (IEEE, 2013); invoked as guidance to meet SHINE Design Criterion 2, Natural phenomena hazards.
2) IEEE Standard 379-2000, IEEE Standard Application of Single-Failure Criterion to Nuclear Power Generating Station Safety Systems (IEEE, 2000); invoked to meet SHINE Design Criterion 1~~3~~5, ~~Instrumentation and controls~~Protection system reliability and testability.
3) IEEE Standard 384-2008, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits (IEEE, 2008); invoked for separation of safety-related and nonsafety-related cables and raceways, as described in Subsection 8a2.1.3 and Subsection 8a2.1.5.
4) IEEE Standard 1023-2004, IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities (IEEE, 2004c); invoked as a guidance to support implementation of human factors into the design of I&C systems.
5) Section 5.2.1 of IEEE Standard 1050-2004, IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations (IEEE, 2004b); invoked as guidance to support electromagnetic compatibility qualification for digital I&C equipment.
6) Regulatory Guide 1.152, Revision 3, Criteria for Use of Computers in Safety Systems of Nuclear Power Plants (USNRC, 2011); invoked to demonstrate secure development and operating environment.
7) The guidance of ANSI/ANS 15.8-1995, Quality Assurance Program Requirements for Research Reactors (R2013) (ANSI/ANS, 1995), as endorsed by Regulatory Guide 2.5, Quality Assurance Program Requirements for Research and Test Reactors (USNRC, 2010), is applied as part of the SHINE Quality Assurance Program for complying with the programmatic requirements of 10 CFR 50.34(b)(6)(ii).

7.5.5 OPERATION AND PERFORMANCE

7.5.5.1 High RVZ RCA Exhaust Radiation

The high RVZ RCA exhaust radiation signal protects against confinement leakage or accidents that could potentially result in excess radiation doses to the public. The RZV RCA exhaust radiation is measured by an analog interface on three different channels, one for each division of ESFAS. When two-out-of-three or more high RVZ RCA exhaust radiation channels are active, then an RCA Isolation is initiated.

When one-out-of-two or more high PVVS carbon delay bed exhaust carbon monoxide channels are active, then a Carbon Delay Bed Isolation for the affected group is initiated.

7.5.5.8 VTS Lift Tank Liquid Detection Switch

The VTS lift tank liquid detection switch signals protect against an overflow of the vacuum lift tanks. The VTS lift tank liquid detection switch signals are measured with a discrete input interface with redundant detection signals common to all lift tanks at the VTS vacuum header. If one-out-of-two or more (Division A and Division B) VTS lift tank liquid detection switch signals are active, then a VTS Safety Actuation is initiated.

7.5.5.9 RDS Liquid Detection Switch

The RDS liquid detection switch signal detects leakage or overflow from other tanks and piping. The RDS liquid detection switch signal is measured with a discrete signal input on two different channels, one for each Division A and Division B of ESFAS. When one-out-of-two or more RDS liquid detection switch signal channels are active, then a VTS Safety Actuation is initiated.

7.5.5.10 High TPS IU Cell 1/2/3/4/5/6/7/8 Target Chamber Exhaust Pressure

The high TPS IU Cell 1/2/3/4/5/6/7/8 target chamber exhaust pressure signal protects against a break in the tritium exhaust lines in the IU cell. The TPS IU Cell 1/2/3/4/5/6/7/8 target chamber exhaust pressure is measured with an analog interface on two different channels, one for each Division A and Division B of ESFAS. When one-out-of-two or more TPS IU Cell 1/2/3/4/5/6/7/8 target chamber exhaust pressure inputs exceed the allowable limit, the appropriate TPS Train A/B/C Isolation is initiated.

7.5.5.11 High TPS IU Cell 1/2/3/4/5/6/7/8 Target Chamber Supply Pressure

The high TPS IU Cell 1/2/3/4/5/6/7/8 target chamber supply pressure signal protects against a break in the tritium supply lines in the IU cell. The TPS IU Cell 1/2/3/4/5/6/7/8 target chamber supply pressure is measured with an analog interface on two different channels, one for each Division A and Division B of ESFAS. When one-out-of-two or more TPS IU Cell 1/2/3/4/5/6/7/8 target chamber supply pressure inputs exceed the allowable limit, the appropriate TPS Train A/B/C Isolation is initiated.

7.5.5.12 High TPS Exhaust to Facility Stack Tritium

The high TPS exhaust to facility stack tritium signal protects against a release of tritium from the ~~exhaust of the~~ TPS glovebox ~~stripper system~~pressure control exhaust and VAC/ITS process vent exhaust into the facility ventilation systems. The TPS exhaust to facility stack tritium is measured with an analog interface on three different channels, one for each division of ESFAS. When ~~one~~two-out-of-~~two~~three or more high TPS exhaust to facility stack tritium channels are active, then a TPS Process Vent ~~Isol~~Actuation is initiated.

7.5.5.13 High TPS ~~Glovebox~~Confinement Tritium

The high TPS ~~glovebox~~confinement tritium signal protects against a release of tritium from TPS equipment into the TPS glovebox. There is an independent and separate tritium measurement for each of the three TPS trains. The TPS ~~glovebox~~confinement tritium concentration is measured with an analog interface on ~~three~~two different channels, one for each ~~d~~Division A and Division B of ESFAS. When one-out-of-two or more high TPS ~~glovebox~~confinement tritium channels are active, then a TPS Train A Isolation, TPS Train B Isolation, or TPS Train C Isolation is initiated for the respective TPS train.

7.5.5.14 TRPS IU Cell Nitrogen Purge

The TRPS IU cell nitrogen purge signal protects against a loss of hydrogen mitigation capabilities in the irradiation units. The TRPS IU cell nitrogen purge signal is transmitted with a discrete input from the TRPS on two different channels, one for each Division A and Division B of ESFAS. When a TRPS IU cell nitrogen purge signal is active, then an ESFAS IU Cell Nitrogen Purge is initiated.

7.5.5.15 Low PVVS Flow

The PVVS flow signal protects against loss of hydrogen mitigation capabilities in the RPF. The PVVS flow is measured with an analog interface on three different channels, one for each division of ESFAS. When two-out-of-three or more high or low PVVS flow channels are active, then an RPF Nitrogen Purge is initiated.

7.5.5.16 MEPS Upper and Lower Three-Way Valves Misaligned

The MEPS upper and lower three-way valves misalignment signal protects against a misalignment of the upper and lower three-way valves, degrading one of the barriers preventing misdirection of chemical reagents or target solution. The MEPS upper and lower three-way valve position indication is measured with a discrete input signal through the respective division the three-way valve is designed to. When two-out-of-two MEPS upper and lower three-way valve position indications indicate they are energized, then a MEPS Alignment Actuation for that area is initiated.

7.5.5.17 IXP Upper and Lower Three-Way Valves Misaligned

The IXP upper and lower three-way valves misalignment signal protects against a misalignment of the upper and lower three-way valves, degrading one of the barriers preventing misdirection of chemical reagents or target solution. The IXP upper and lower three-way valve position indication is measured with a discrete input signal through the respective division the three-way valve is designed to. When two-out-of-two IXP upper and lower three-way valve position indications indicate they are energized, then an IXP Alignment Actuation is initiated.

7.5.5.18 TSPS Dissolution Tank Level Switch

The TSPS dissolution tank level switch signal protects against a criticality event due to excess fissile material in a non-favorable geometry system. The TSPS dissolution tank level switch signal is measured with a discrete input signal on two different channels, one for each Division A and Division B of ESFAS. When one-out-of-two or more TSPS dissolution tank level switch signals are active for either dissolution tank, a Dissolution Tank Isolation is initiated.

Table 7.5-1 – ESFAS Monitored Variables
(Sheet 2 of 6)

Variable	Analytical Limit	Logic	Range	Accuracy	Response Time
MEPS [ ]$^{PROP/ECI}$ conductivity extraction area A	8.8 micromho/cm	1/2↑	0.1 to 50 micromho/cm	3 percent	5 seconds
MEPS [ ]$^{PROP/ECI}$ conductivity extraction area B	8.8 micromho/cm	1/2↑	0.1 to 50 micromho/cm	3 percent	5 seconds
MEPS [ ]$^{PROP/ECI}$ conductivity extraction area C	8.8 micromho/cm	1/2↑	0.1 to 50 micromho/cm	3 percent	5 seconds
Carbon delay bed group 1 exhaust carbon monoxide	20 ppm	1/2↑	0 to 30 ppm	10 percent	15 seconds
Carbon delay bed group 2 exhaust carbon monoxide	20 ppm	1/2↑	0 to 30 ppm	10 percent	15 seconds
Carbon delay bed group 3 exhaust carbon monoxide	20 ppm	1/2↑	0 to 30 ppm	10 percent	15 seconds
VTS vacuum header liquid detection switch signal	Active	1/2↑	Active/Inactive	Discrete input signal	5.5 seconds
RDS liquid detection switch signal	Active	1/2↑	Active/Inactive	Discrete input signal	5.5 seconds
TPS exhaust to facility stack tritium	~~80 µ~~1Ci/m^3	2/3↑	1 to ~~100~~2,000,000 µCi/m^3	10 percent	5 seconds
TPS IU cell 1 target chamber exhaust pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 2 target chamber exhaust pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 3 target chamber exhaust pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds

Table 7.5-1 – ESFAS Monitored Variables (Sheet 3 of 6)

Variable	Analytical Limit	Logic	Range	Accuracy	Response Time
TPS IU cell 4 target chamber exhaust pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 5 target chamber exhaust pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 6 target chamber exhaust pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 7 target chamber exhaust pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 8 target chamber exhaust pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 1 target chamber supply pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 2 target chamber supply pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 3 target chamber supply pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 4 target chamber supply pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 5 target chamber supply pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 6 target chamber supply pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds

Table 7.5-1 – ESFAS Monitored Variables
(Sheet 4 of 6)

Variable	Analytical Limit	Logic	Range	Accuracy	Response Time
TPS IU cell 7 target chamber supply pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS IU cell 8 target chamber supply pressure	8 psia	1/2↑	0 to 19.5 psia	1 percent	10 seconds
TPS ~~glovebox~~confinement A tritium	~~150~~ 1000 Ci/m^3	~~2/3~~1/2↑	0.001 to 50,000 Ci/m^3	10 percent	5 seconds
TPS confinement B tritium	1000 Ci/m^3	1/2↑	0.001 to 50,000 Ci/m^3	10 percent	5 seconds
TPS confinement C tritium	1000 Ci/m^3	1/2↑	0.001 to 50,000 Ci/m^3	10 percent	5 seconds
PVVS flow	5.0 scfm	2/3↓	1-20 scfm	3 percent	0.5 seconds
TSPS dissolution tank 1 level switch signal	Active	1/2↑	Active/Inactive	Discrete input signal	1 second
TSPS dissolution tank 2 level switch signal	Active	1/2↑	Active/Inactive	Discrete input signal	1 second
TRPS IU cell 1 nitrogen purge signal	Active	1/1↑	Active/Inactive	Discrete input signal	500 ms
TRPS IU cell 2 nitrogen purge signal	Active	1/1↑	Active/Inactive	Discrete input signal	500 ms
TRPS IU cell 3 nitrogen purge signal	Active	1/1↑	Active/Inactive	Discrete input signal	500 ms
TRPS IU cell 4 nitrogen purge signal	Active	1/1↑	Active/Inactive	Discrete input signal	500 ms
TRPS IU cell 5 nitrogen purge signal	Active	1/1↑	Active/Inactive	Discrete input signal	500 ms
TRPS IU cell 6 nitrogen purge signal	Active	1/1↑	Active/Inactive	Discrete input signal	500 ms

Table 7.5-2 – Fail Safe Component Positions on ESFAS Loss of Power

(Sheet 2 of 3)

IXP FNHS supply valve

IXP liquid nitrogen supply valve

~~ATIS header GBSS isolation~~TPS train A glovebox pressure control exhaust isolation valve~~s~~

~~ATIS header GBSS bypass isolation valves~~TPS train A ITS isolation valves

~~GBSS RVZ isolation valves~~TPS train A helium AOV supply valve

~~ATIS header return line isolation valves~~TPS train A helium SOV supply valve

TPS ~~process evacuation header isolation~~train A vacuum isolation valves

~~ATIS header deuterium supply~~TPS train B glovebox pressure control exhaust isolation ~~isolation~~ valve~~s~~

TPS train B ITS isolation valves

TPS train B helium AOV supply valve

TPS train B helium SOV supply valve

~~Storage and separation system GBSS raffinate~~TPS train B vacuum ~~-~~ isolation valves

~~ATIS header tritium supply isolation~~TPS train C glovebox pressure control exhaust isolation valve~~s~~

~~ATIS glovebox exhaust header~~TPS train C ITS isolation valves

~~TPS process evacuation GBSS isolation~~TPS train C helium AOV supply valve~~s~~

~~TPS glovebox nitrogen supply valves~~TPS train C helium SOV supply valve

TPS train C vacuum isolation valves

N2PS RVZ2 north header valves

N2PS RVZ2 south header valves

TSPS RPCS supply cooling valves

TSPS RPCS return cooling valve

FAIL-SAFE POSITION: OPEN

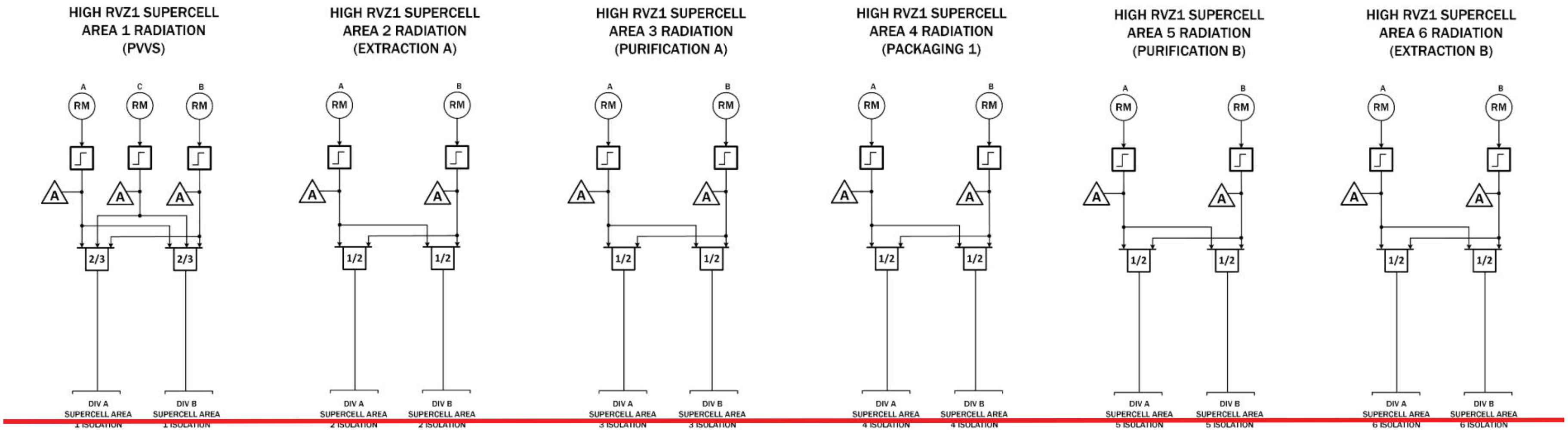
RVZ1 exhaust train 1 blower breakers
RVZ1 exhaust train 2 blower breakers
RVZ2 exhaust train 1 blower breakers
RVZ2 exhaust train 2 blower breakers
RVZ2 supply train 1 blower breakers
RVZ2 supply train 2 blower breakers
VTS vacuum transfer pump 1 breakers
VTS vacuum transfer pump 2 breakers
VTS vacuum transfer pump 3 breakers
VTS vacuum break valves
PVVS blower bypass valves
PVVS carbon guard bed bypass valves
PVVS carbon delay bed group 1 outlet isolation valves
PVVS carbon delay bed group 2 outlet isolation valves
PVVS carbon delay bed group 3 outlet isolation valves
MEPS A extraction feed pump breakers
MEPS B extraction feed pump breakers
MEPS C extraction feed pump breakers
N2PS IU cell header valves
N2PS RPF header valves

FAIL-SAFE POSITION: SUPPLYING

PVVS carbon delay bed group 1 three-way valves

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 1 of 24)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 2 of 24)



Trip Determination

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 3 of 24)

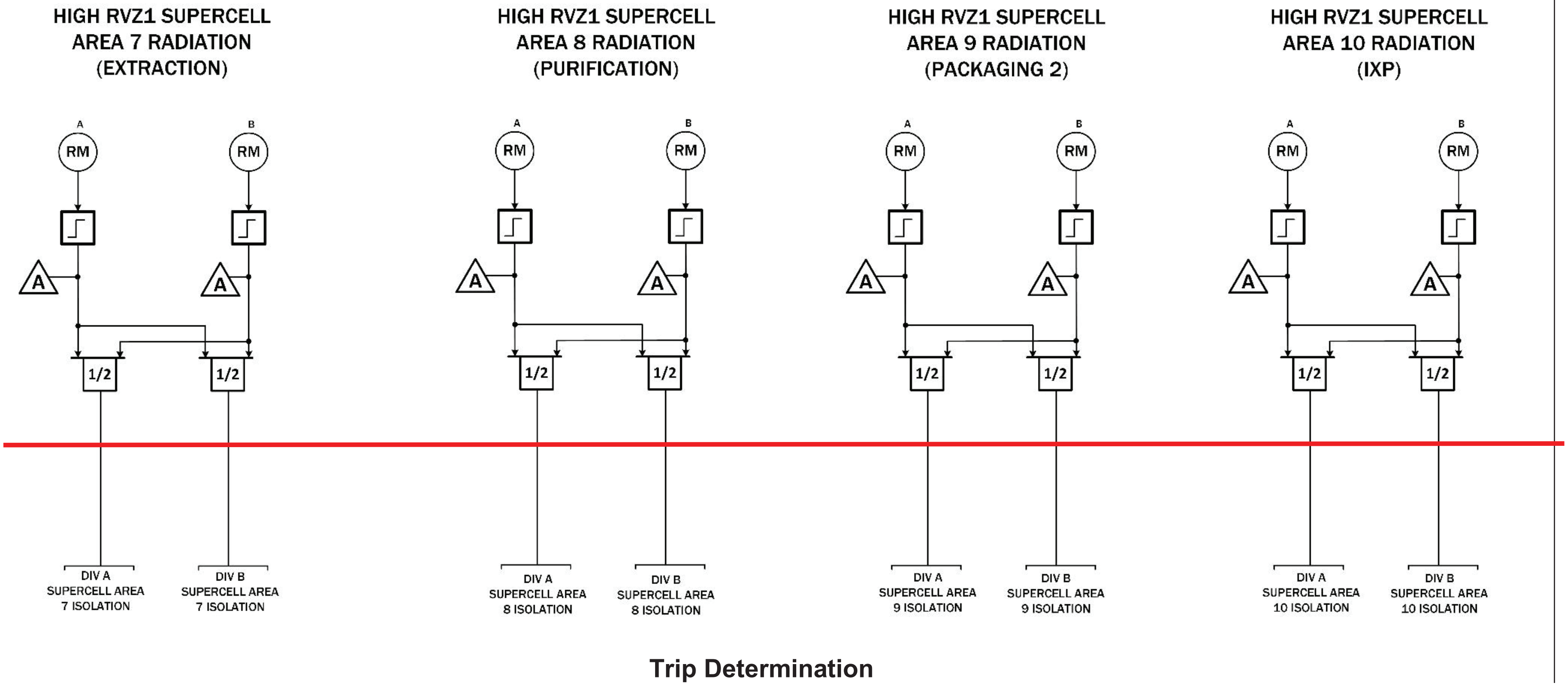
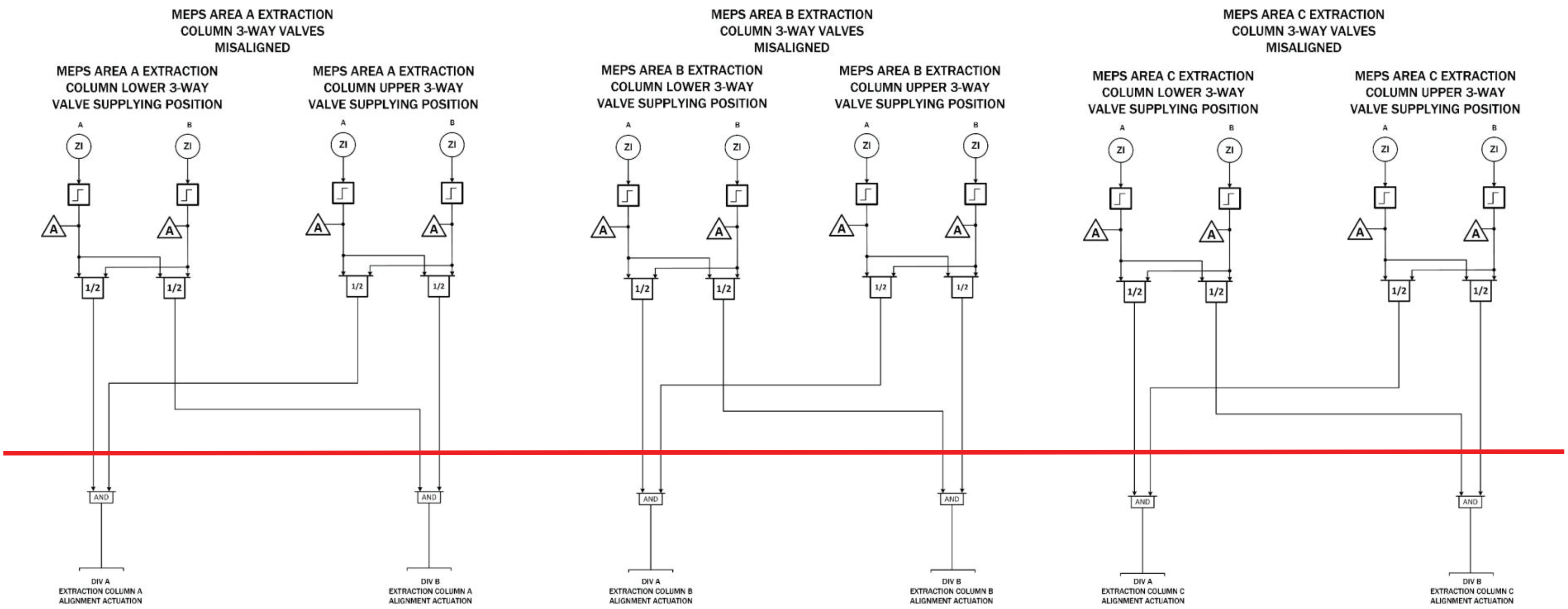


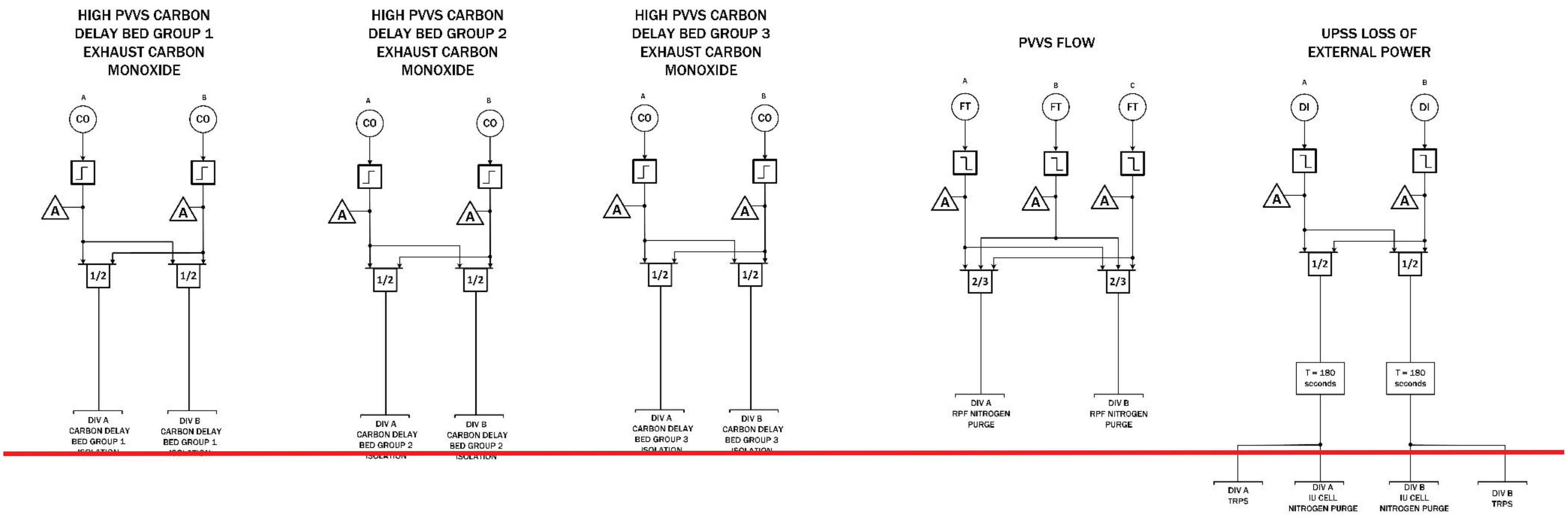
Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 4 of 24)



Trip Determination

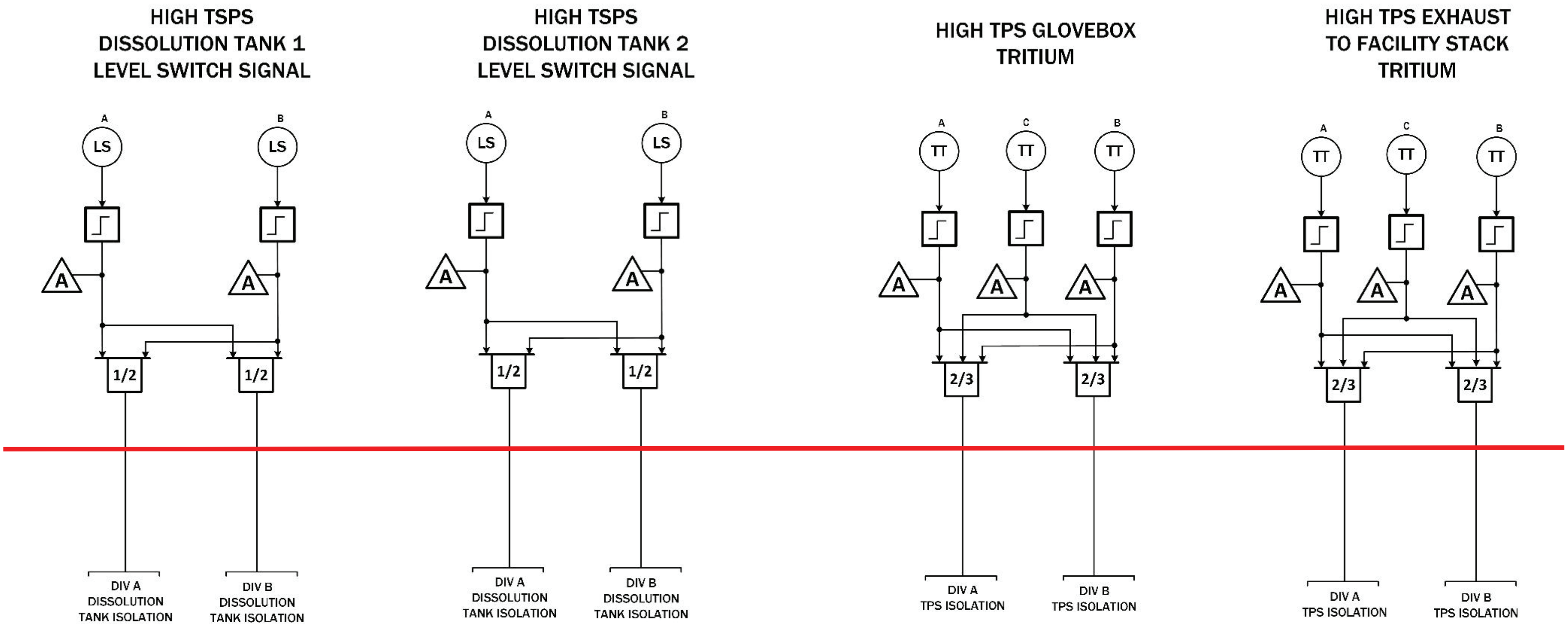
Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 5 of 24)

Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 6 of 24)



Trip Determination

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 7 of 24)



Trip Determination

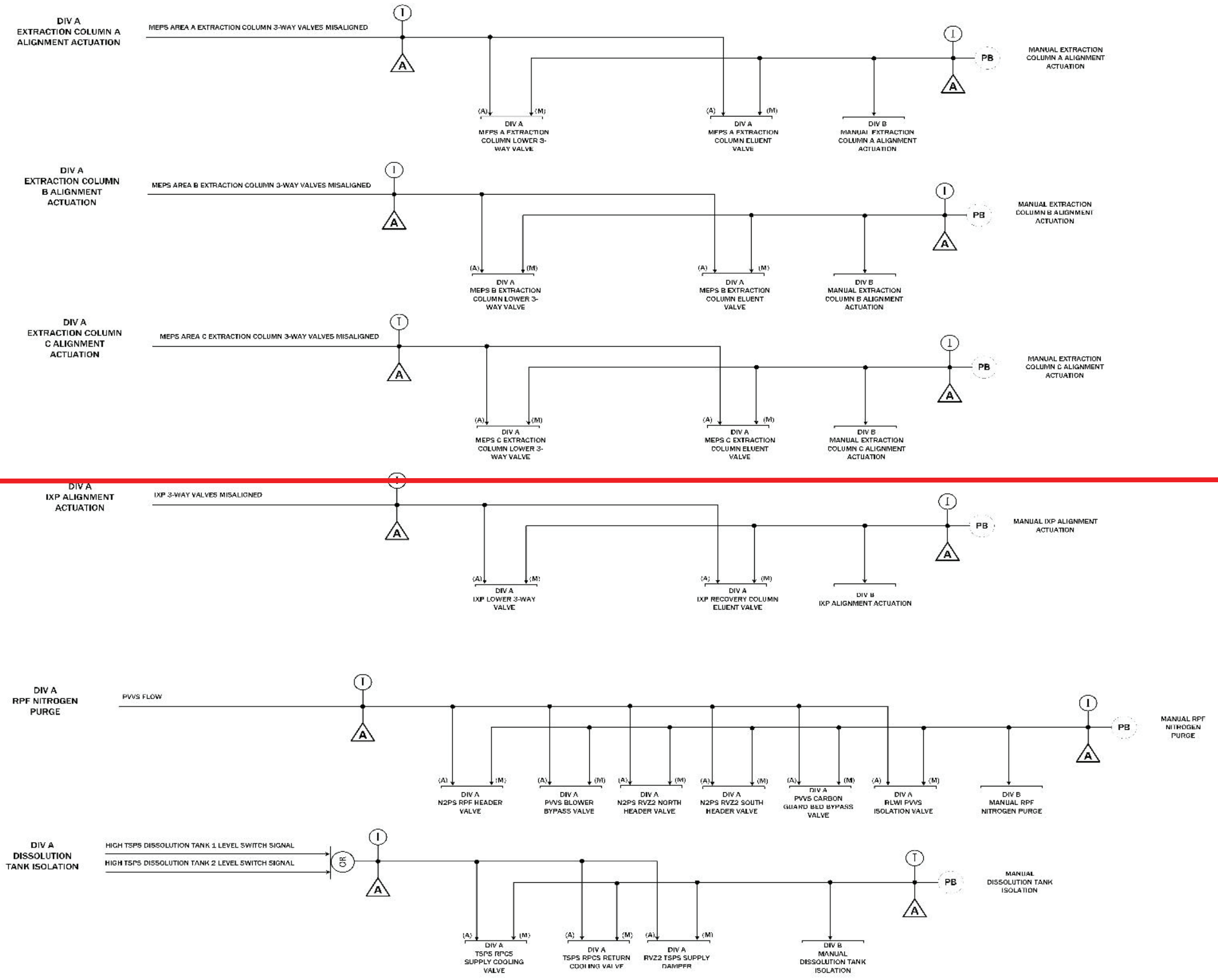
Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 8 of 24)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 9 of 24)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 10 of 24)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 11 of 24)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 12 of 24)



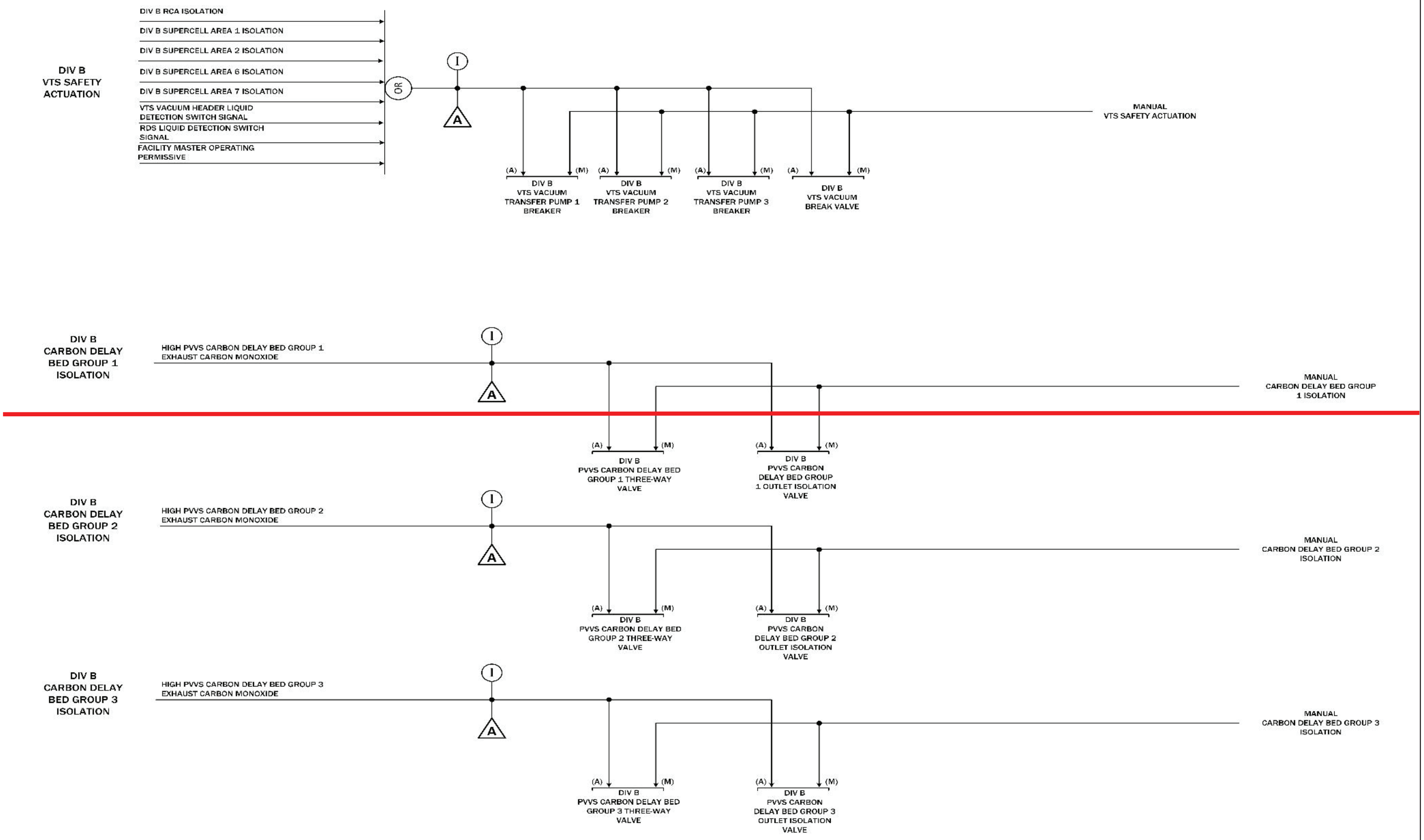
Safety Functions

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 13 of 24)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 14 of 24)

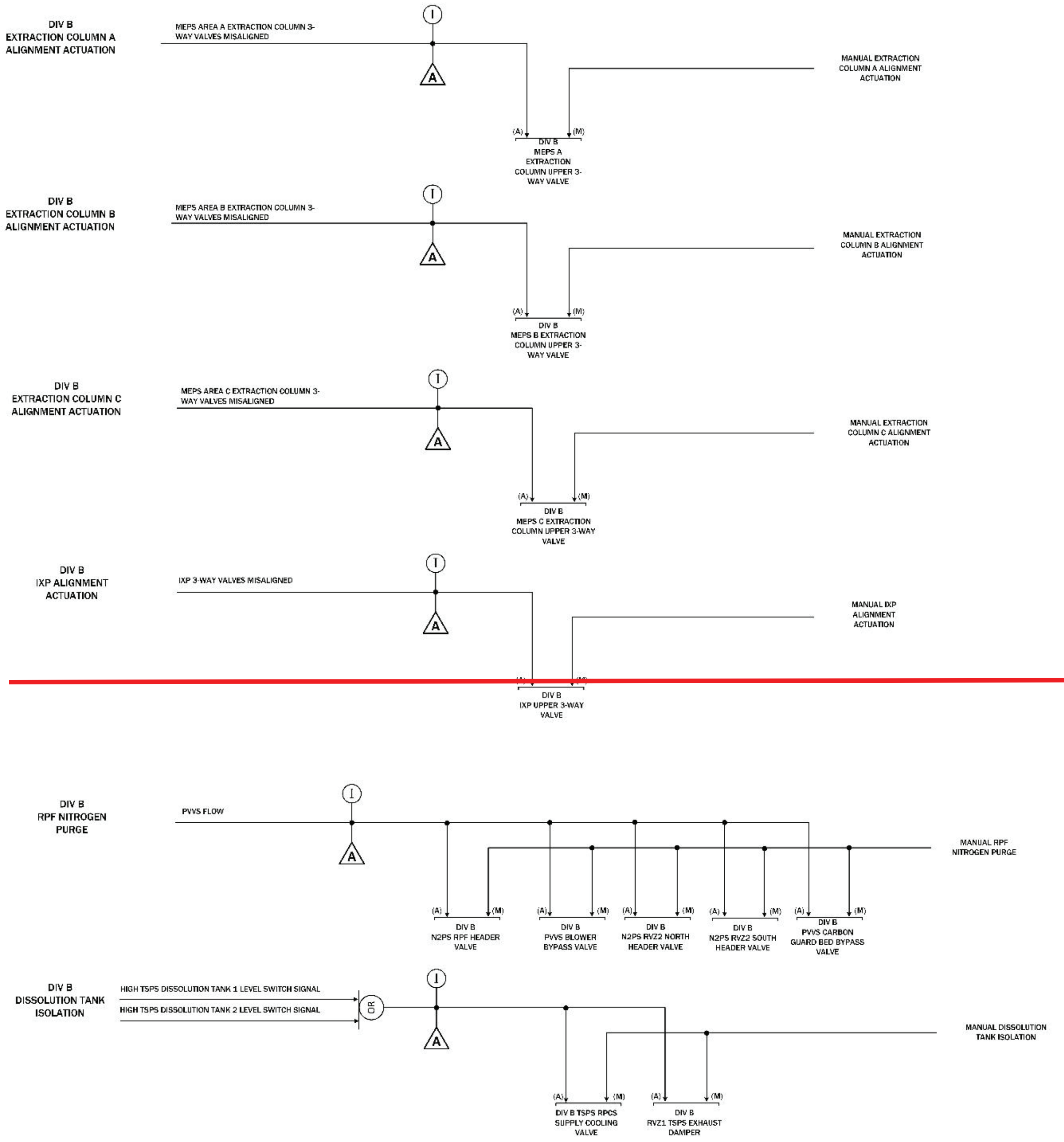
Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 15 of 24)

Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 16 of 24)



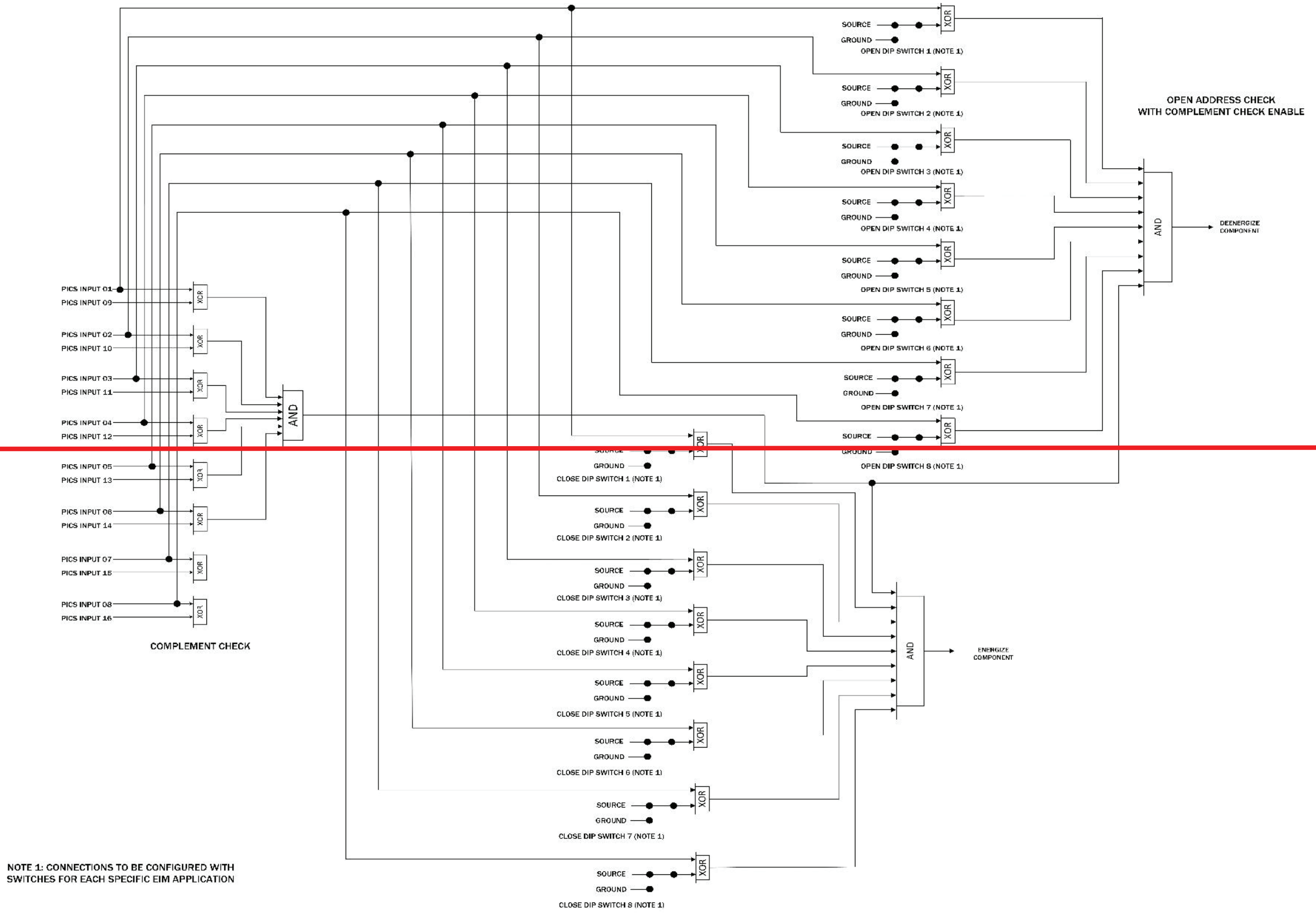
Safety Functions

Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 17 of 24)



Safety Functions

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 18 of 24)

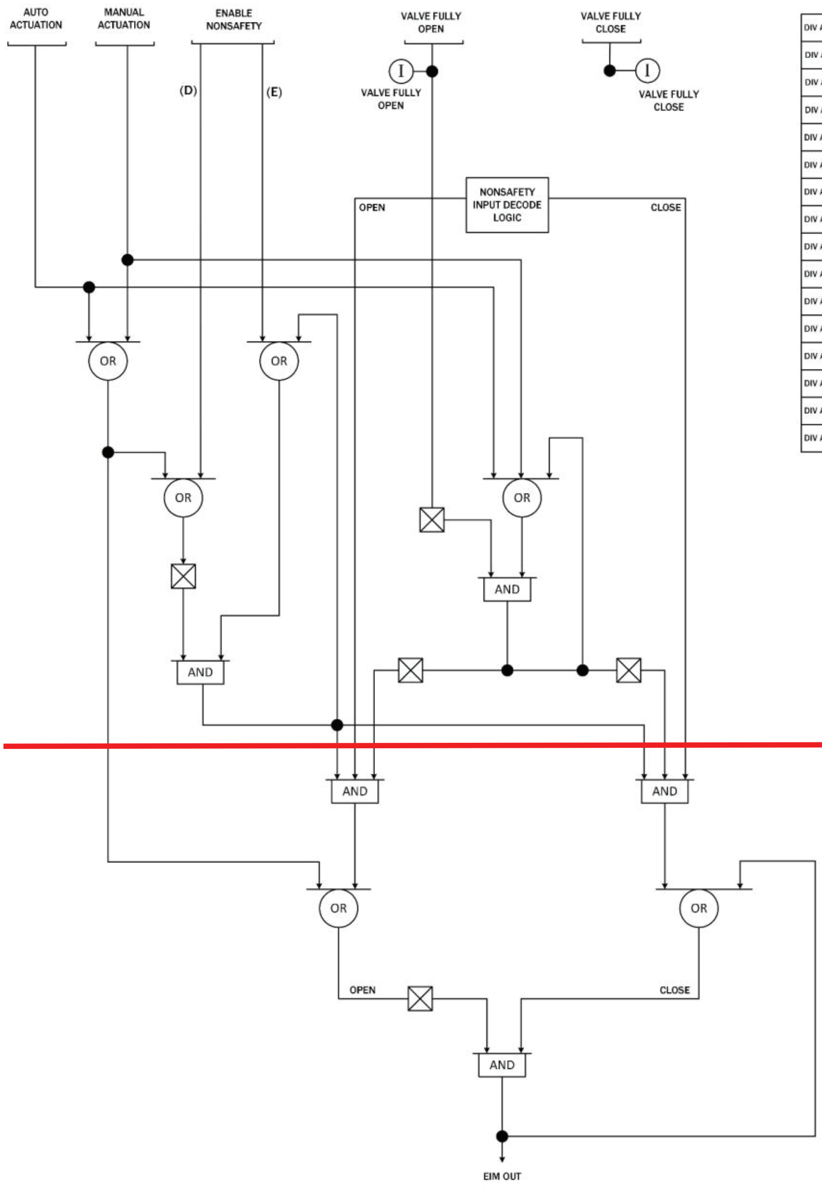


NOTE 1: CONNECTIONS TO BE CONFIGURED WITH SWITCHES FOR EACH SPECIFIC EIM APPLICATION

Nonsafety Decode

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 19 of 24)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 20 of 24)

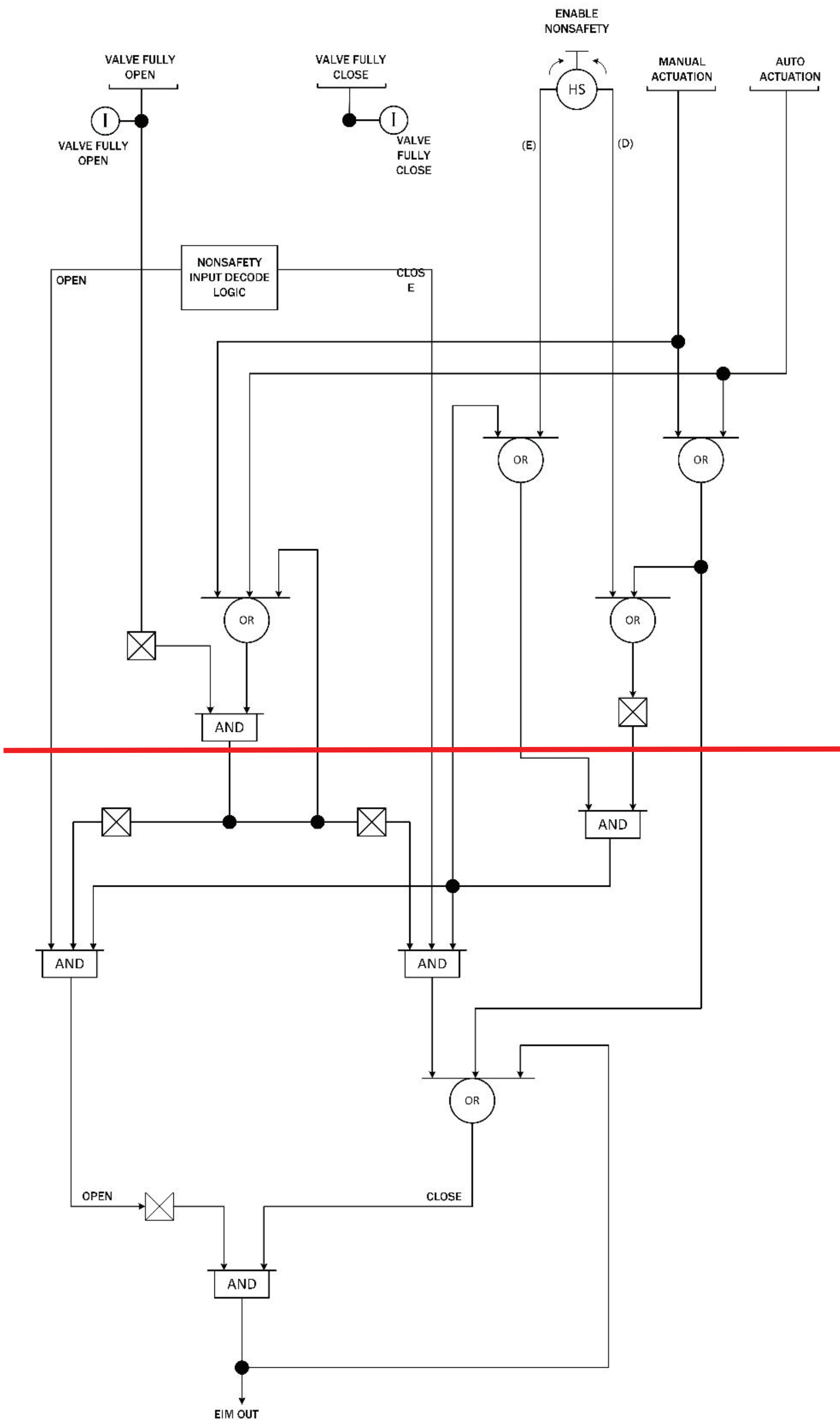


DIV A RZV1 EXHAUST TRAIN 1 BLOWER BREAKER	DIV B RZV1 EXHAUST TRAIN 1 BLOWER BREAKER
DIV A RZV1 EXHAUST TRAIN 2 BLOWER BREAKER	DIV B RZV1 EXHAUST TRAIN 2 BLOWER BREAKER
DIV A RZV2 EXHAUST TRAIN 1 BLOWER BREAKER	DIV B RZV2 EXHAUST TRAIN 1 BLOWER BREAKER
DIV A RZV2 EXHAUST TRAIN 2 BLOWER BREAKER	DIV B RZV2 EXHAUST TRAIN 2 BLOWER BREAKER
DIV A RZV2 SUPPLY TRAIN 1 BLOWER BREAKER	DIV B RZV2 SUPPLY TRAIN 1 BLOWER BREAKER
DIV A RZV2 SUPPLY TRAIN 2 BLOWER BREAKER	DIV B RZV2 SUPPLY TRAIN 2 BLOWER BREAKER
DIV A VTS VACUUM TRANSFER PUMP BREAKER 1	DIV B VTS VACUUM TRANSFER PUMP BREAKER 1
DIV A VTS VACUUM TRANSFER PUMP BREAKER 2	DIV B VTS VACUUM TRANSFER PUMP BREAKER 2
DIV A VTS VACUUM TRANSFER PUMP BREAKER 3	DIV B VTS VACUUM TRANSFER PUMP BREAKER 3
DIV A VTS VACUUM BREAK VALVE	DIV B VTS VACUUM BREAK VALVE
DIV A N2PS IU CELL HEADER VALVE	DIV B N2PS IU CELL HEADER VALVE
DIV A N2PS RPF HEADER VALVE	DIV B N2PS RPF HEADER VALVE
DIV A PVVS BLOWER BYPASS VALVE	DIV B PVVS BLOWER BYPASS VALVE
DIV A MEPS A EXTRACTION FEED PUMP BREAKER	DIV B MEPS A EXTRACTION FEED PUMP BREAKER
DIV A MEPS B EXTRACTION FEED PUMP BREAKER	DIV B MEPS B EXTRACTION FEED PUMP BREAKER
DIV A MEPS C EXTRACTION FEED PUMP BREAKER	DIV B MEPS C EXTRACTION FEED PUMP BREAKER

NOTE: OUTPUT OF EIM IS DEENERGIZED TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER

Priority Logic

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 21 of 24)

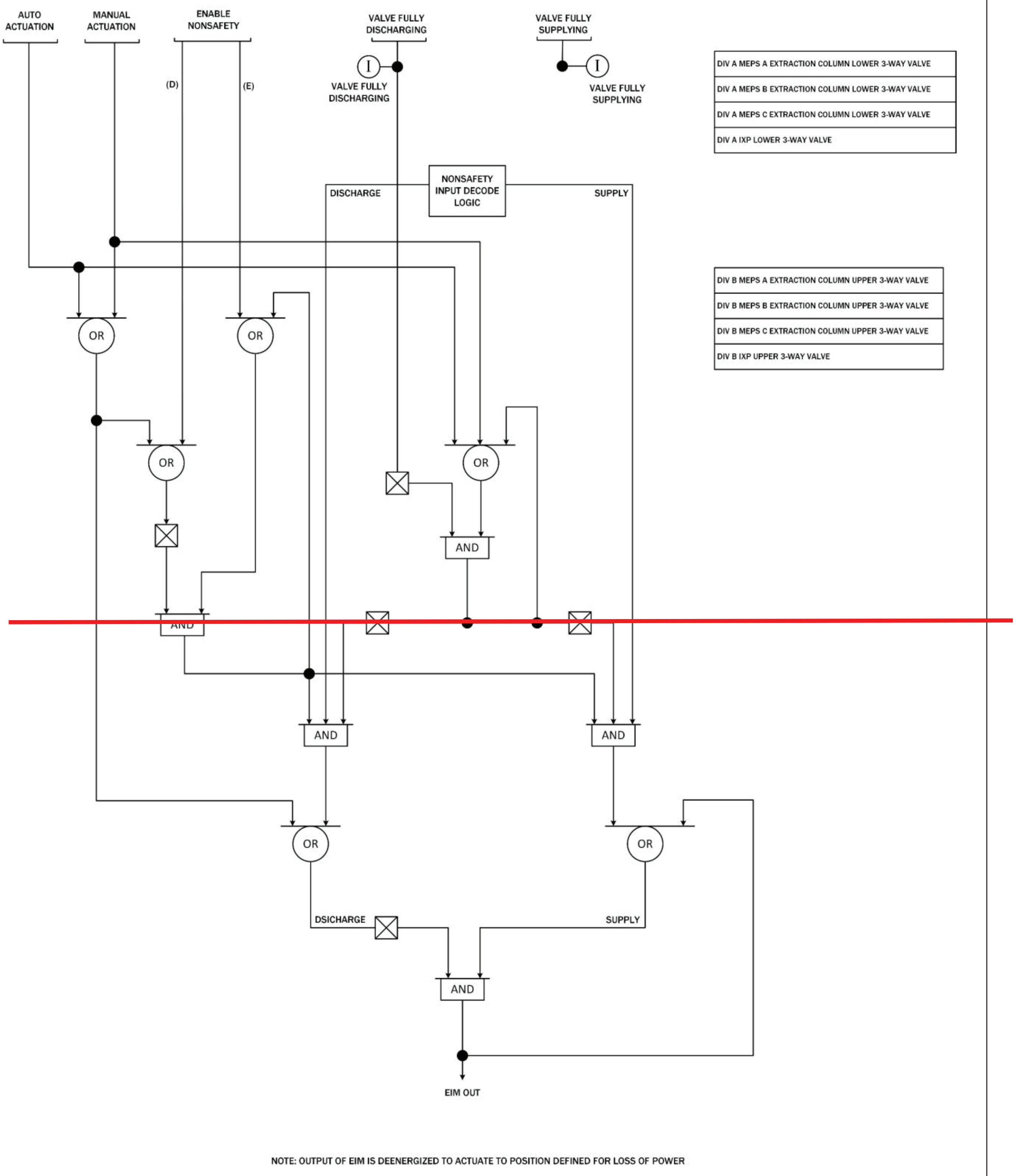


DIV A PVVS CARBON DELAY BED GROUP 1 OUTLET ISOLATION VALVE
DIV A PVVS CARBON DELAY BED GROUP 2 OUTLET ISOLATION VALVE
DIV A PVVS CARBON DELAY BED GROUP 3 OUTLET ISOLATION VALVE
DIV B PVVS CARBON DELAY BED GROUP 1 OUTLET ISOLATION VALVE
DIV B PVVS CARBON DELAY BED GROUP 2 OUTLET ISOLATION VALVE
DIV B PVVS CARBON DELAY BED GROUP 3 OUTLET ISOLATION VALVE

NOTE: OUTPUT OF EIM IS DEENERGIZE TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER

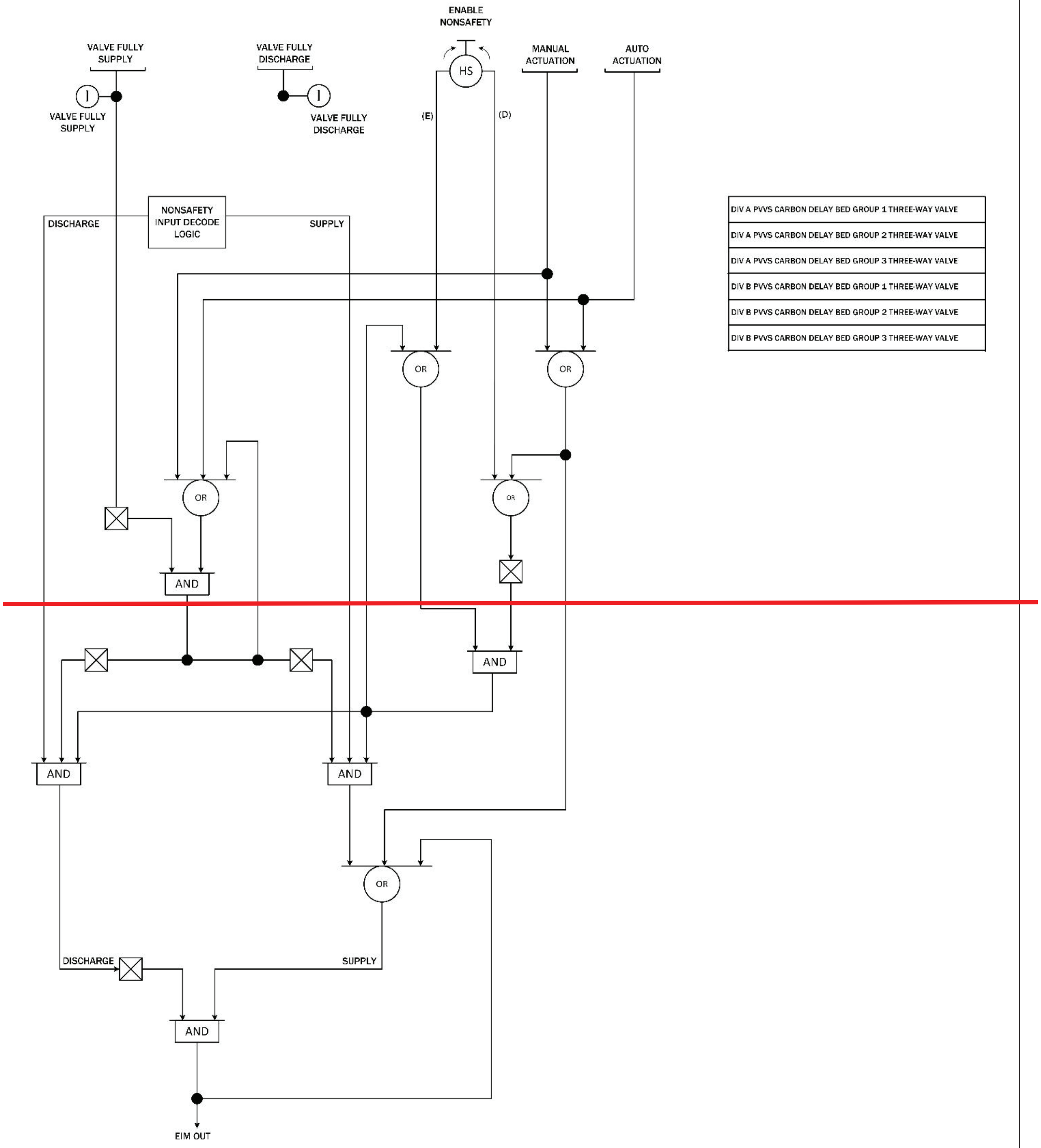
Priority Logic

**Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 22 of 24)**



Priority Logic

Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 23 of 24)

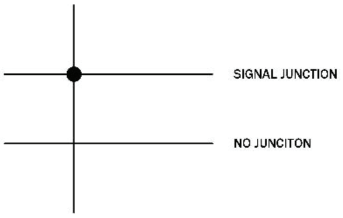


NOTE: OUTPUT OF EIM IS DEENERGIZE TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER

Priority Logic

Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 24 of 24)

A	ALARM PROVIDED TO PROCESS INTEGRATED CONTROL SYSTEM	RM	RADIATION MONITOR
I	INDICATION PROVIDED TO PROCESS INTEGRATED CONTROL SYSTEM	LS	LEVEL SWITCH
OR	LOGICAL "OR" GATE	ZI	POSITION INDICATION
AND	LOGICAL "AND" GATE	CT	CONDUCTIVITY TRANSMITTER
☒	LOGICAL "NOT" OR INVERTER GATE	PT	PRESSURE TRANSMITTER
XOR	LOGICAL "XOR" GATE	TT	TRITIUM TRANSMITTER
2/3	TWO-OUT-OF-THREE VOTING GATE	TE	TEMPERATURE ELEMENT
1/2	ONE-OUT-OF-TWO VOTING GATE	CO	CARBON MONOXIDE TRANSMITTER
	BISTABLE – INCREASING SETPOINT	FT	FLOW TRANSMITTER
	BISTABLE – DECREASING SETPOINT	DI	DISCRETE INPUT
PB	PUSH BUTTON	(A)	AUTOMATIC ACTUATION
HS	THREE POSITION HAND SWITCH, RETURN TO CENTER	(M)	MANUAL ACTUATION
HS	TWO POSITION HAND SWITCH	(E)	ENABLE NONSAFETY "ENABLED"
T = XX seconds	TIMER THAT INITIATES ON A LOGIC "1", RESETS ON LOGIC "0" AND OUTPUTS A LOGIC "1" IF TIMER HAS EXPIRED	(D)	ENABLE NONSAFETY "DISABLED"

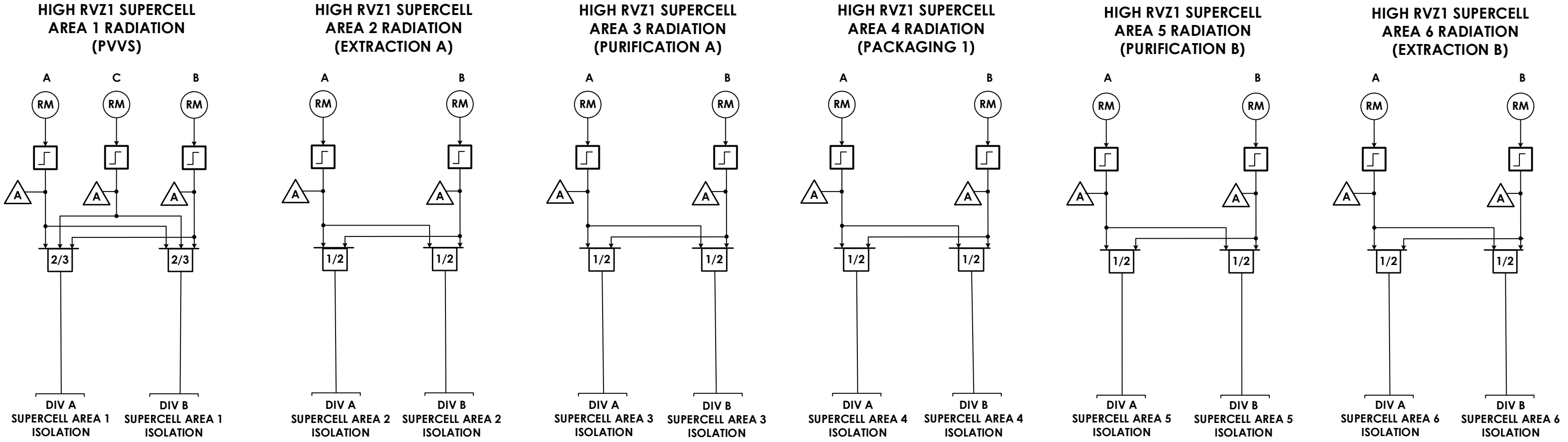


ACRONYMS
ATIS – ACCELERATOR TRITIUM INTERFACE SYSTEM
DIV – DIVISION
EIM – EQUIPMENT INTERFACE MODULE
FNHS – FACILITY NITROGEN HANDLING SYSTEM
GBSS – GLOVEBOX STRIPPER SYSTEM
IU – IRRADIATION UNIT
IXP – IODINE AND XENON PURIFICATION SYSTEM
MEPS – MOLYBDENUM EXTRACTION AND PURIFICATION SYSTEM
N2PS – NITROGEN PURGE SYSTEM
PICS – PROCESS INTEGRATED CONTROL SYSTEM
PVVS – PROCESS VESSEL VENTILATION SYSTEM
RCA – RADIOLOGICAL CONTROLLED AREA
RLWI – RADIOLOGICAL LIQUID WASTE IMMOBILIZATION
RVZ1 – RADIOLOGICAL VENTILATION ZONE 1
RVZ2 – RADIOLOGICAL VENTILATION ZONE 2
RVZ3 – RADIOLOGICAL VENTILATION ZONE 3
SSS – STORAGE AND SEPARATION SYSTEM
TPS – TRITIUM PURIFICATION SYSTEM
TSPS – TARGET SOLUTION PREPARATION SYSTEM
VTS – VACUUM TRANSFER SYSTEM

Legend

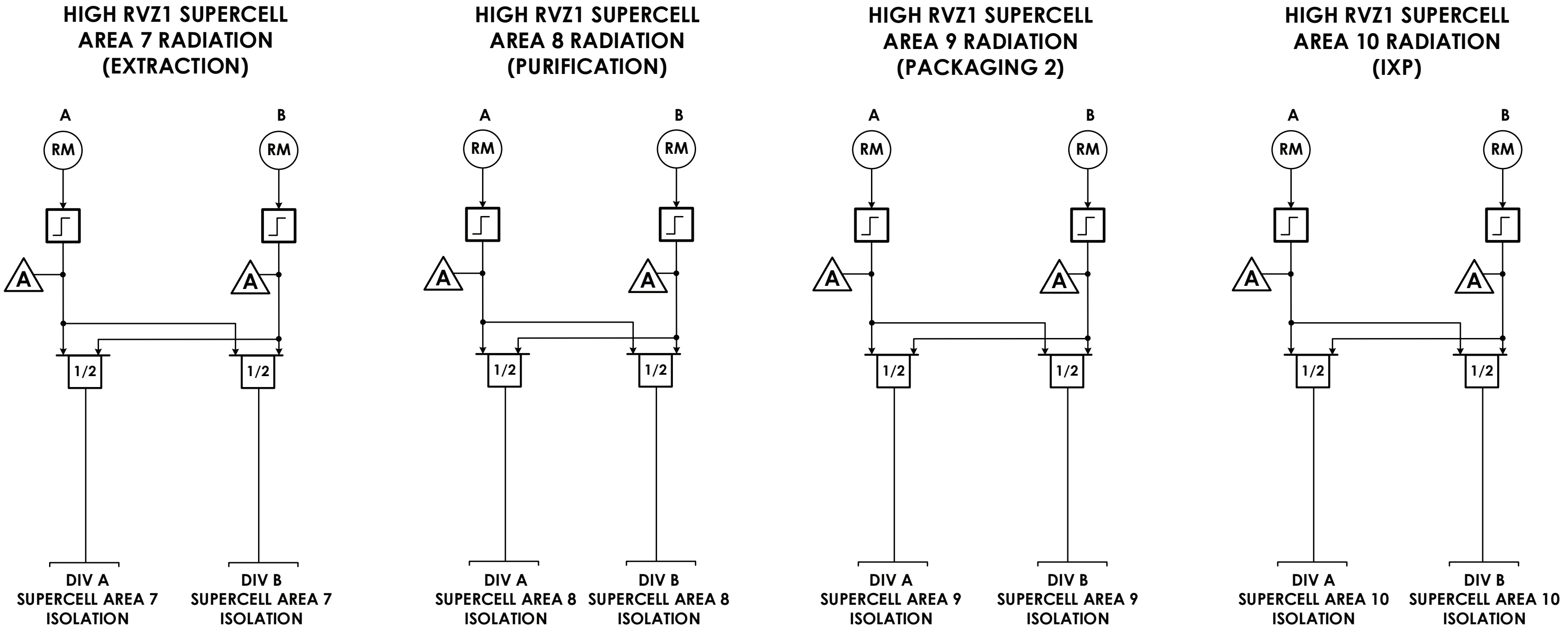
Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 1 of 27)

Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 2 of 27)



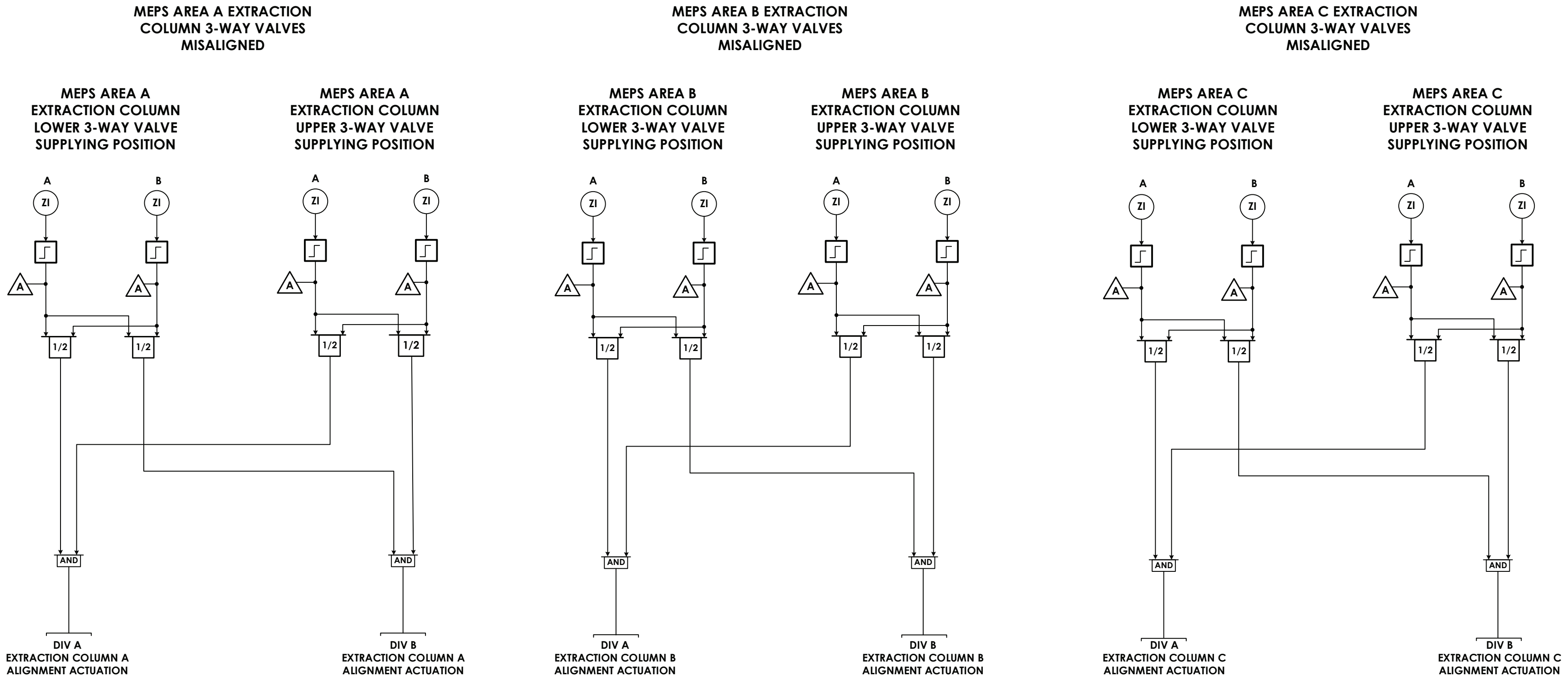
Trip Determination

Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 3 of 27)



Trip Determination

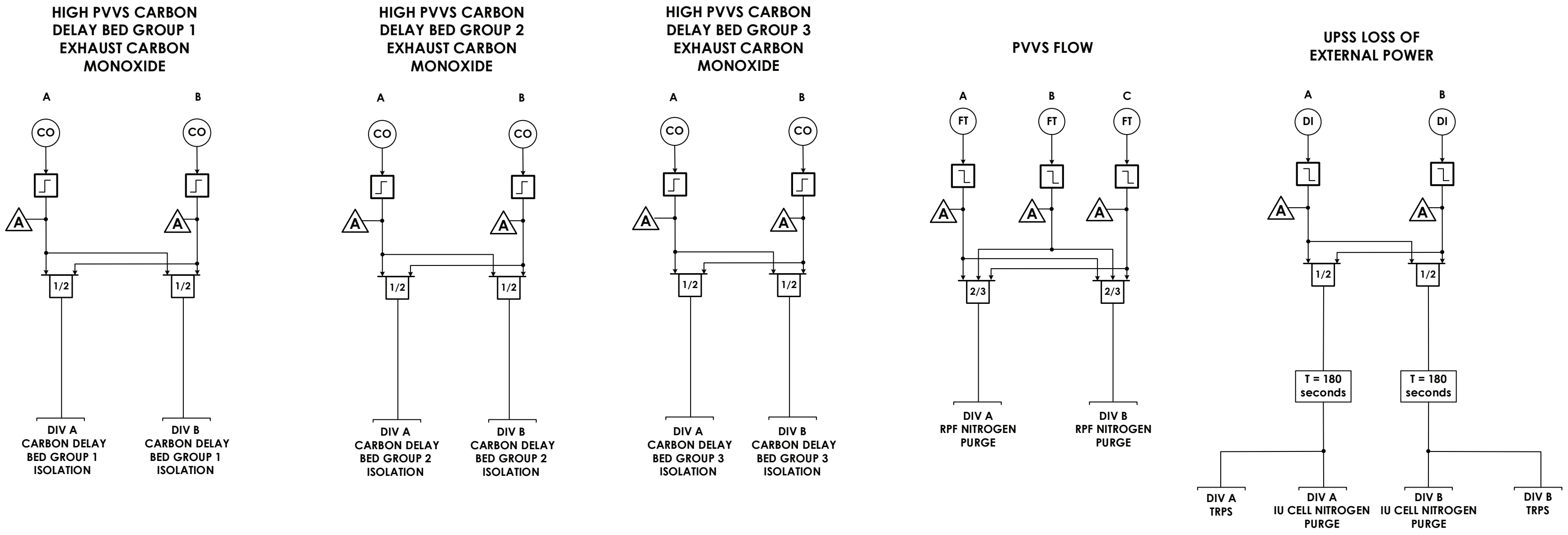
Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 4 of 27)



Trip Determination

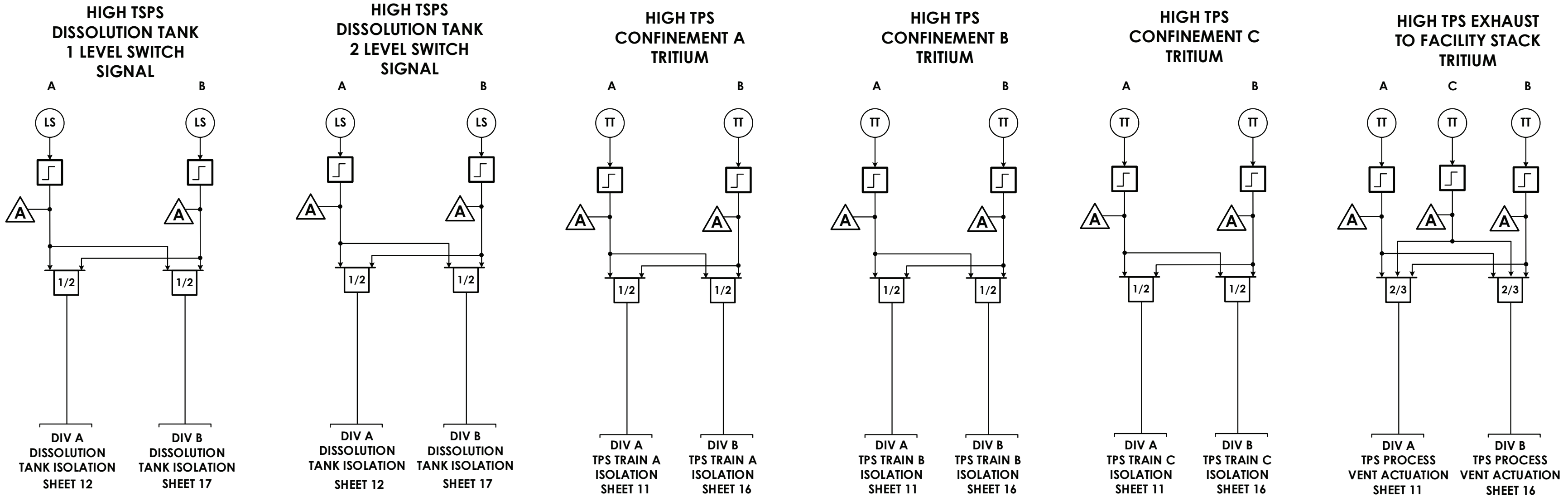
Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 5 of 27)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 6 of 27)



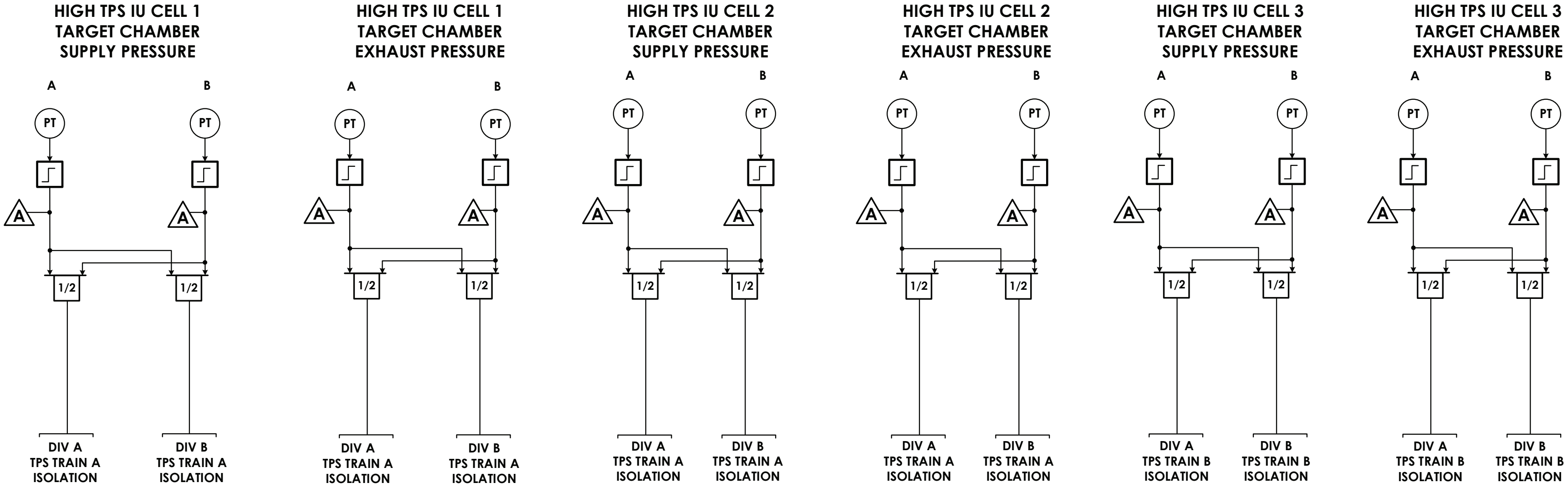
Trip Determination

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 7 of 27)



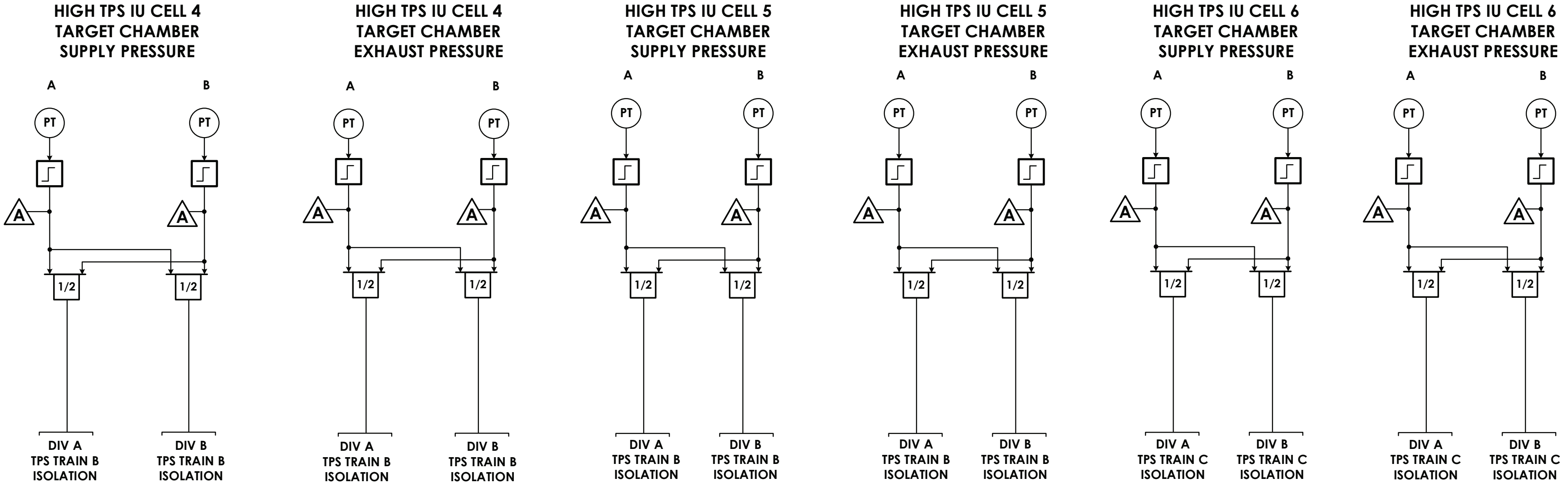
Trip Determination

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 8 of 27)



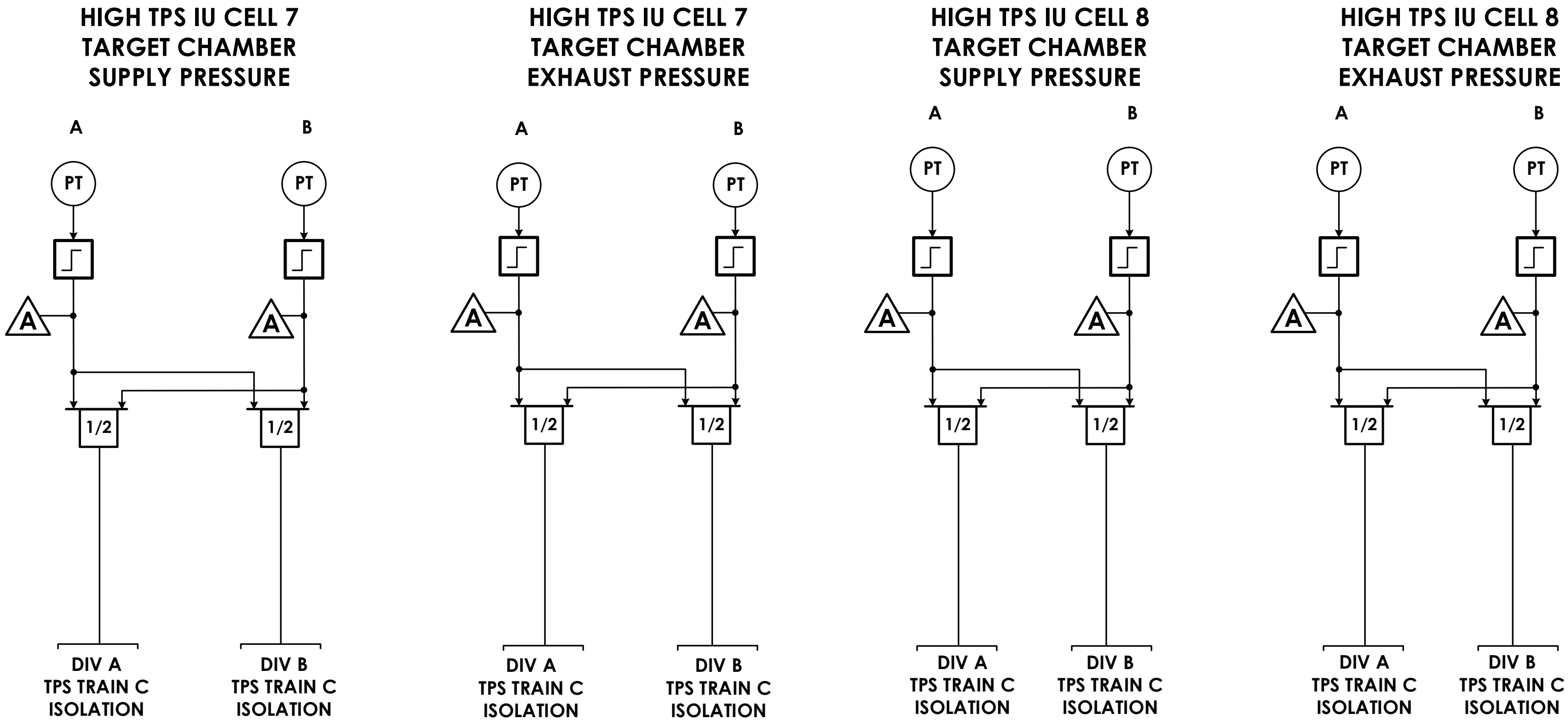
Trip Determination

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 9 of 27)



Trip Determination

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 10 of 27)



HIGH TPS IU CELL 7 TARGET CHAMBER SUPPLY PRESSURE

HIGH TPS IU CELL 7 TARGET CHAMBER EXHAUST PRESSURE

HIGH TPS IU CELL 8 TARGET CHAMBER SUPPLY PRESSURE

HIGH TPS IU CELL 8 TARGET CHAMBER EXHAUST PRESSURE

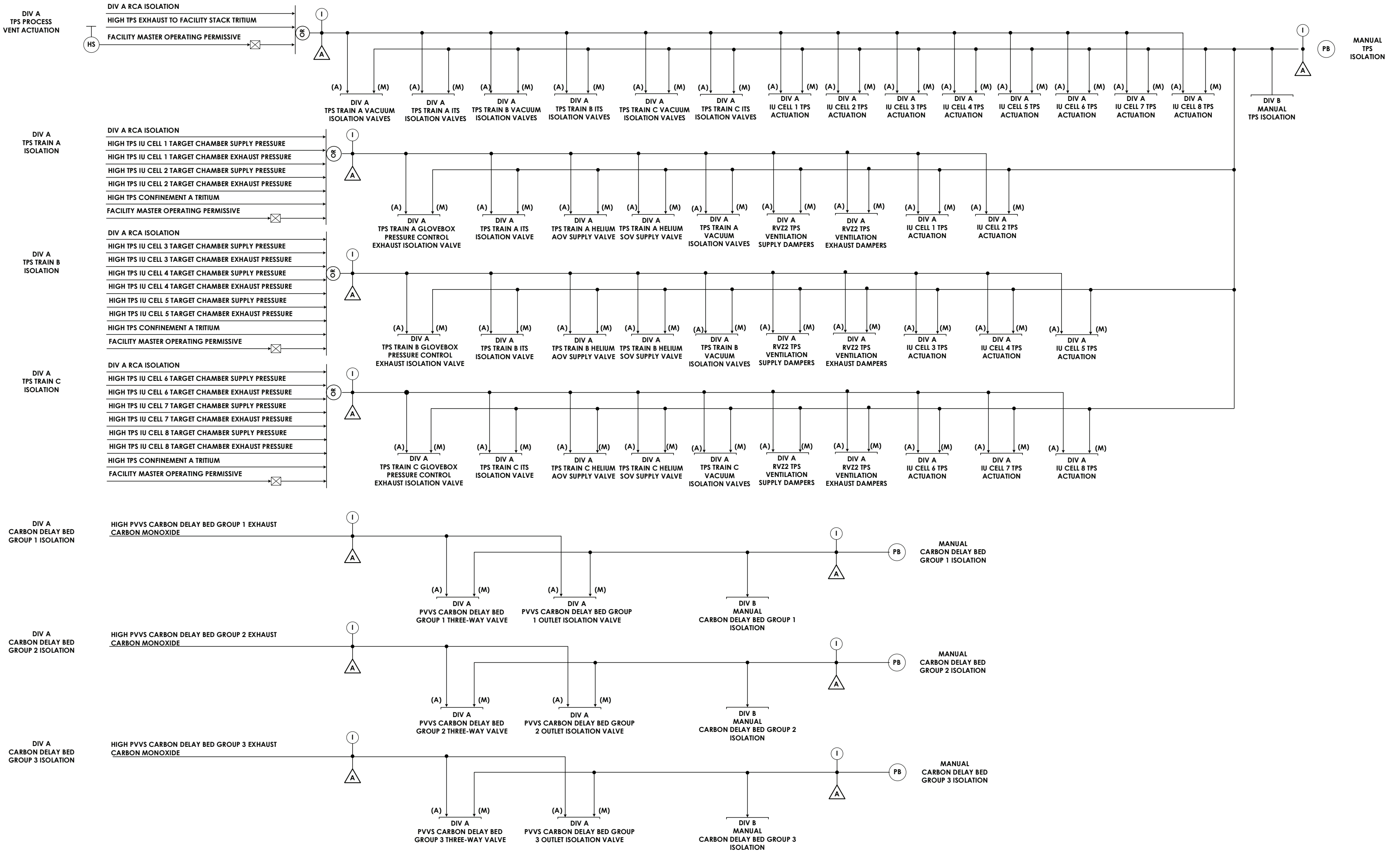
Trip Determination

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 11 of 27)

**Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 12 of 27)**

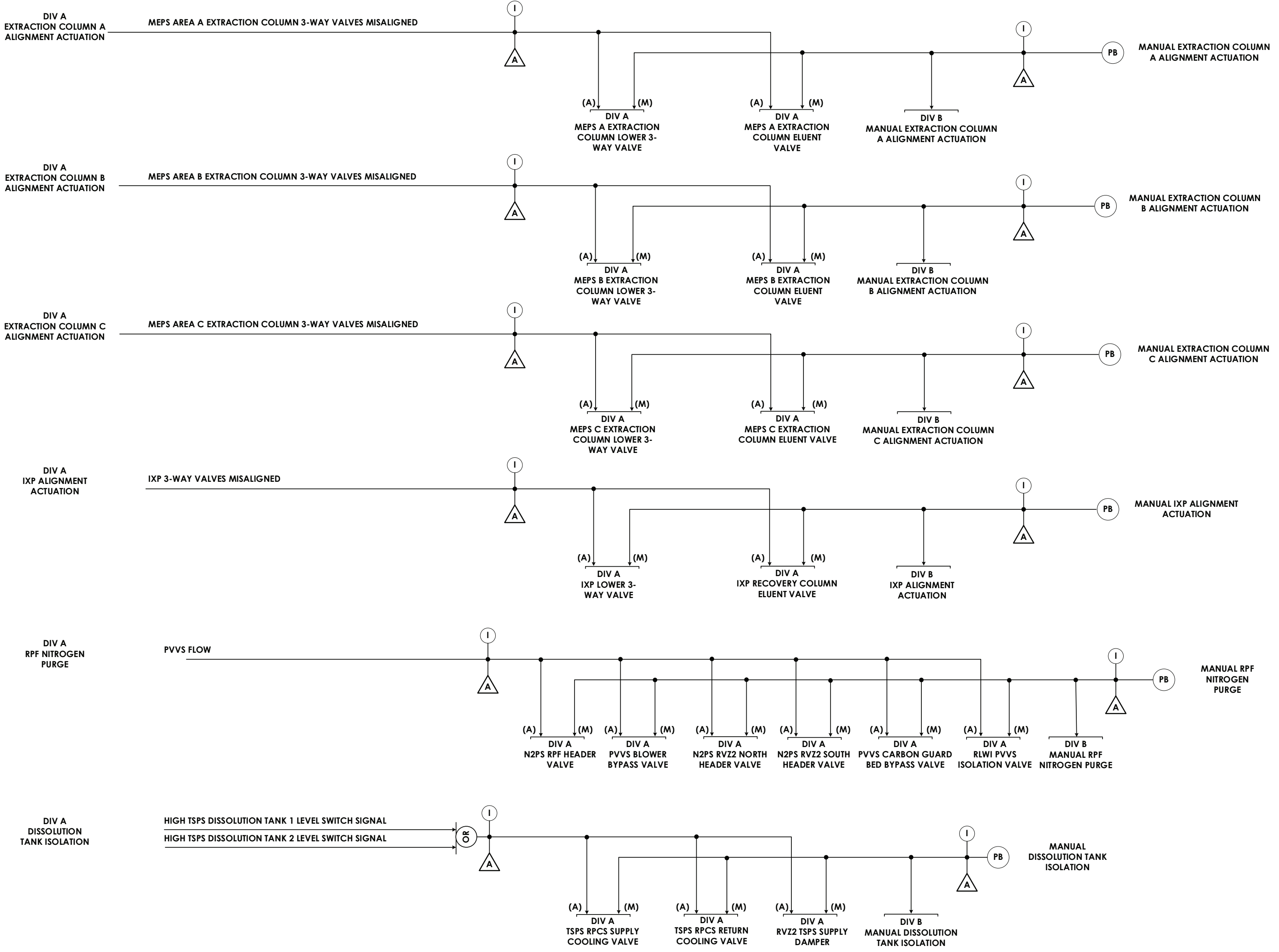
Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 13 of 27)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 14 of 27)



Safety Actuation

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 15 of 27)



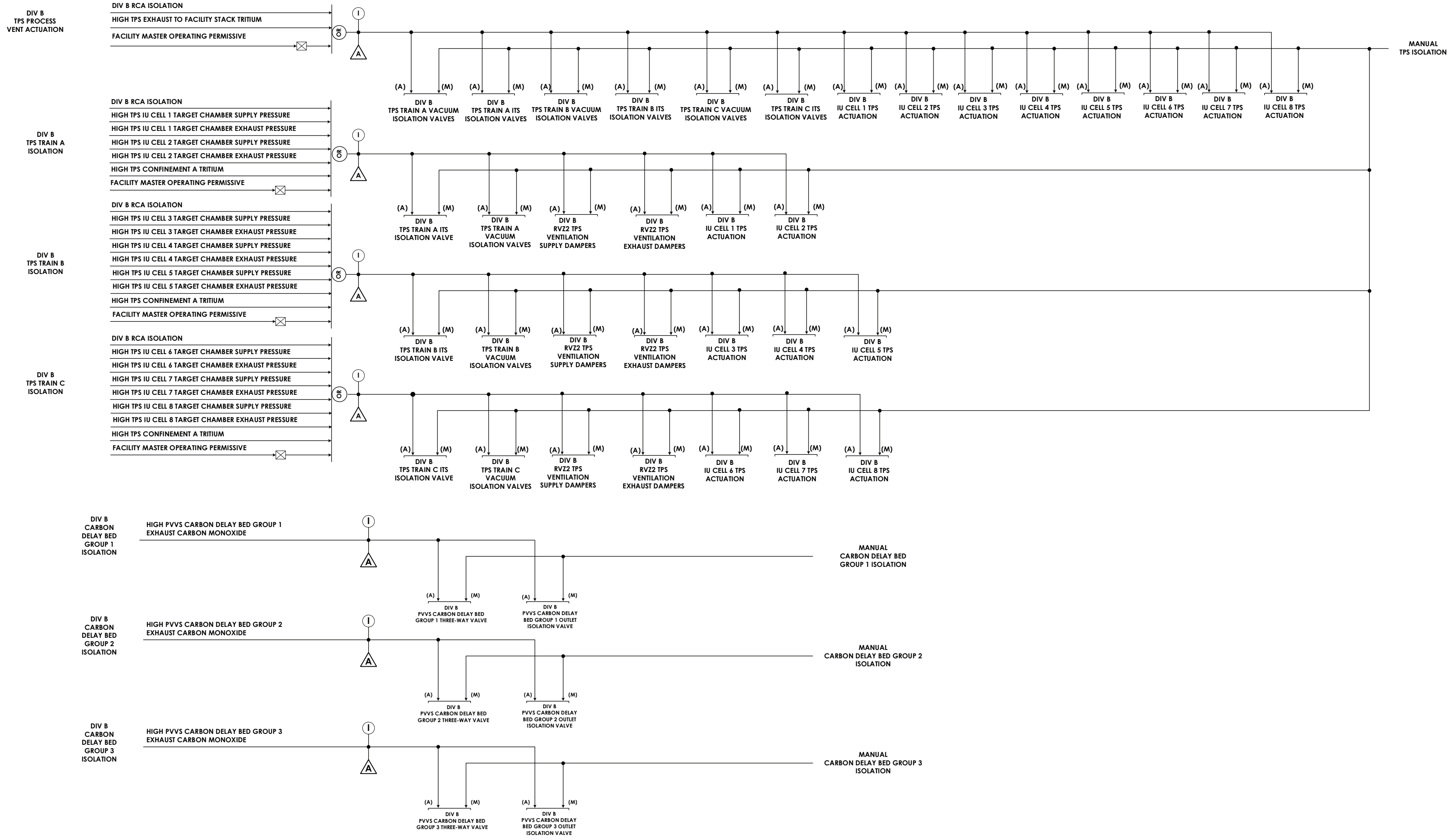
Safety Actuation

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 16 of 27)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 17 of 27)

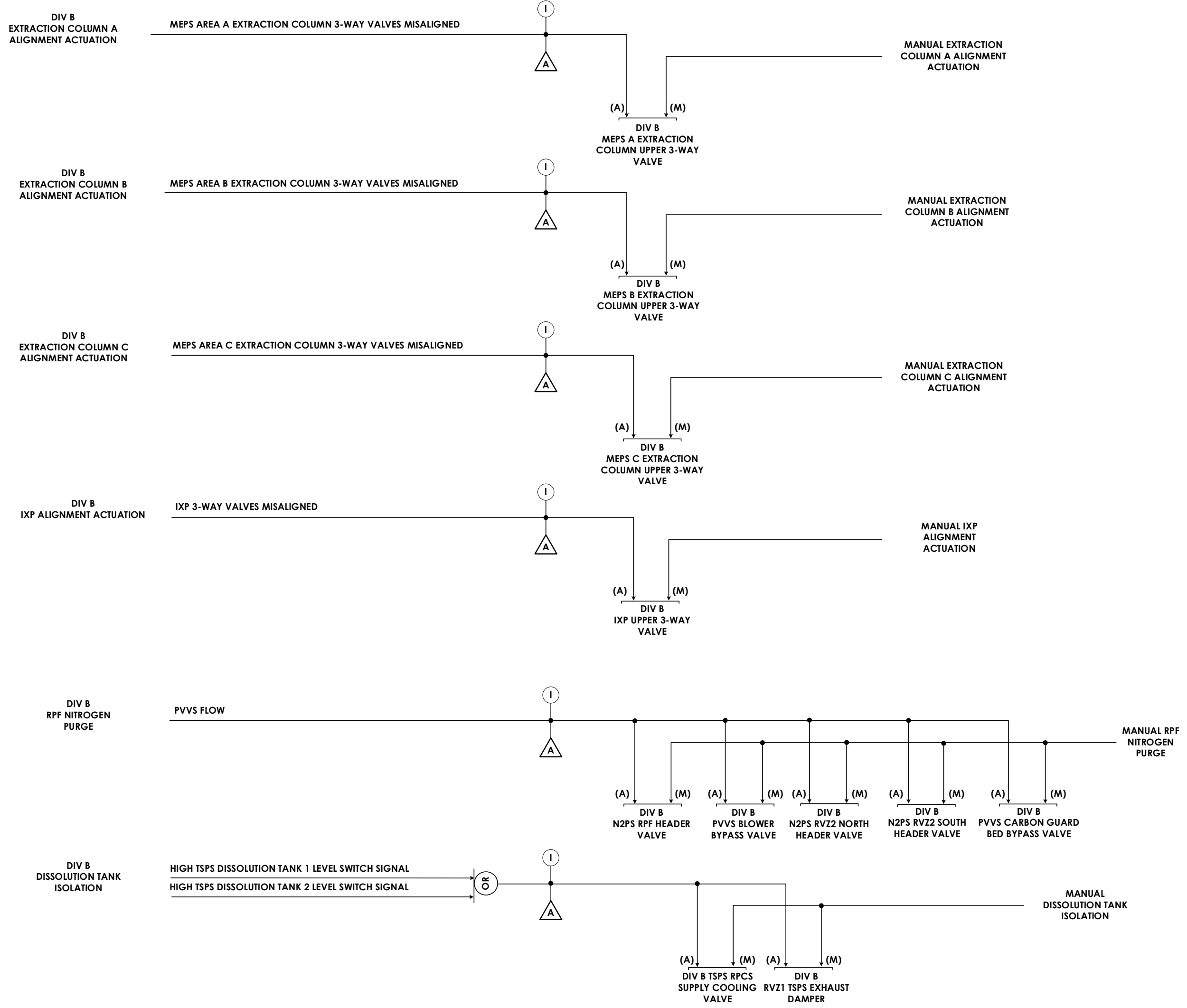
Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 18 of 27)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 19 of 27)



Safety Actuation

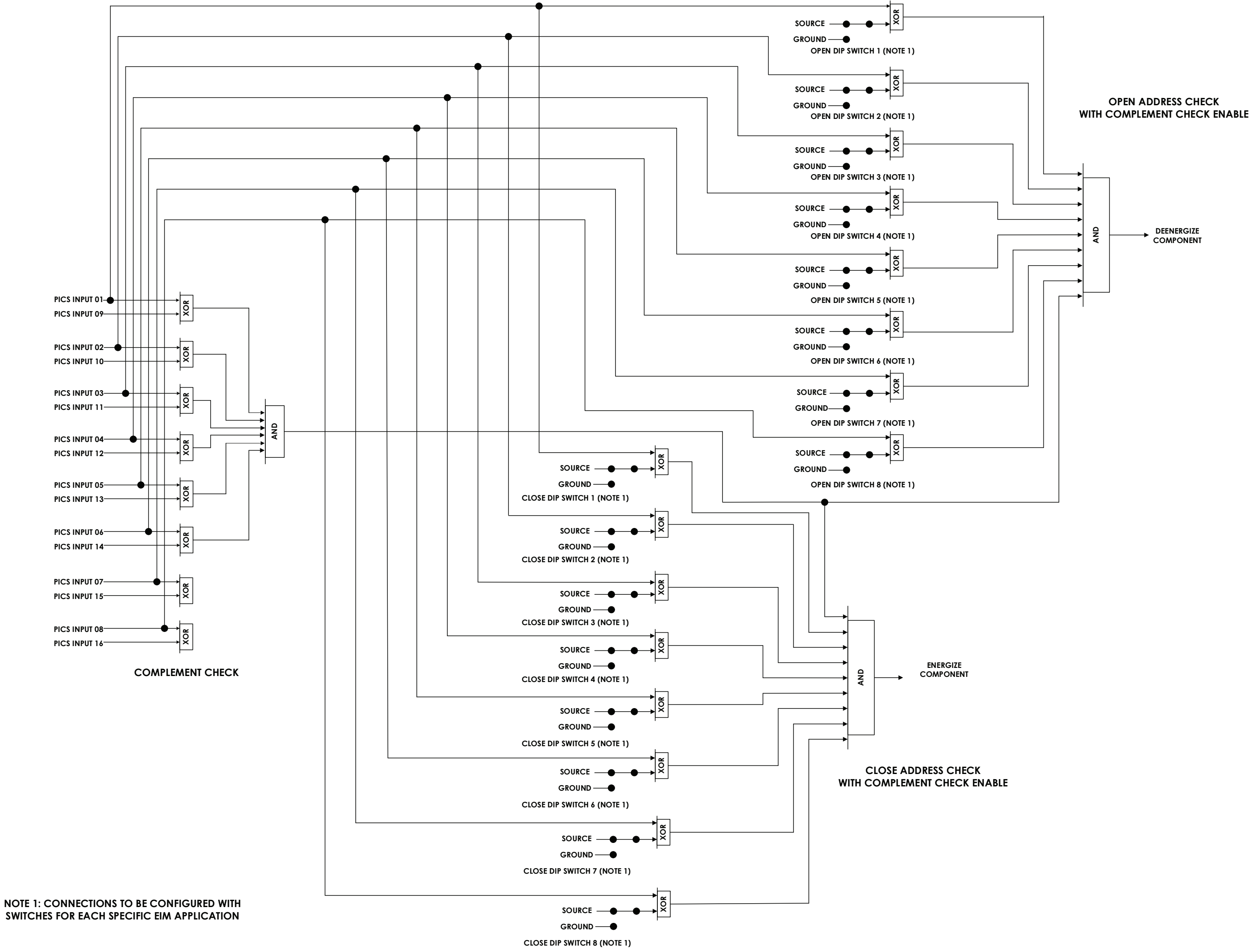
Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 20 of 27)



Safety Actuation

Figure 7.5-1 – ESFAS Logic Diagrams

(Sheet 21 of 27)

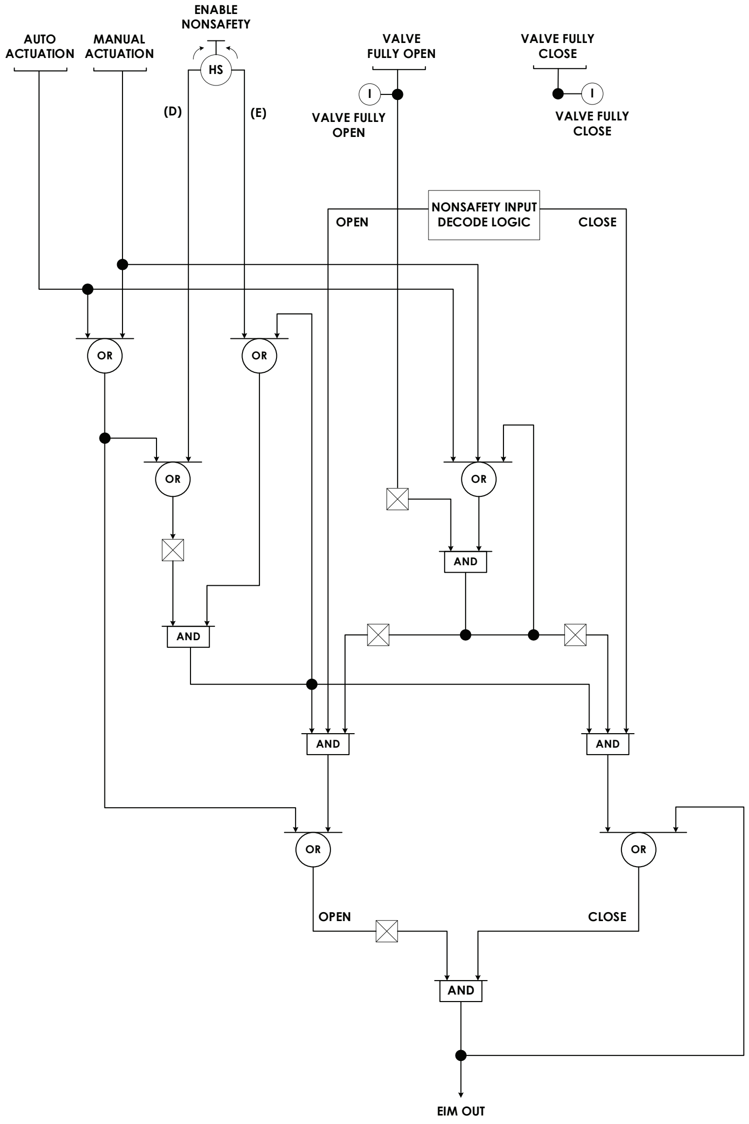


NOTE 1: CONNECTIONS TO BE CONFIGURED WITH SWITCHES FOR EACH SPECIFIC EIM APPLICATION

Nonsafety Interface Decode

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 22 of 27)

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 23 of 27)

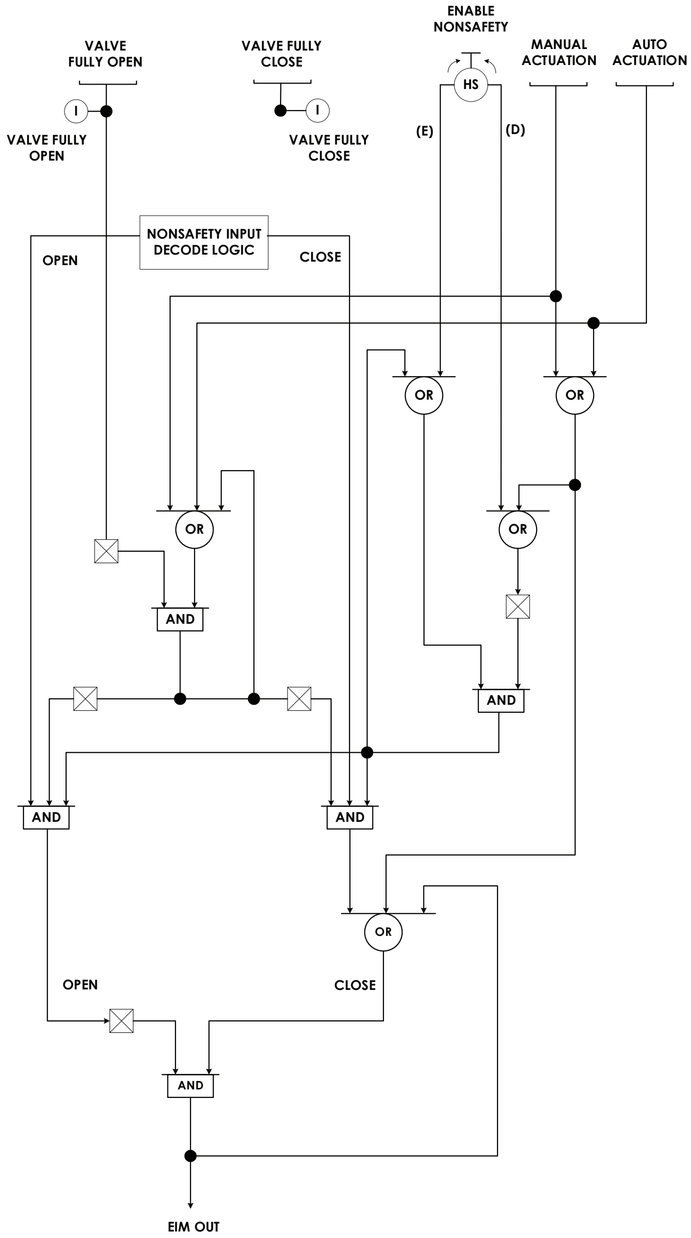


DIV A RZV1 EXHAUST TRAIN 1 BLOWER BREAKER	DIV B RZV1 EXHAUST TRAIN 1 BLOWER BREAKER
DIV A RZV1 EXHAUST TRAIN 2 BLOWER BREAKER	DIV B RZV1 EXHAUST TRAIN 2 BLOWER BREAKER
DIV A RZV2 EXHAUST TRAIN 1 BLOWER BREAKER	DIV B RZV2 EXHAUST TRAIN 1 BLOWER BREAKER
DIV A RZV2 EXHAUST TRAIN 2 BLOWER BREAKER	DIV B RZV2 EXHAUST TRAIN 2 BLOWER BREAKER
DIV A RZV2 SUPPLY TRAIN 1 BLOWER BREAKER	DIV B RZV2 SUPPLY TRAIN 1 BLOWER BREAKER
DIV A RZV2 SUPPLY TRAIN 2 BLOWER BREAKER	DIV B RZV2 SUPPLY TRAIN 2 BLOWER BREAKER
DIV A VTS VACUUM TRANSFER PUMP BREAKER 1	DIV B VTS VACUUM TRANSFER PUMP BREAKER 1
DIV A VTS VACUUM TRANSFER PUMP BREAKER 2	DIV B VTS VACUUM TRANSFER PUMP BREAKER 2
DIV A VTS VACUUM TRANSFER PUMP BREAKER 3	DIV B VTS VACUUM TRANSFER PUMP BREAKER 3
DIV A VTS VACUUM BREAK VALVE	DIV B VTS VACUUM BREAK VALVE
DIV A N2PS IU CELL HEADER VALVE	DIV B N2PS IU CELL HEADER VALVE
DIV A N2PS RPF HEADER VALVE	DIV B N2PS RPF HEADER VALVE
DIV A PVVS BLOWER BYPASS VALVE	DIV B PVVS BLOWER BYPASS VALVE
DIV A MEPS A EXTRACTION FEED PUMP BREAKER	DIV B MEPS A EXTRACTION FEED PUMP BREAKER
DIV A MEPS B EXTRACTION FEED PUMP BREAKER	DIV B MEPS B EXTRACTION FEED PUMP BREAKER
DIV A MEPS C EXTRACTION FEED PUMP BREAKER	DIV B MEPS C EXTRACTION FEED PUMP BREAKER

NOTE: OUTPUT OF EIM IS DEENERGIZE TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER

Priority Logic

Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 24 of 27)

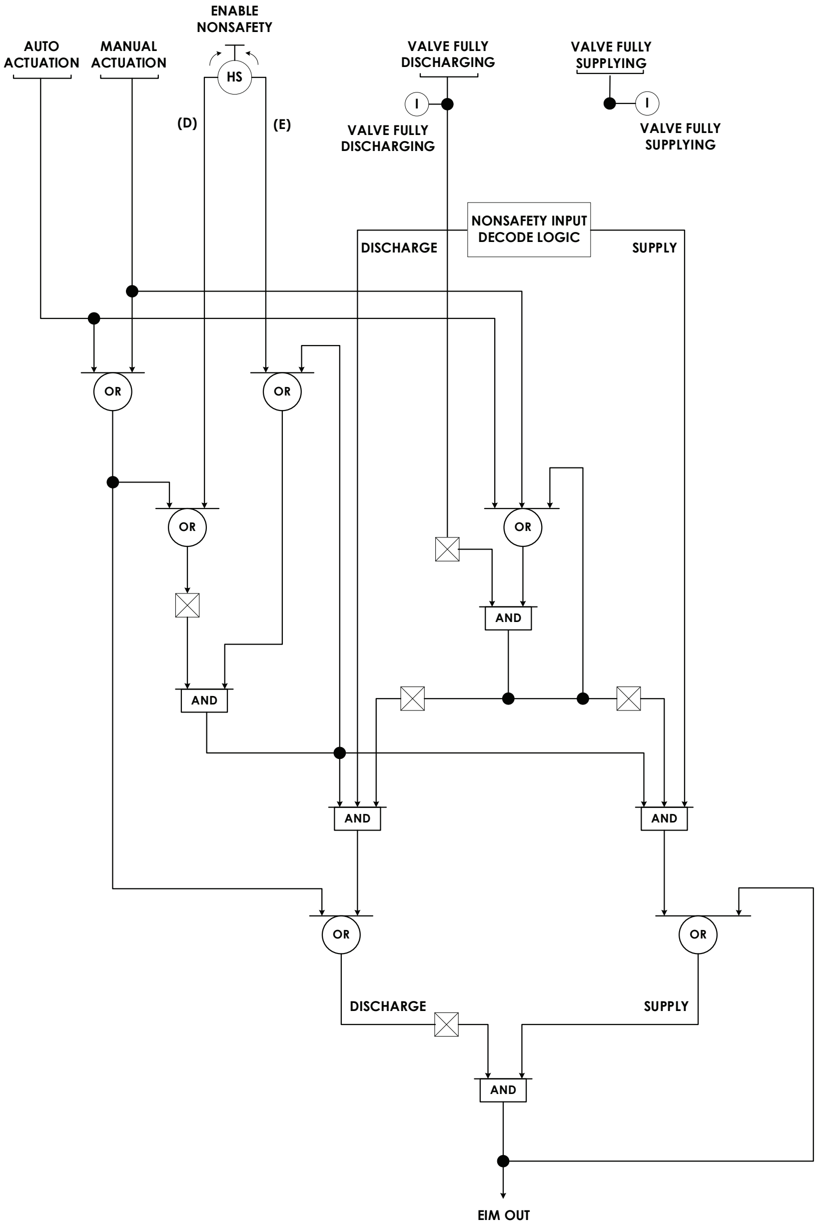


DIV A PVVS CARBON DELAY BED GROUP 1 OUTLET ISOLATION VALVE
DIV A PVVS CARBON DELAY BED GROUP 2 OUTLET ISOLATION VALVE
DIV A PVVS CARBON DELAY BED GROUP 3 OUTLET ISOLATION VALVE
DIV B PVVS CARBON DELAY BED GROUP 1 OUTLET ISOLATION VALVE
DIV B PVVS CARBON DELAY BED GROUP 2 OUTLET ISOLATION VALVE
DIV B PVVS CARBON DELAY BED GROUP 3 OUTLET ISOLATION VALVE

NOTE: OUTPUT OF EIM IS DEENERGIZE TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER

Priority Logic

Figure 7.5-1 – ESFAS Logic Diagrams
(Sheet 25 of 27)

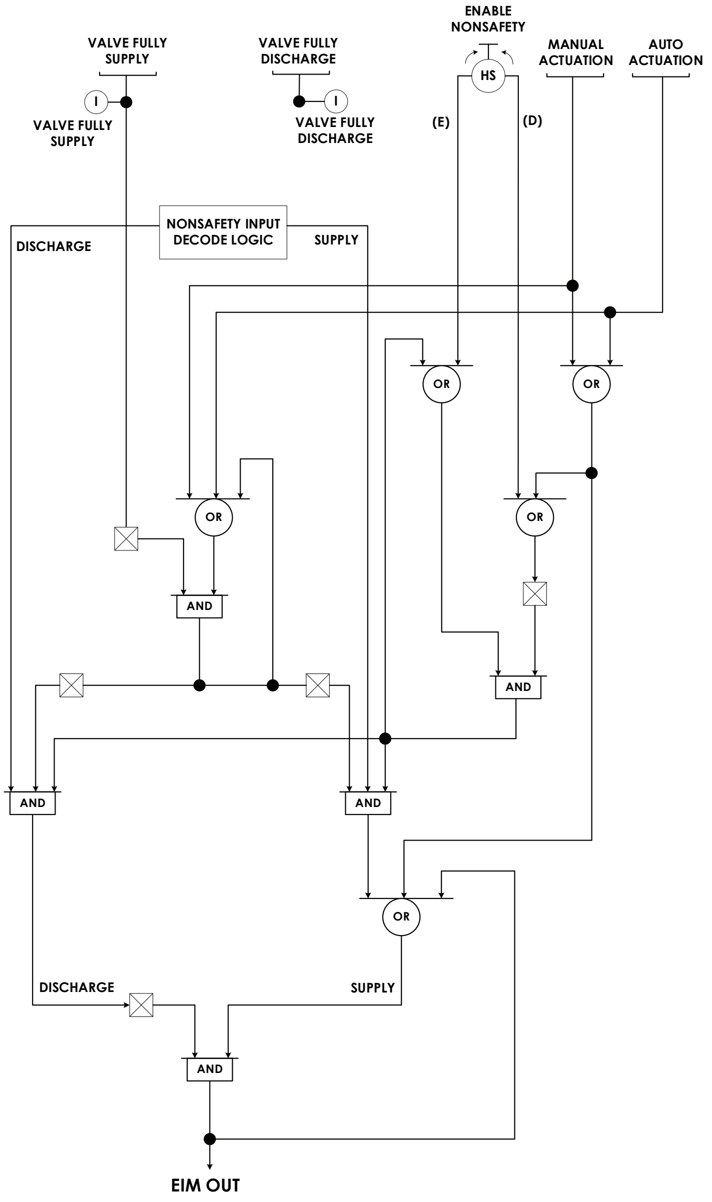


DIV A MEPS A EXTRACTION COLUMN LOWER 3-WAY VALVE
DIV A MEPS B EXTRACTION COLUMN LOWER 3-WAY VALVE
DIV A MEPS C EXTRACTION COLUMN LOWER 3-WAY VALVE
DIV A IXP LOWER 3-WAY VALVE
DIV B MEPS A EXTRACTION COLUMN UPPER 3-WAY VALVE
DIV B MEPS B EXTRACTION COLUMN UPPER 3-WAY VALVE
DIV B MEPS C EXTRACTION COLUMN UPPER 3-WAY VALVE
DIV B IXP UPPER 3-WAY VALVE

NOTE: OUTPUT OF EIM IS DEENERGIZE TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER

Priority Logic

Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 26 of 27)



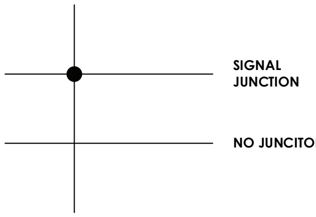
DIV A PVVS CARBON DELAY BED GROUP 1 THREE-WAY VALVE
DIV A PVVS CARBON DELAY BED GROUP 2 THREE-WAY VALVE
DIV A PVVS CARBON DELAY BED GROUP 3 THREE-WAY VALVE
DIV B PVVS CARBON DELAY BED GROUP 1 THREE-WAY VALVE
DIV B PVVS CARBON DELAY BED GROUP 2 THREE-WAY VALVE
DIV B PVVS CARBON DELAY BED GROUP 3 THREE-WAY VALVE

NOTE: OUTPUT OF EIM IS DEENERGIZE TO ACTUATE TO POSITION DEFINED FOR LOSS OF POWER

Priority Logic

Figure 7.5-1 – ESFAS Logic Diagrams (Sheet 27 of 27)

A	ALARM PROVIDED TO PROCESS INTEGRATED CONTROL SYSTEM	RM	RADIATION MONITOR
I	INDICATION PROVIDED TO PROCESS INTEGRATED CONTROL SYSTEM	LS	LEVEL SWITCH
OR	LOGICAL “OR” GATE	ZI	POSITION INDICATION
AND	LOGICAL “AND” GATE	CT	CONDUCTIVITY TRANSMITTER
☒	LOGICAL “NOT” OR INVERTER GATE	PT	PRESSURE TRANSMITTER
XOR	LOGICAL “XOR” GATE	TT	TRITIUM TRANSMITTER
2/3	TWO-OUT-OF-THREE VOTING GATE	TE	TEMPERATURE ELEMENT
1/2	ONE-OUT-OF-TWO VOTING GATE	CO	CARBON MONOXIDE TRANSMITTER
▁▔	BISTABLE – INCREASING SETPOINT	FT	FLOW TRANSMITTER
▔▁	BISTABLE – DECREASING SETPOINT	DI	DISCRETE INPUT
PB	PUSH BUTTON	(A)	AUTOMATIC ACTUATION
HS	THREE POSITION HAND SWITCH, RETURN TO CENTER	(M)	MANUAL ACTUATION
HS	TWO POSITION HAND SWITCH	(E)	ENABLE NONSAFETY “ENABLED”
T = XX Seconds	TIMER THAT INITIATES ON A LOGIC “1”, RESETS ON LOGIC “0” AND OUTPUTS A LOGIC “1” IF TIMER HAS EXPIRED	(D)	ENABLE NONSAFETY “DISABLED”



ACRONYMS
DIV – DIVISION
EIM – EQUIPMENT INTERFACE MODULE
FNHS – FACILITY NITROGEN HANDLING SYSTEM
GBSS – GLOVEBOX STRIPPER SYSTEM
IU – IRRADIATION UNIT
IXP – IODINE AND XENON PURIFICATION SYSTEM
MEPS – MOLYBDENUM EXTRACTION AND PURIFICATION SYSTEM
N2PS – NITROGEN PURGE SYSTEM
PICS – PROCESS INTEGRATED CONTROL SYSTEM
PVVS – PROCESS VESSEL VENTILATION SYSTEM
RCA – RADIOLOGICAL CONTROLLED AREA
RLWI – RADIOLOGICAL LIQUID WASTE IMMOBILIZATION
RVZ1 – RADIOLOGICAL VENTILATION ZONE 1
RVZ2 – RADIOLOGICAL VENTILATION ZONE 2
RVZ3 – RADIOLOGICAL VENTILATION ZONE 3
SSS – STORAGE AND SEPARATION SYSTEM
TPS – TRITIUM PURIFICATION SYSTEM
TSPS – TARGET SOLUTION PREPARATION SYSTEM
VTS – VACUUM TRANSFER SYSTEM

Legend

Figure 7.5-4 – Radiologically Controlled Area Isolation (Sheet 1 of 2)

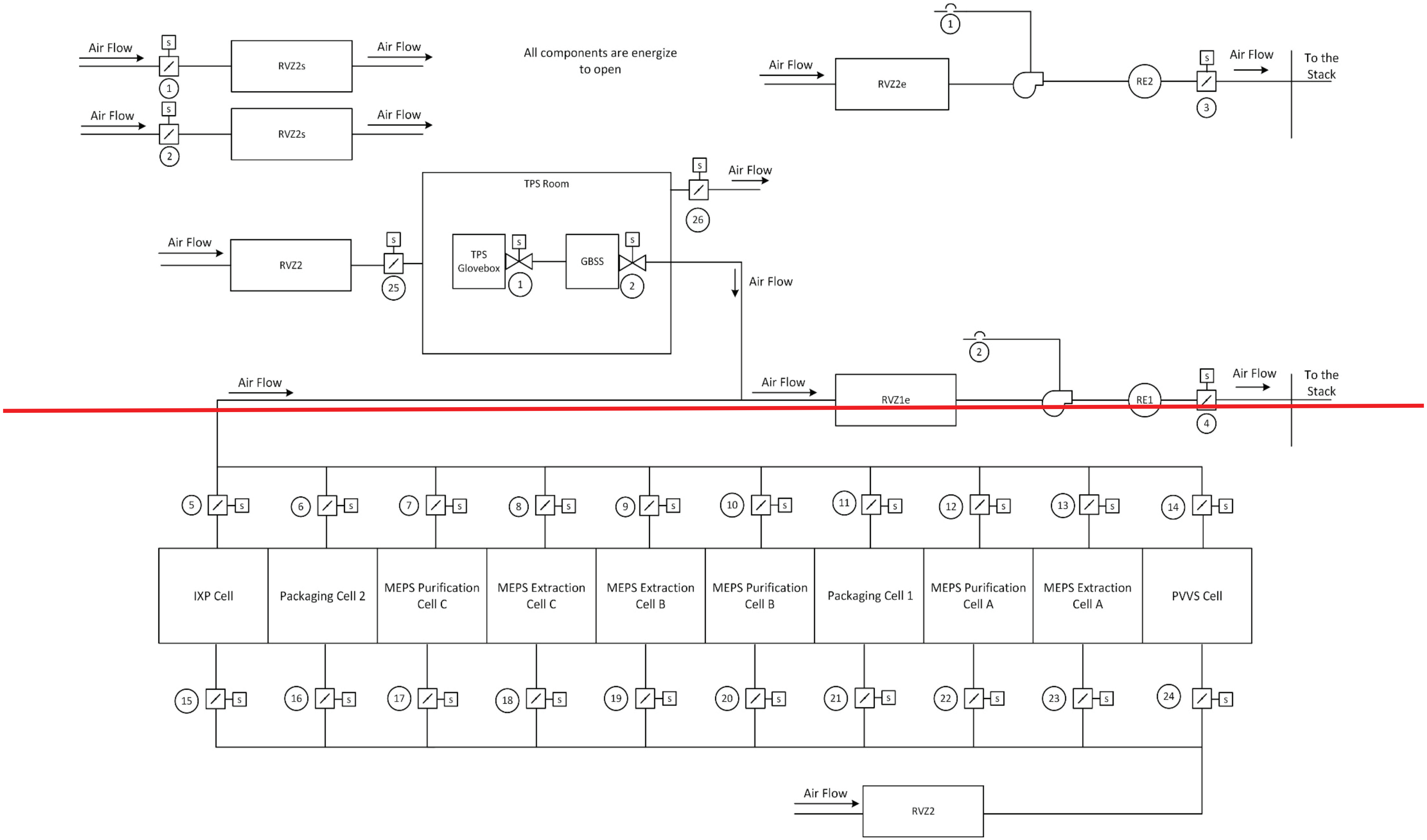


Figure 7.5-4 – Radiologically Controlled Area Isolation (Sheet 2 of 2)

Damper 1 – RVZ2 train 1 RCA supply damper
Damper 2 – RVZ2 train 2 RCA supply damper
Damper 3 – RVZ2 RCA exhaust damper
Damper 4 – RVZ1 RCA exhaust damper
Damper 5 – 14 – supercell outlet isolation dampers
Damper 15 – 24 – supercell inlet isolation dampers
Damper 25 – TPS room inlet isolation damper
Damper 26 – TPS room outlet isolation damper

Breaker 1 – RVZ1 blower breaker
Breaker 2 – RVZ2 blower breaker

Valve 1 – TPS glovebox isolation valve
Valve 2 – GBSS isolation valve

RE1 – RVZ1 RCA exhaust radiation detector
RE2 – RVZ2 RCA exhaust radiation detector

RCA Isolation

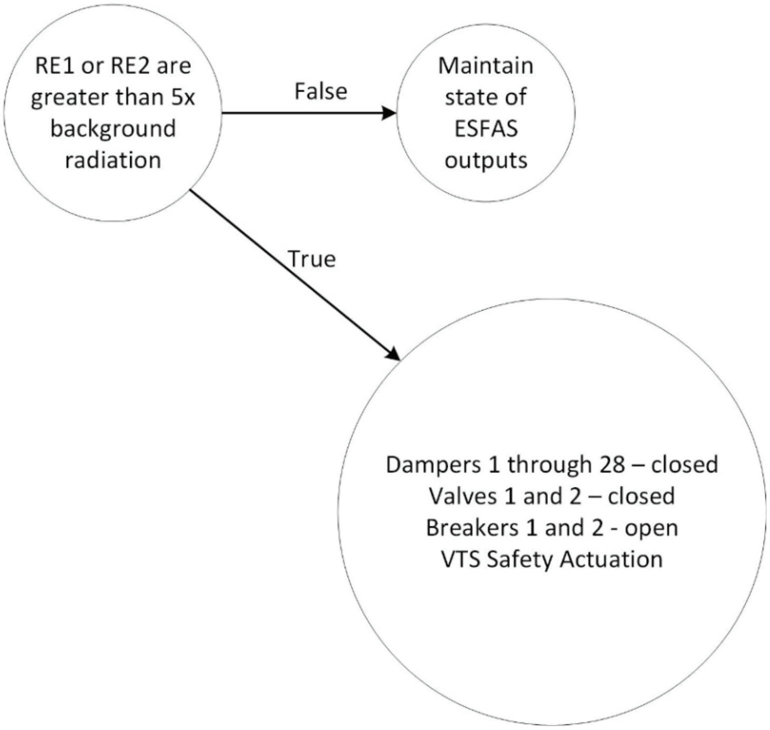


Figure 7.5-4 – Radiologically Controlled Area Isolation (Sheet 1 of 2)

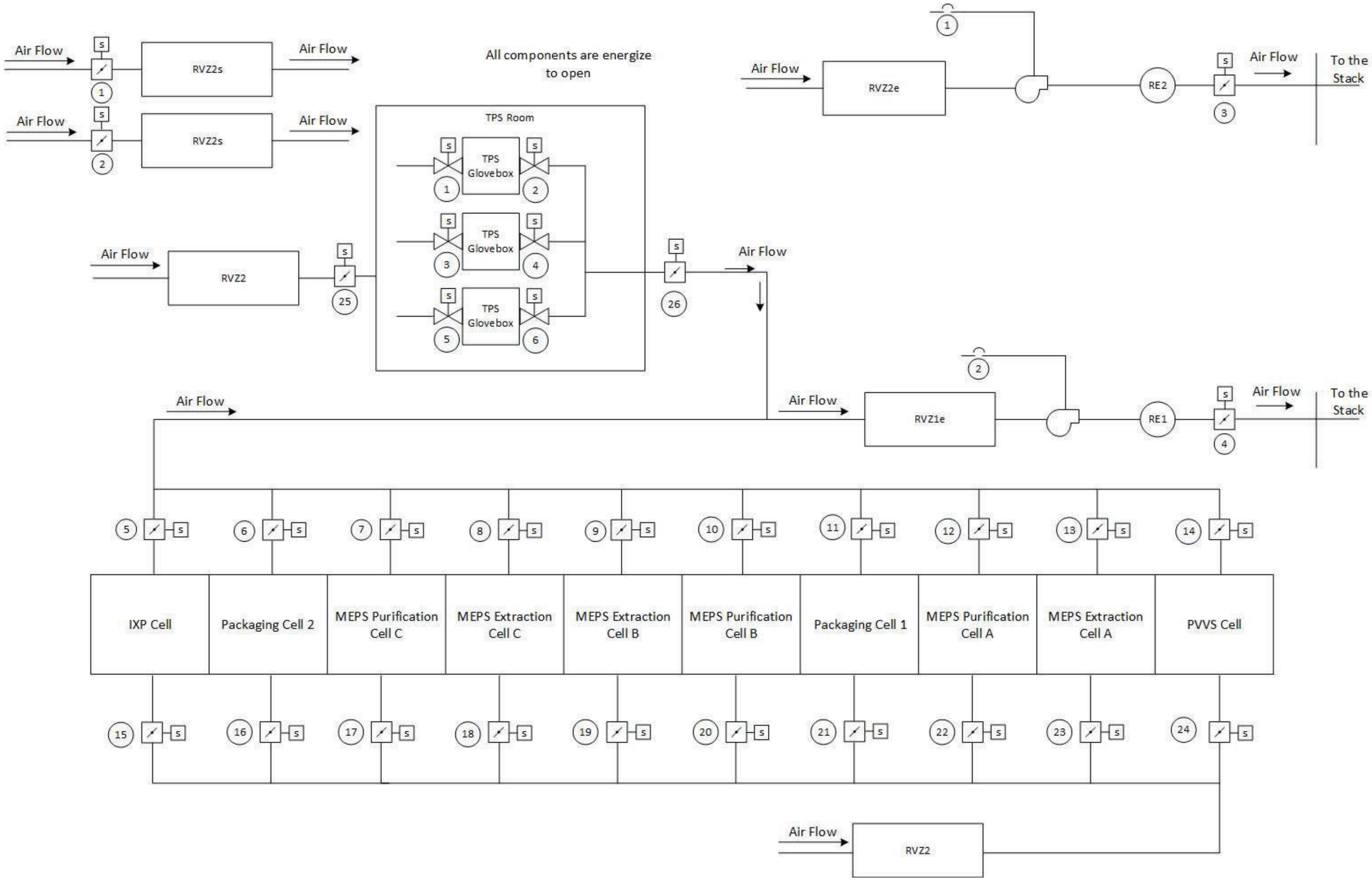


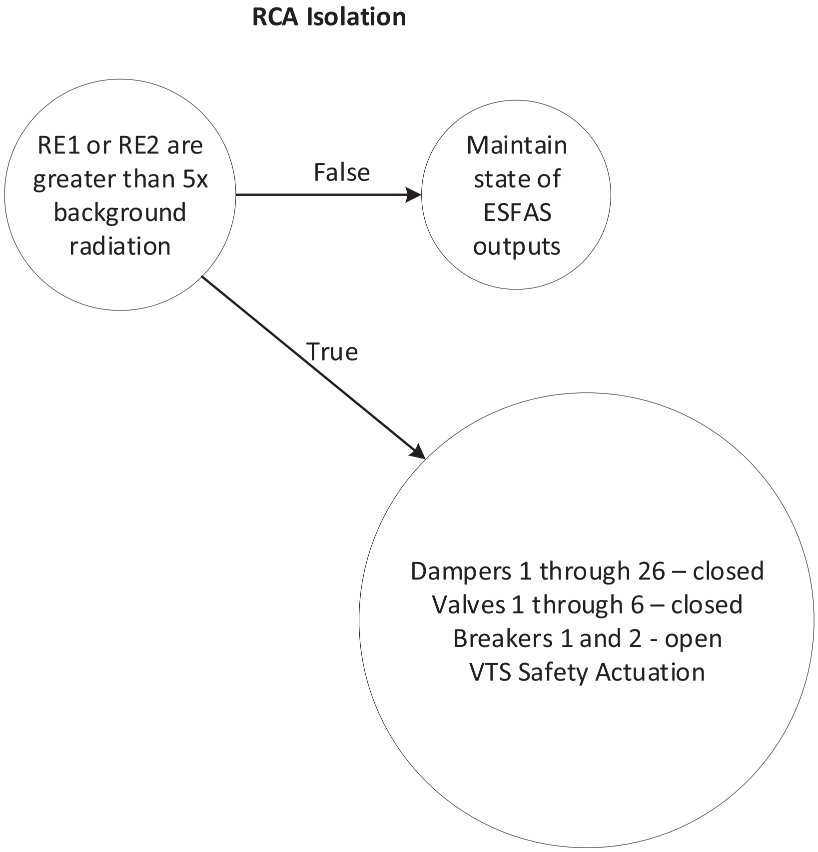
Figure 7.5-4 – Radiologically Controlled Area Isolation (Sheet 2 of 2)

Damper 1 – RVZ2 train 1 RCA supply damper
Damper 2 – RVZ2 train 2 RCA supply damper
Damper 3 – RVZ2 RCA exhaust damper
Damper 4 – RVZ1 RCA exhaust damper
Damper 5 – 14 – supercell outlet isolation dampers
Damper 15 – 24 – supercell inlet isolation dampers
Damper 25 – TPS room inlet isolation damper
Damper 26 – TPS room outlet isolation damper

Breaker 1 – RVZ1 blower breaker
Breaker 2 – RVZ2 blower breaker

Valve 1 – TPS train A RVZ1e valve
Valve 2 – TPS train A confinement valves
Valve 3 – TPS train B RVZ1e valve
Valve 4 – TPS train B confinement valves
Valve 5 – TPS train C RVZ1e valve
Valve 6 – TPS train C confinement valves

RE1 – RVZ1 RCA exhaust radiation detector
RE2 – RVZ2 RCA exhaust radiation detector



The following codes and standards are applied to the design of the safety-related process radiation monitors:

- Institute of Electrical and Electronics Engineers (IEEE) 344-2013, Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations (IEEE, 2013), Section 8, for seismic qualification of radiation monitors

7.7.1.5 Operation and Performance

The safety-related process radiation monitors are designed to operate under normal conditions, during anticipated transients, and during design basis accidents such that they will perform their safety function.

Functionality

TRPS process radiation monitors monitor the ventilation line from the primary closed loop cooling system (PCLS) expansion tanks, which are located in each irradiation unit (IU) cell. These monitors provide an actuation signal when radiation levels exceed pre-determined limits, indicative of a release of target solution or fission products within the PCLS or the primary confinement atmosphere (with which the tank communicates). The actuation results in an IU Cell Safety Actuation for that unit.

ESFAS process monitors associated with the supercell monitor the ventilation exhaust from each hot cell and provide an actuation signal when radiation levels exceed pre-determined limits, indicative of a release of target solution or fission products within that hot cell. The actuation results in isolation of the affected hot cell.

ESFAS process monitors associated with the radiological ventilation zone 1 (RVZ1) and radiological ventilation zone 2 (RVZ2) exhaust are designed to provide an actuation signal when radiation levels in the RCA ventilation exhaust systems exceed pre-determined limits, indicative of a failure of a confinement boundary within the facility. The actuation results in isolation of RVZ1, RVZ2, and radiological ventilation zone 3 (RVZ3) ventilation.

The TPS process monitors associated with ~~the TPS glovebox~~tritium confinement are designed to provide an actuation signal when tritium concentrations within the TPS gloveboxes exceed predetermined limits, indicative of a failure of TPS process equipment and release of tritium into the TPS glovebox. The actuation results in isolation of the ~~glovebox~~tritium confinement and ventilation associated with the TPS room.

The TPS ~~process~~tritium monitors associated with the TPS ~~glovebox stripper system (GBSS)~~ exhaust to facility stack are designed to provide an actuation signal when tritium concentrations in the TPS exhaust ~~of the GBSS~~to facility stack exceed predetermined limits, indicative of a ~~failure of the GBSS or~~ release of tritium ~~into~~out of the TPS ~~glovebox~~. The actuation results in isolation of the ~~glovebox and~~ TPS process vent exhaust lines and ventilation associated with the TPS room.

~~The TPS process monitors associated with each IU gas return line are designed to provide an interlock to prevent transition to Mode 2 (irradiation) when [~~

~~]$^{PROP/ECI}$.~~

Table 7.7-1 – Safety-Related Process Radiation Monitors
(Sheet 2 of 5)

Unit	Monitored Material	Monitored Location	Unit Location	Function	Total Available Divisions	Minimum Required Divisions	Operability Requirements
8	Fission products	Supercell exhaust ventilation	Supercell exterior	Detect elevated radiation levels from purification cell C (input to ESFAS)	2	2	Whenever radioisotope products are present in the hot cell and hot cell isolation dampers are not closed
9	Fission products	Supercell exhaust ventilation	Supercell exterior	Detect elevated radiation levels from packaging cell 2 (input to ESFAS)	2	2	
10	Fission products	Supercell exhaust ventilation	Supercell exterior	Detect elevated radiation levels from iodine and xenon purification cell (input to ESFAS)	2	2	
11	Fission products	RVZ1 exhaust	Mezzanine (RPF general area)	Detect elevated radiation levels from RVZ1 RCA exhaust (input to ESFAS)	3	2	Whenever facility operations are not secured or RVZ isolation dampers are not closed
12	Fission products	RVZ2 exhaust	Mezzanine (RPF general area)	Detect elevated radiation levels from RVZ2 RCA exhaust (input to ESFAS)	3	2	
13	Tritium	TPS confinement A ~~glovebox~~ atmosphere	TPS room	Detect elevated tritium concentration in tritium purification system ~~glovebox~~confinement (input to ESFAS)	~~3~~2	2	Whenever tritium is present in the TPS ~~glovebox~~confinement in gaseous form
14	Tritium	TPS confinement B atmosphere	TPS room	Detect elevated tritium concentration in tritium purification system confinement (input to ESFAS)	2	2	Whenever tritium is present in the TPS confinement in gaseous form

Table 7.7-1 – Safety-Related Process Radiation Monitors (Sheet 3 of 5)

Unit	Monitored Material	Monitored Location	Unit Location	Function	Total Available Divisions	Minimum Required Divisions	Operability Requirements
15	Tritium	TPS confinement C atmosphere	TPS room	Detect elevated tritium concentration in tritium purification system confinement (input to ESFAS)	2	2	Whenever tritium is present in the TPS confinement in gaseous form
~~14~~16	Tritium	~~GBSS~~TPS exhaust	TPS room	Detect elevated tritium concentration in tritium purification system ~~glovebox stripper system~~ exhaust to RVZ1e (input to ESFAS)	3	2	Whenever tritium is present in the TPS ~~glovebox~~exhaust to RVZ1e in gaseous form and TPS confinement isolation devices are not closed
~~15~~	~~Tritium~~	~~IU 1 Accelerator TPS Interface System (ATIS) glovebox~~	~~IF general area~~	~~Detect tritium concentration in ATIS return line from IU 1 (input to TRPS)~~	~~2~~	~~2~~	~~Mode 1 (Startup)~~ ~~and~~ ~~Mode 2 (Irradiation)~~
~~16~~	~~Tritium~~	~~IU 2 ATIS glovebox~~	~~IF general area~~	~~Detect tritium concentration in ATIS return line from IU 2 (input to TRPS)~~	~~2~~	~~2~~	

Table 7.7-1 – Safety-Related Process Radiation Monitors
(Sheet 4 of 5)

Unit	Monitored Material	Monitored Location	Unit Location	Function	Total Available Divisions	Minimum Required Divisions	Operability Requirements
~~17~~	~~Tritium~~	~~IU 3 ATIS glovebox~~	~~IF general area~~	~~Detect tritium concentration in ATIS return line from IU 3 (input to TRPS)~~	~~2~~	~~2~~	~~Mode 1 (Startup)~~ ~~and~~ ~~Mode 2 (Irradiation)~~
~~18~~	~~Tritium~~	~~IU 4 ATIS glovebox~~	~~IF general area~~	~~Detect tritium concentration in ATIS return line from IU 4 (input to TRPS)~~	~~2~~	~~2~~	
~~19~~	~~Tritium~~	~~IU 5 ATIS glovebox~~	~~IF general area~~	~~Detect tritium concentration in ATIS return line from IU 5 (input to TRPS)~~	~~2~~	~~2~~	
~~20~~	~~Tritium~~	~~IU 6 ATIS glovebox~~	~~IF general area~~	~~Detect tritium concentration in ATIS return line from IU 6 (input to TRPS)~~	~~2~~	~~2~~	
~~21~~	~~Tritium~~	~~IU 7 ATIS glovebox~~	~~IF general area~~	~~Detect tritium concentration in ATIS return line from IU 7 (input to TRPS)~~	~~2~~	~~2~~	
~~22~~	~~Tritium~~	~~IU 8 ATIS glovebox~~	~~IF general area~~	~~Detect tritium concentration in ATIS return line from IU 8 (input to TRPS)~~	~~2~~	~~2~~	
~~23~~17	Fission products	IU 1 primary closed loop cooling system (PCLS) expansion tank exhaust	Cooling room	Detect elevated radiation levels from IU 1 PCLS expansion tank exhaust (input to TRPS)	3	2	Modes 1 through 4
~~24~~18	Fission products	IU 2 PCLS expansion tank exhaust	Cooling room	Detect elevated radiation levels from IU 2 PCLS expansion tank exhaust (input to TRPS)	3	2	Modes 1 through 4

Table 7.7-1 – Safety-Related Process Radiation Monitors
(Sheet 5 of 5)

Unit	Monitored Material	Monitored Location	Unit Location	Function	Total Available Divisions	Minimum Required Divisions	Operability Requirements
~~25~~19	Fission products	IU 3 PCLS expansion tank exhaust	Cooling room	Detect elevated radiation levels from IU 3 PCLS expansion tank exhaust (input to TRPS)	3	2	Modes 1 through 4
~~26~~20	Fission products	IU 4 PCLS expansion tank exhaust	Cooling room	Detect elevated radiation levels from IU 4 PCLS expansion tank exhaust (input to TRPS)	3	2	Modes 1 through 4
~~27~~21	Fission products	IU 5 PCLS expansion tank exhaust	Cooling room	Detect elevated radiation levels from IU 5 PCLS expansion tank exhaust (input to TRPS)	3	2	Modes 1 through 4
~~28~~22	Fission products	IU 6 PCLS expansion tank exhaust	Cooling room	Detect elevated radiation levels from IU 6 PCLS expansion tank exhaust (input to TRPS)	3	2	Modes 1 through 4
~~29~~23	Fission products	IU 7 PCLS expansion tank exhaust	Cooling room	Detect elevated radiation levels from IU 7 PCLS expansion tank exhaust (input to TRPS)	3	2	Modes 1 through 4
~~30~~24	Fission products	IU 8 PCLS expansion tank exhaust	Cooling room	Detect elevated radiation levels from IU 8 PCLS expansion tank exhaust (input to TRPS)	3	2	Modes 1 through 4

shall ensure at least two decades of overlap in indication is maintained while observation is transferred from one channel to another.

NFDS Criterion 3 – The NFDS power range channels shall provide reliable TSV power level while the source range channel provides count rate information from detectors that directly monitor the neutron flux.

NFDS Criterion 4 – The NFDS log power range channel (i.e., wide range channel) and a linear flux monitoring channel (i.e., power range channel) shall accurately sense neutrons during irradiation, even in the presence of intense high gamma radiation.

NFDS Criterion 5 – The NFDS shall provide redundant TSV power level indication through the licensed maximum power range.

NFDS Criterion 6 – The location and sensitivity of at least one NFDS detector in the source range channel, along with the location and emission rate of the subcritical multiplication source, shall be designed to ensure that changes in reactivity will be reliably indicated even with the TSV shut down.

NFDS Criterion 7 – The NFDS shall have at least one detector in the power range channel to provide reliable readings to a predetermined power level above the licensed maximum power level.

NFDS Criterion 8 – The NFDS shall be separated from the PICS to the extent that any removal of a component or channel common to both the NFDS and the PICS preserves the reliability, redundancy, and independence of the NFDS.

NFDS Criterion 9 – The NFDS detectors shall be qualified for continuous submerged operation within the light water pool. The NFDS detector housings shall be watertight and supported by a sleeve structure, mounted to the SASS, at specific locations surrounding the SASS.

NFDS Criterion 10 – The timing of NFDS communications shall be deterministic.

7.8.2.2 Single Failure

NFDS Criterion 1~~2~~1 – The NFDS shall be designed to perform its protective functions after experiencing a single random active failure in nonsafety control systems or in the NFDS, and such failure shall not prevent the NFDS from performing its intended functions or prevent safe shutdown of an IU cell.

NFDS Criterion 1~~3~~2 – The NFDS shall be designed such that no single failure can cause the failure of more than one redundant component.

7.8.2.3 Independence

NFDS Criterion 1~~4~~3 – Physical separation and electrical isolation shall be used to maintain the independence of NFDS circuits and equipment among redundant safety divisions or with nonsafety systems so that the safety functions required during and following any maximum hypothetical accident or postulated accident can be accomplished.

NFDS Criterion 1~~5~~4 – The NFDS shall be designed such that no communication – within a single safety channel, between safety channels, and between safety and nonsafety systems – adversely affects the performance of required safety functions.

7.8.2.4 Fail Safe

NFDS Criterion 1~~6~~5 – The NFDS and associated components shall be designed to assume a safe state on loss of electrical power.

NFDS Criterion 1~~7~~6 – The NFDS shall not be designed to fail or operate in a mode that could prevent the TRPS from performing its intended safety function. The design of the NFDS shall consider:

1) The effect of NFDS on accidents
2) The effects of NFDS failures
3) The effects of NFDS failures caused by accidents.

The failure analyses shall cover hardware and software failures associated with the NFDS.

7.8.2.5 Setpoints

NFDS Criterion 1~~8~~7 – Neutron flux setpoints for an actuation of the NFDS shall be based on a documented analysis methodology that identifies assumptions and accounts for uncertainties, such as environmental allowances and measurement computational errors associated with each element of the instrument channel. The setpoint analysis parameters and assumptions shall be consistent with the safety analysis, system design basis, technical specifications, facility design, and expected maintenance practices.

NFDS Criterion 1~~9~~8 – Adequate margin shall exist between setpoints and safety limits so that the TRPS initiates protective actions before safety limits are exceeded.

NFDS Criterion ~~20~~19 – The sensitivity of each NFDS sensor channel shall be commensurate with the precision and accuracy to which knowledge of the variable measured is required for the protective function.

7.8.2.6 Equipment Qualification

NFDS Criterion 2~~1~~0 – The effects of electromagnetic interference/radio-frequency interference (EMI/RFI) and power surges on the NFDS shall be adequately addressed.

7.8.2.7 Surveillance

NFDS Criterion 2~~2~~1 – The NFDS shall provide the capability for calibration, inspection, and testing to validate the desired functionality of the NFDS.

NFDS Criterion 2~~3~~2 – Equipment in the NFDS (from the input circuitry to output actuation circuitry) shall be designed to allow testing, calibration, and inspection to ensure operability. If testing is required or can be performed as an option during operation, the NFDS shall retain the capability to accomplish its safety function while under test.

NFDS Criterion 2~~4~~3 – Testing, calibration, and inspections of the NFDS shall be sufficient to confirm that surveillance test and self-test features address failure detection, self-test capabilities, and actions taken upon failure detection.

NFDS Criterion 2~~5~~4 – The design of the NFDS and the justification for test intervals shall be consistent with the surveillance testing intervals as part of the facility technical specifications.

7.8.2.8 Classification and Identification

NFDS Criterion 2~~6~~5 – NFDS equipment shall be distinctively identified to indicate its safety classification and to associate equipment according to divisional or channel assignments.

7.8.2.9 Human Factors

NFDS Criterion 2~~7~~6 – The NFDS shall be designed to provide the information necessary to support annunciation of the channel initiating a protective action to the operator.

7.8.2.10 Quality

NFDS Criterion 2~~8~~7 – Controls over the design, fabrication, installation, and modification of the NFDS shall conform to the guidance of ANSI/ANS 15.8-1995, Quality Assurance Program Requirements for Research Reactors (ANSI/ANS, 1995), as endorsed by Regulatory Guide 2.5, Quality Assurance Program Requirements for Research and Test Reactors (USNRC, 2010).

NFDS Criterion 2~~9~~8 – The quality of the components and modules in the NFDS shall be commensurate with the importance of the safety function to be performed.

7.8.3 DESIGN BASIS

The NFDS monitors neutron flux levels inside the target solution vessel and provides signals to the TRPS that predetermined limits have been reached or exceeded as well as continuous indication of flux level to assist in the TRPS initiating its safety functions.

7.8.3.1 Monitored Variables

The NFDS measures the flux over three separate ranges, source range, wide range, and power range. The source range measures low flux levels common to what would be expected during the filling cycle prior to irradiation of the target solution. The power range measures high flux levels in the ranges that are expected when the neutron driver is operating and irradiating the target solution. The wide range connects the gap between the source range and the power range with overlap and is usable during both source and power range levels.

In the source range, individual pulses are created as a result of neutron interaction with the detector and are recorded by the NFDS. The range of the source range measurement counts pulses up to 1.0E+05 counts per second (cps). The inverse of the count rate can also be used to estimate the critical fill level using the 1/M methodology.

In the power range, the neutron flux is measured in terms of the design power levels of the TSV. The range of measurement of the power range is indicated as 0 percent to 125 percent.

7.8.4.6 Equipment Qualification

NFDS rack mounted equipment is installed in a mild operating environment and is designed to meet the environmental conditions described in Subsection 7.8.3.3. Rack mounted TRPS equipment is tested to appropriate standards to show that the effects of EMI/RFI and power surges are adequately addressed. Appropriate grounding of the NFDS is performed in accordance with Section 5.2.1 of Institute of Electrical and Electronics Engineers (IEEE) Standard 1050-2004, IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations (IEEE, 2004b).

7.8.4.7 Surveillance

The NFDS supports testing and calibration to ensure operability as required by the technical specifications. The NFDS is designed to allow operators to remove portions of the NFDS from service when not required for operation without impacting NFDS components specific to other IU cells. As an all analog system, the only form of fault detection normally available is the “source range missing” and “power range missing” discrete signals provided to the PICS.

7.8.4.8 Classification and Identification

Each division of the NFDS is uniquely labeled and identified in accordance with SHINE identification and classification procedures.

7.8.4.9 Human Factors

The NFDS provides the following signals to the TRPS to transmit to the PICS for display to the operator:

- Source range neutron flux
- Source range rate
- Wide range neutron flux
- Wide range rate
- Power range neutron flux
- Source range missing signal
- Power range missing signal

Operator display criteria and design are addressed in Section 7.6.

7.8.4.10 Codes and Standards

The following codes and standards are applied to the NFDS design:

1) Section 8 of IEEE Standard 344-2013, IEEE Standard for Seismic Qualification of Equipment for Nuclear Power Generating Stations (IEEE, 2013); invoked as guidance to meet SHINE Design Criterion 2, Natural phenomena hazards.
2) IEEE Standard 379-2000, IEEE Standard Application of the Single-Failure Criterion to Nuclear Power Generating Station Safety Systems (IEEE, 2000); invoked to meet SHINE Design Criterion 1~~3~~5, ~~Instrumentation and controls~~Protection system reliability and testability.

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
AC	alternating current
BT	bus train
CAAS	criticality accident alarm system
CAMS	continuous air monitoring system
DC	direct current
EMI	electromagnetic interference
ESFAS	engineered safety features actuation system
FDCS	facility data and communications system
FFPS	facility fire detection and suppression
FVZ4	facility ventilation zone 4
~~GBSS~~	~~glovebox stripper system~~
HCFD	hot cell fire detection and suppression system
HVAC	heating, ventilation, and air conditioning
Hz	hertz
IEEE	Institute of Electrical and Electronics Engineers

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
RVZ1	radiological ventilation zone 1
RVZ1e	radiological ventilation zone 1 exhaust subsystem
RVZ2	radiological ventilation zone 2
RVZ2e	radiological ventilation zone 2 exhaust subsystem
RVZ2s	radiological ventilation zone 2 supply subsystem
SEC	secondary enclosure cleanup
SGS	standby generator system
SRM	stack release monitor
SRMS	stack release monitor system
TPS	tritium purification system
TOGS	TSV off-gas system
TRPS	TSV reactivity protection system
TSV	target solution vessel
UP	utility power
UPSS	uninterruptible electrical power supply system

Each battery charger supplies power to the safety-related 125 VDC bus for its division. The loads on each DC bus consist of the following:

- Engineered safety features actuation system (ESFAS)
- Target solution vessel (TSV) reactivity protection system (TRPS)
- TSV off-gas system (TOGS) recombiner heaters
- Nitrogen purge system (N2PS) solenoid valves
- TSV dump valves

~~Separate feeds connected to the 125 VDC bus, isolated from the safety-related portion of the bus by isolation overcurrent devices (fuses), provide power to the following nonsafety-related load:~~

- ~~TPS glovebox stripper system (GBSS) heaters~~

~~The TPS GBSS heaters are associated equipment, as defined in Section 4.5.2 of IEEE 384 (IEEE, 2008).~~

Each 125 VDC bus supplies power to an associated 208Y/120 VAC bus via an inverter. The two 208Y/120 VAC buses can also each receive power directly from the associated emergency 480 VAC NPSS bus through a bypass transformer. The safety-related loads on each AC bus consist of the following:

- ESFAS radiation monitors
- TRPS radiation monitors
- ~~TPS GBSS tritium monitors~~
- TPS ~~glovebox~~ tritium monitors
- Neutron driver assembly system (NDAS) high voltage power supply breaker undervoltage hold circuits
- Vacuum transfer system (VTS) vacuum pump breaker undervoltage hold trip circuits
- Molybdenum extraction and purification system (MEPS) undervoltage hold trip circuits
- Radiological ventilation zone 1 (RVZ1) exhaust subsystem (RVZ1e) exhaust fans, Radiological ventilation zone 2 (RVZ2) exhaust subsystem (RVZ2e) exhaust fans, and RVZ2 supply subsystem (RVZ2s) air handling units undervoltage hold trip circuits
- TOGS blowers
- Neutron flux detection system (NFDS) power cabinets and detectors for the associated division

Separate distribution panels connected to the 208Y/120 VAC bus, isolated from the safety-related portion of the bus by isolation overcurrent devices, provide power to nonsafety-related loads important for providing alerts to facility personnel and for monitoring the status of the facility.

These loads consist of:

- Main facility stack release monitor (SRM)
- Process vessel vent system (PVVS) carbon delay bed effluent monitor
- TPS ~~GBSS~~secondary enclosure cleanup (SEC) blowers
- Criticality accident alarm system (CAAS)

Additional details about the UPSS loads are provided in Table 8a2.2-1.

Upon a loss of NPSS power and unavailability of SGS power, the AC and DC UPSS buses are powered by the safety-related battery bank for each division. Each UPSS division is located in a separate fire area in the safety-related, seismic portion of the main production facility. The UPSS is required to perform its safety function before, during, and after a seismic event, and is qualified by one of the testing methods described in Chapter 8 of IEEE 344 (IEEE, 2004).

The battery sizing for the UPSS loads is shown in Table 8a2.2-2, using the sizing guidance provided in Sections 6.1.1, 6.2.1, 6.2.2, 6.2.3, 6.2.4, 6.3.2 and 6.3.3 of IEEE 485 (IEEE, 2010). Batteries are vented lead-acid. Transfer of loads from the NPSS to the UPSS is automatic and requires no control power.

The required reserve for loads is listed in Table 8a2.2-2. 15 percent of the total is reserved to accommodate variations of power during equipment procurement and an additional 10 percent is initially reserved for future needs that may be identified during the lifetime of the facility.

The run time requirements in Table 8a2.2-2 are based on:

1) Equipment required to prevent hydrogen deflagration is powered for five minutes,
2) Equipment used to minimize transient effects on the facility due to short duration power loss is powered for five minutes,
3) Equipment used to provide alerts for facility personnel and monitor the status of the facility during immediate recovery efforts is powered for two hours, or
4) Defense-in-depth power for nonsafety-related equipment used to monitor and reduce the tritium source term in the ~~TPS glove box stripper system~~tritium confinement is powered for six hours. |

The UPSS is designed and tested to be resistant to the electromagnetic interference (EMI)/radio frequency interference (RFI) environment. When equipment (e.g., portable radios) poses risks to the UPSS equipment or distribution wiring, administrative controls prevent the use of the equipment where it can adversely affect the UPSS.

8a2.2.4 STANDBY GENERATOR SYSTEM DESIGN BASIS

The design of the SGS is based on Criterion 27, Electrical power systems, and Criterion 28, Inspection and testing of electric power systems, of the SHINE design criteria. The SHINE design criteria are described in Section 3.1.

The purpose of the SGS is to provide a temporary source of nonsafety-related alternate power to the UPSS and selected additional loads for operational convenience and defense-in-depth.

The SGS:

- Will provide for the separation or isolation of safety-related circuits from nonsafety-related circuits, including the avoidance of electromagnetic interference with safety-related instrumentation and control functions;
- Will provide an alternate source of power for the safety-related electrical buses;
- Will provide an alternate source of power to systems required for life-safety or important for facility monitoring;
- Will automatically start and supply loads upon a loss of off-site power; and

8a2.2.5 STANDBY GENERATOR SYSTEM CODES AND STANDARDS

The SGS is designed in accordance with NFPA 70 - 2017, National Electrical Code (NFPA, 2017) as adopted by the State of Wisconsin (Chapter SPS 316 of the Wisconsin Administrative Code, Electrical).

8a2.2.6 STANDBY GENERATOR SYSTEM DESCRIPTION

The SGS consists of a 480Y/277 VAC, 60 Hertz (Hz) natural gas-driven generator, a 480 VAC switchgear, and two SGS cross-tie breakers to allow the SGS switchgear to be connected to either or both emergency 480 VAC NPSS buses. Upon a loss of off-site power (LOOP) (i.e., undervoltage or overvoltage sensed on utility service), the SGS automatically starts, both non-vital breakers (NV BKR 1 and NV BKR 2) automatically open, and the associated SGS cross-tie breakers (SGS BKR 1 and SGS BKR 2) automatically close to provide power to the associated emergency 480 VAC NPSS bus.

The loads supplied by the SGS include the loads supplied by the UPSS (see Table 8a2.2-1), as well as the following facility loads:

- Emergency lighting
- Facility data and communications system (FDCS) equipment
- Radiation area monitoring system (RAMS) detectors
- Continuous air monitoring system (CAMS) detectors
- Facility fire detection and suppression system (FFPS)
- Hot cell fire detection and suppression system (HCFD)
- PICS equipment
- PVVS equipment
- TPS SEC heaters
- Switchgear station batteries (NPSS, SGS)
- Facility access control system (FACS)
- Facility ventilation zone 4 (FVZ4) UPSS battery room and equipment room exhaust fans
- FDCS dedicated cooling systems

FDCS equipment, PICS equipment, and the FFPS contain nonsafety-related unit batteries or local uninterruptible power supplies to provide power to span the time between the LOOP event and the start of the SGS.

Emergency lighting located inside the main production facility is provided with unit batteries capable of supplying 90 minutes of illumination.

Operation of the SGS is not required for any safety function at the SHINE facility.

8a2.2.7 EMERGENCY ELECTRICAL POWER SYSTEM OPERATION

Electrical loads for the main production facility, site, and support buildings are normally supplied by the NPSS, as described in Section 8a2.1. When the NPSS is in operation, it supplies power to the UPSS battery chargers, which provide power to the loads on the 125 VDC bus and to the 208Y/120 VAC loads via the UPSS inverter. The battery charger is used to keep the battery bank fully charged and maintained at float charge.

Table 8a2.2-1 – UPSS Load List
(Sheet 1 of 2)

Load Description	kVA Loads UPS-A	kVA Loads UPS-B	Required Runtime
Target solution vessel (TSV) off-gas system (TOGS)			
Blowers (8)	48.1	48.1	5 Min
Recombiner heaters (16)	32.0	32.0	5 Min
Nitrogen purge system (N2PS) valves	2.2	2.2	5 Min
TSV dump valves	3.0	3.0	5 Min
Neutron flux detection system (NFDS)	12.0	12.0	120 Min
TSV reactivity protection system (TRPS)	1.5	1.5	120 Min
TRPS radiation monitors	7.7	7.7	120 Min
Engineered safety features actuation system (ESFAS) radiation monitors	7.7	7.7	120 Min
Neutron driver assembly system (NDAS) hold circuits (8)	0.5	0.5	120 Min
Vacuum transfer system (VTS) hold circuits (3)	0.2	0.2	120 Min
Molybdenum extraction and purification system (MEPS) pump hold circuits (3)	0.2	0.2	120 Min
Radiological ventilation exhaust and supply fans hold circuit	0.4	0.4	120 Min
ESFAS	0.5	0.4	6 Hrs
Tritium purification system (TPS) tritium monitors (~~6~~9)	~~1.0~~1.2	~~1.0~~1.2	6 Hrs
Criticality accident alarm system (CAAS), nonsafety-related	0.9	0.9	120 Min
Stack release monitoring system (SRMS), nonsafety-related	0.0	3.8	120 Min

Table 8a2.2-1 – UPSS Load List
(Sheet 2 of 2)

Load Description	kVA Loads UPS-A	kVA Loads UPS-B	Required Runtime
TPS ~~glovebox stripper system (GBSS)~~secondary enclosure cleanup (SEC) blowers (3), nonsafety-related	~~0.8~~0.2	~~0.8~~0.3	6 Hrs
~~Blowers~~			
~~Heaters~~	~~2.0~~	~~2.0~~	~~6 Hrs~~
Note: Required charger kVA does not include battery charging			
Total:	**~~120.7~~118**	**~~124.5~~122**	
Required Reserve:	**~~32.0~~31**	**~~33.1~~32**	
Minimum Charger kVA:	**~~153~~149**	**~~158~~155**	

Table 8a2.2-2 – UPSS Battery Sizing
(Sheet 1 of 2)

Load Description	Amp-Hours Battery A	Amp-Hours Battery B
Target solution vessel (TSV) off-gas system (TOGS)		
Blowers (8)	58	58
Recombiner heaters (16)	31	31
Nitrogen purge system (N2PS) valves	2	2
TSV dump valves	3	3
Neutron flux detection system (NFDS)	350	350
TSV reactivity protection system (TRPS)	34	34
TRPS radiation monitors	224	224
Engineered safety features actuation system (ESFAS) radiation monitors	224	224
Neutron driver assembly system (NDAS) hold circuits (8)	16	16
Vacuum transfer system (VTS) hold circuits (3)	6	6
Molybdenum extraction and purification system (MEPS) pump hold circuits (3)	6	6
Radiological ventilation exhaust and supply fans hold circuit	12	12
ESFAS	33	29
Tritium purification system (TPS) tritium monitors (~~6~~9)	~~84~~105	~~84~~105
Criticality accident alarm system (CAAS), nonsafety-related	26	26
Stack release monitoring system (SRMS), nonsafety-related	0	112

Table 8a2.2-2 – UPSS Battery Sizing
(Sheet 2 of 2)

Load Description	Amp-Hours Battery A	Amp-Hours Battery B
TPS ~~glovebox stripper system (GBSS)~~secondary enclosure cleanup (SEC) subsystem, nonsafety-related		
Blowers	~~69~~15	~~69~~29
~~Heaters~~	~~140~~	~~140~~
Note: Total amp-hours include inverter efficiency		
Subtotal:	**~~1317~~1144**	**~~1425~~1267**
Subtotal with 1.25% aging factor:	**~~1649~~1430**	**~~1784~~1584**
Total with 10% reserve and 80% discharge:	**~~2268~~1967**	**~~2453~~2177**

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
AGS	American Glovebox Society
AHU	air handling unit
ALARA	as low as is reasonably achievable
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
~~ATIS~~	~~accelerator TPS interface system~~
atm	atmosphere (unit of pressure)
BPVC	Boiler and Pressure Vessel Code
CAAS	criticality accident alarm system
CHO	Chemical Hygiene Officer
Ci	curies (unit of measurement of radioactivity)
CMAA	Crane Manufacturers Association of America
Cs	cesium
DAW	dry active waste
DU	depleted uranium

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
FVZ4	facility ventilation zone 4
FVZ4e	FVZ4 exhaust subsystem
FVZ4r	FVZ4 room cooling recirculation subsystem
FVZ4s	FVZ4 supply and transfer air subsystem
g	gram
~~GBSS~~	~~glovebox stripper system~~
gU/l	gram of uranium per liter
HDPE	high-density polyethylene
HEPA	high efficiency particulate air
HMI	human machine interface
HPLC	high-performance liquid chromatogrpahy
HVAC	heating, ventilation, and air conditioning
I-131	iodine-131
ICBS	irradiation cell biological shield
ICP-MS	inductively coupled plasma mass spectroscopy
ICP-OES	inductively coupled plasma optical emission spectroscopy

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
UHF	ultra high frequency
UPS	uninterruptible power supply
UPSS	uninterruptible electrical power supply system
URSS	uranium receipt and storage system
VAC/ITS	vacuum/impurity treatment subsystem
VAV	variable air volume
VFD	variable frequency drive
VoIP	voice over internet protocol
VTS	vacuum transfer system

Details of the inspection and testing requirements of safety-related RV systems are provided in Subsection 9a2.1.1.5.

9a2.1.1.2 System Description

Radiological Ventilation Zone 1

RVZ1 is divided into two subsystems: RVZ1r and RVZ1e. A flow diagram of RVZ1r is provided in Figure 9a2.1-2. A flow diagram of RVZ1e is provided in Figure 9a2.1-3.

RVZ1r provides cooling for systems within the irradiation unit (IU) cell and the target solution vessel (TSV) off-gas system (TOGS) cell. RVZ1r recirculates, filters, and cools air within the IU cell and the TOGS cell. The system includes two fan coil units and associated ductwork and dampers per each set of IU/TOGS cells. Each set of RVZ1r units is located within the primary cooling room and forms a portion of the confinement boundary for the IU/TOGS cells that it serves. RVZ1r provides sampling, ventilation, and cleanup connections for the primary confinement.

RVZ1e exhausts air from the areas with a high potential for contamination in the facility. The air is filtered and directed out of the SHINE facility through the exhaust stack. The subsystem includes fans, filters, ductwork, dampers, and high efficiency filter banks. It also includes the necessary transfer ductwork to allow makeup from the RCA general area into the exhausted areas.

RVZ1e is designed to maintain ventilation zone 1 areas at a lower pressure than ventilation zone 2 areas. The design inhibits backflow with the use of backflow dampers at the discharge of the RVZ1e and RVZ2e exhaust fans in order to minimize the spread of contamination. RVZ1e ductwork provides sampling locations for radiation detectors, fire detection equipment, stack release monitoring, and an exhaust stack connection point for RVZ2e and the process vessel vent system (PVVS).

The RVZ1 serves the following areas:

- IU cells
- TOGS cells
- ~~Glovebox stripper system (GBSS)~~Tritium purification system (TPS) process equipment
- Primary closed loop cooling system (PCLS) expansion tank
- Uranium receipt and storage system (URSS) glovebox
- Radioactive liquid waste immobilization (RLWI) shielded enclosure
- Supercell
- Target solution preparation system (TSPS) glovebox
- Target solution dissolution tanks
- Target solution preparation tank
- ~~HVAC enclosures~~

Radiological Ventilation Zone 2

RVZ2 includes three subsystems: RVZ2e, RVZ2s, and RVZ2r. A flow diagram of RVZ2e is provided in Figure 9a2.1-4. A flow diagram of RVZ2s air handling units (AHUs) is provided in Figure 9a2.1-5. A flow diagram of RVZ2s distribution and RVZ2r is provided in Figure 9a2.1-6.

RVZ2e exhausts air from the general areas of the RCA. The subsystem includes fans, filters, ductwork, dampers, and high efficiency filter banks. It also includes the necessary transfer ductwork to allow makeup from the RCA general area into the exhausted rooms. The transfer ductwork is located in the following spaces:

- from the irradiation facility (IF) general area to the ~~tritium purification system (~~TPS~~)~~ room;
- from each of the cooling rooms to the IF general area;
- from the storage to the preparation room;
- from the transfer aisle to the storage room;
- from the analytical lab to the quality control (QC) lab;
- from the QC lab to the workspace;
- from RCA labyrinth to the workspace; and
- from the workspace to the transfer aisle.

RVZ2 provides ventilation and humidity control for ventilation zone 2 rooms within the RCA. RVZ2e provides an exhaust path for the QC lab and analytical laboratory fume hoods within the RCA and maintains the QC lab and analytical labs at positive pressure with respect to the ventilation zone 2 general area. The system is designed to maintain the RCA at a lower pressure than areas outside of the RCA. The RVZ2e design inhibits backflow within ductwork that could spread contamination. RVZ2e ductwork provides sampling locations for engineered safety features actuation system (ESFAS) radiation detectors and fire detection equipment.

RVZ2s supplies conditioned outside air into the RCA to provide ventilation and to make up for RVZ1e and RVZ2e exhaust volumes. The system includes AHUs, filters, ductwork, and dampers. RVZ2s provides cooling, heating, humidification for all systems within ventilation zone 2 as well as maintains the QC lab and analytical labs at positive pressure with respect to the ventilation zone 2 general area.

RVZ2r recirculates, filters, and conditions air within the RCA. The system includes AHUs, filters, ductwork, and dampers. The RVZ2r units are located within the RCA. RVZ2r provides additional cooling for systems within ventilation zone 2. RVZ2r is also used to cool air being supplied to the supercell, which reduces the flow rate required to cool the equipment within the supercell. The filters and bubble-tight dampers on the inlet side of the supercell are part of RVZ1e.

Areas served by RVZ2 include:

- ~~GBSS~~ TPS fume hoods
- QC lab hood
- Analytical lab hood
- RCA exhaust filter room
- Access control area
- Don/doff rooms
- Decontamination room
- Labyrinths
- Analytical lab
- QC lab
- Workspace
- Transfer aisle
- Radioisotope process facility cooling system (RPCS) room
- Storage rooms

Figure 9a2.1-1 – Ventilation System Zone Designations Within the SHINE Facility

Figure 9a2.1-1 – Ventilation System Zone Designations Within the SHINE Facility

Figure 9a2.1-2 – Radiological Ventilation Zone 1 Recirculating Cooling Subsystem (RVZ1r) Flow Diagram

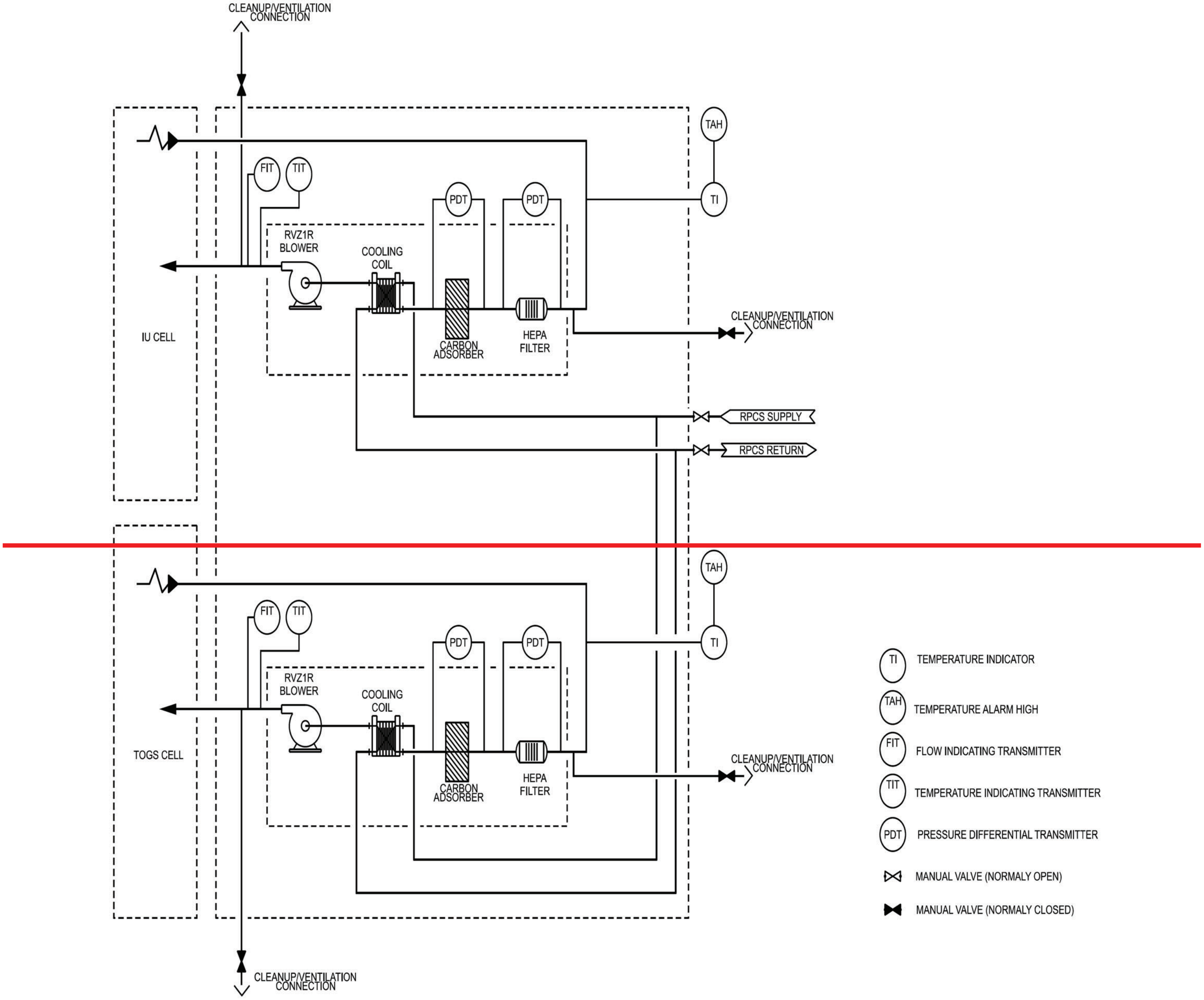


Figure 9a2.1-2 – Radiological Ventilation Zone 1 Recirculating Cooling Subsystem (RVZ1r) Flow Diagram

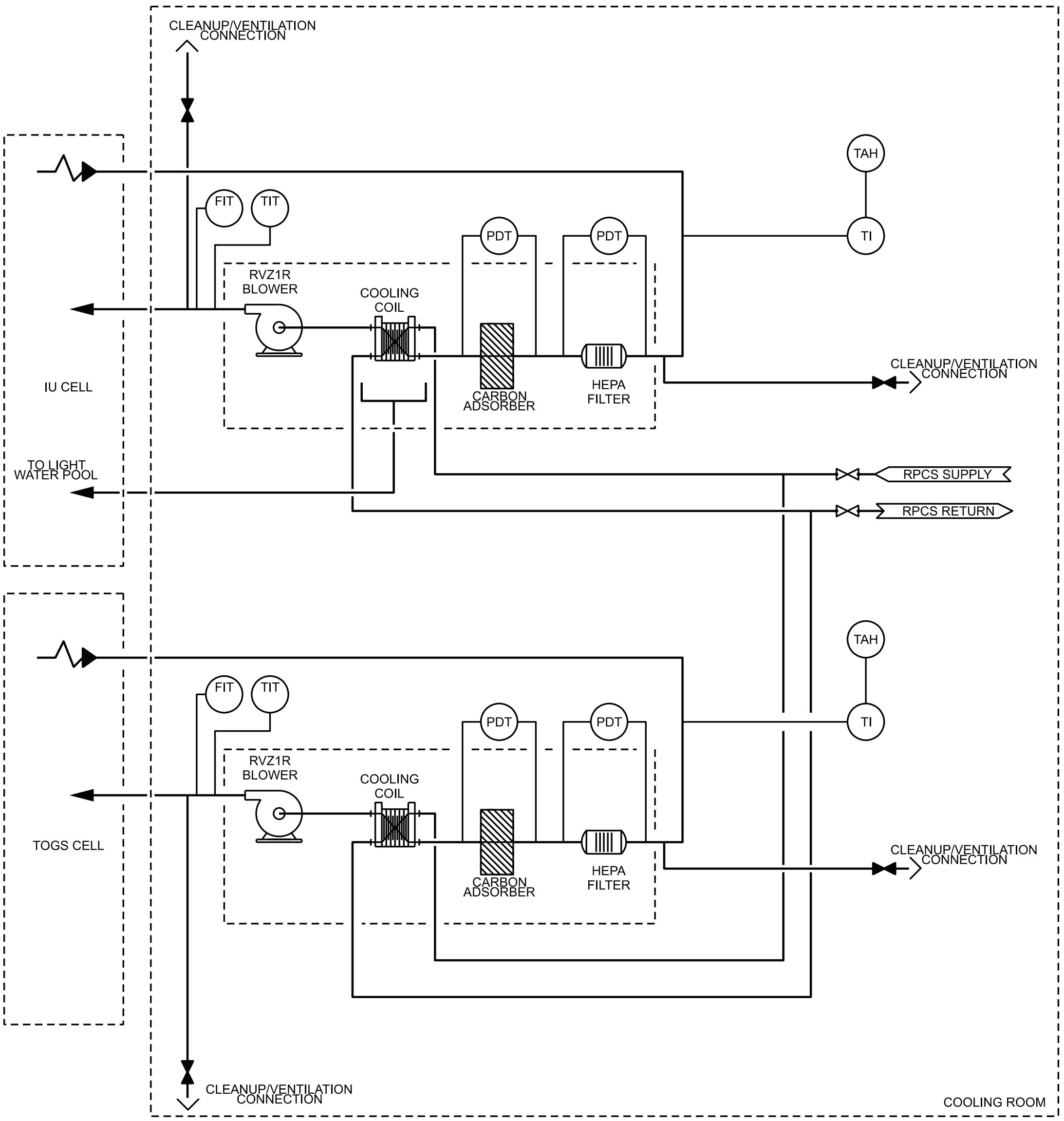


Figure 9a2.1-3 – Radiological Ventilation Zone 1 Exhaust Subsystem (RVZ1e) Flow Diagram

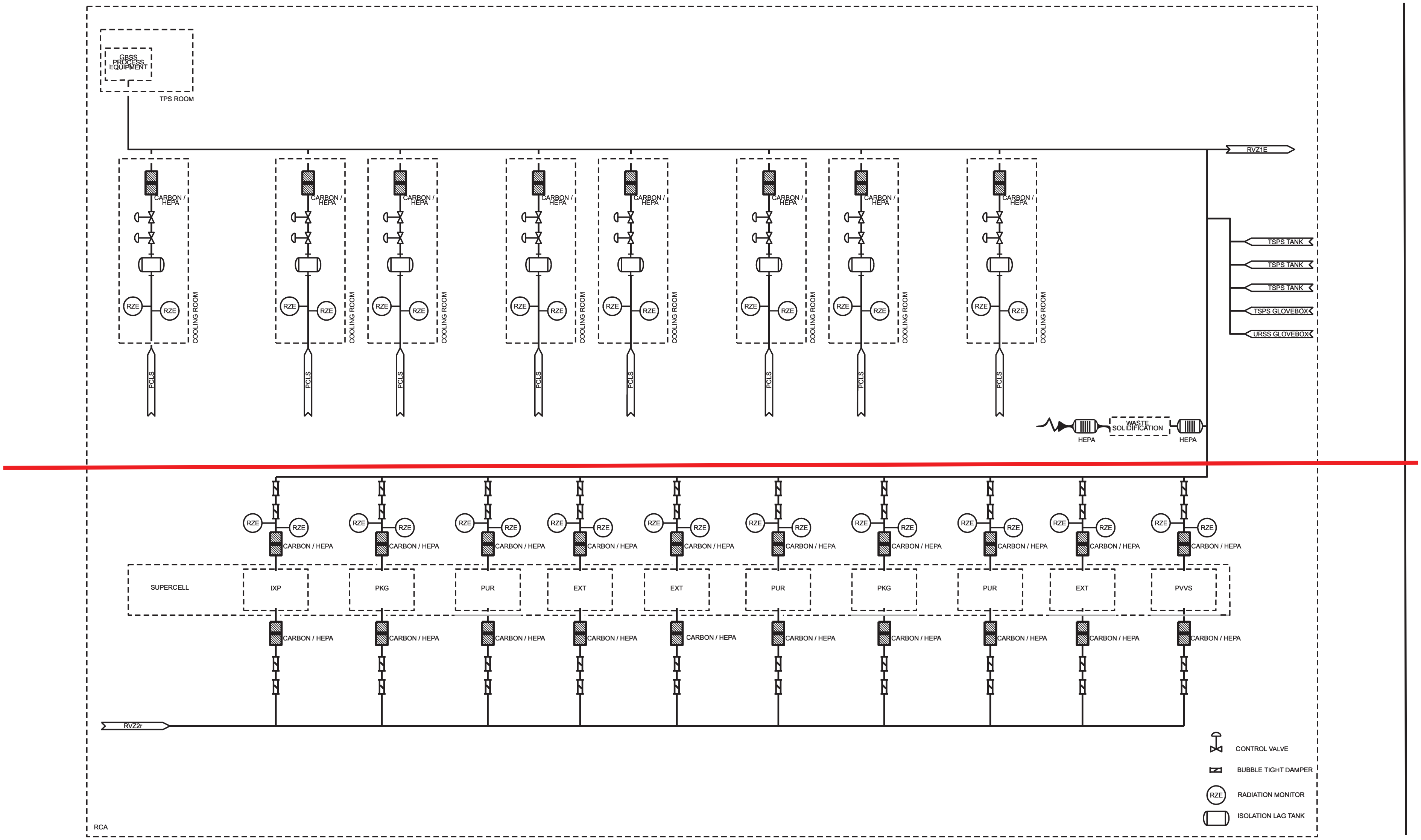


Figure 9a2.1-3 – Radiological Ventilation Zone 1 Exhaust Subsystem (RVZ1e) Flow Diagram

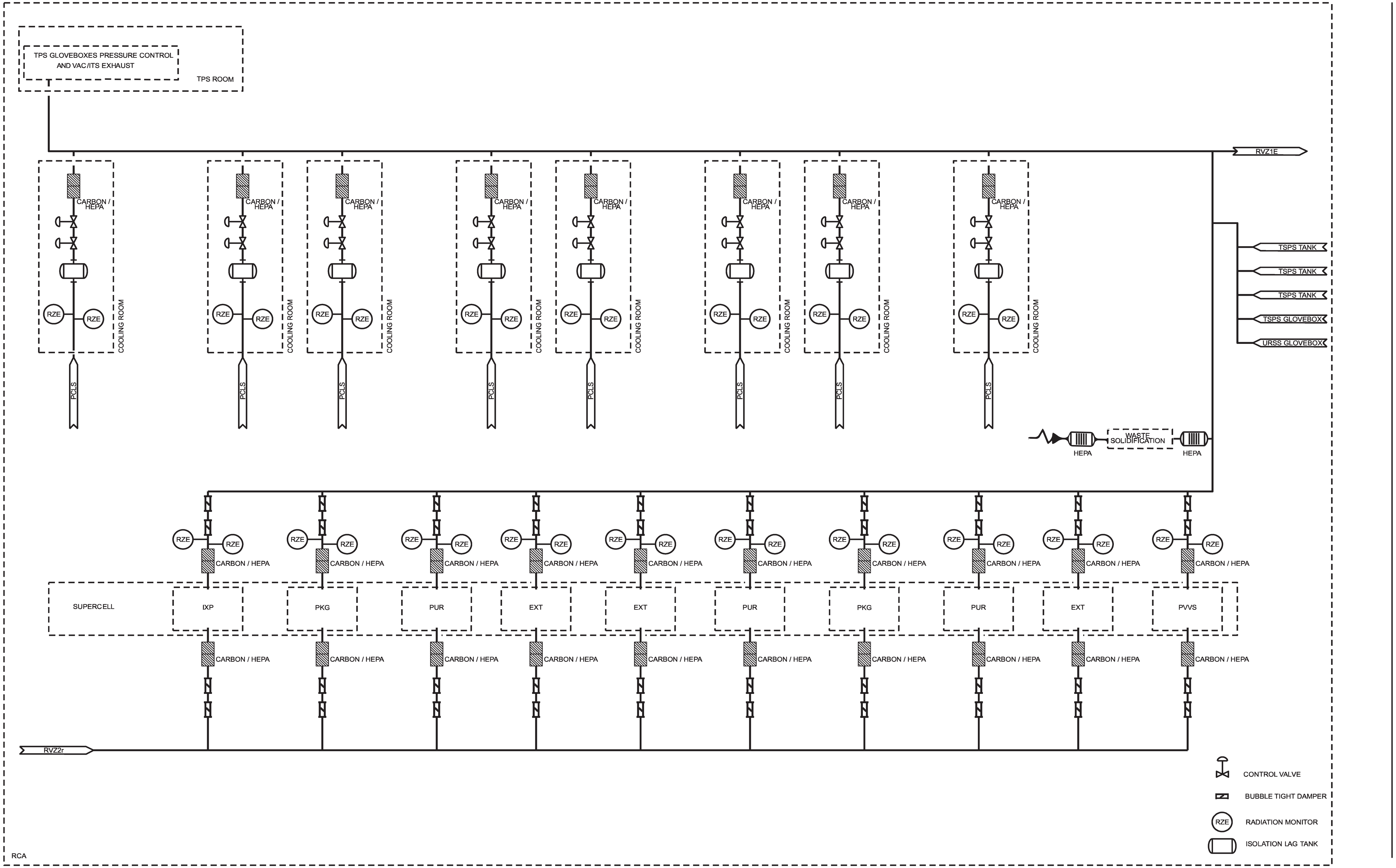


Figure 9a2.1-4 – Radiological Ventilation Zone 2 Exhaust Subsystem (RVZ2e) Flow Diagram

Figure 9a2.1-4 – Radiological Ventilation Zone 2 Exhaust Subsystem (RVZ2e) Flow Diagram

9a2.7 OTHER AUXILIARY SYSTEMS

This section describes auxiliary systems in the irradiation facility (IF) that are not described elsewhere.

9a2.7.1 TRITIUM PURIFICATION SYSTEM

The tritium purification system (TPS) is a tritium-deuterium isotope separation system designed to receive mixed tritium-deuterium gas from operating neutron driver assembly system (NDAS) units and provide high purity tritium and deuterium streams to each operating NDAS unit. The TPS components are located in the ~~IF in the~~ TPS room ~~[ ]SRI. Major subsystems of the TPS are identified below and are classified by their function and location within the IF~~. The TPS consists of three trains which service~~s up to~~ the eight NDAS units ~~operating simultaneously~~.

9a2.7.1.1 Tritium Purification System Subsystems

9a2.7.1.1.1 Isotope Separation Subsystem

The ~~main~~ isotope separation ~~section~~subsystem of ~~the~~ each TPS train receives mixed tritium-deuterium gas from operating NDAS units, removes trace impurities from the gas stream, performs isotope separation of the mixed gas stream, and provides ~~purified streams of~~controlled flows of high purity tritium ~~and deuterium back~~ to ~~the~~ operating NDAS units to drive the tritium-deuterium fusion reaction in the NDAS target chamber. The TPS isotope separation subsystem also flushes and evacuates process lines before entering a maintenance period and after maintenance is complete.

9a2.7.1.1.2 ~~Accelerator TPS Interface System~~

~~The accelerator TPS interface system (ATIS) provides the interface between each NDAS unit and the supply and return gas lines of TPS. There are eight instances of ATIS, one for each IU. The ATIS controls delivery of high purity tritium and deuterium gas to the NDAS and returns mixed tritium-deuterium gas to the isotope separation process. The ATIS also includes interfaces with the NDAS to allow for NDAS evacuation before maintenance and exhausting of NDAS secondary enclosures. Each instance of ATIS operates independently depending on the status of the NDAS unit it serves.~~

9a2.7.1.1.3 ~~ATIS Header~~TPS-NDAS Interface Lines

The ~~ATIS header~~TPS-NDAS interface lines consist~~s~~ of multiple transfer lines ~~and supports~~ between the main TPS process equipment and each ~~ATIS~~NDAS. The transfer lines ~~consist of the supply and return lines for deuterium and tritium as well as lines for process evacuation and ATIS glovebox purge gas. Transfer lines that contain tritium are jacketed to prevent leaks in the lines from introducing tritium directly to the IF environment~~travel through subgrade penetrations between the TPS room and each NDAS. Monitoring capability is provided for the ~~ATIS header~~interface lines to detect potential tritium leaks. The TPS-NDAS interface lines are protected from mechanical impact between the TPS gloveboxes and subgrade penetrations.

9a2.7.1.1.4 TPS Gloveboxes

The TPS glovebox ~~is a~~es are confinement gloveboxes that enclose~~s~~ the isotope separation process equipment. The TPS glovebox ~~is~~es are maintained at negative pressure relative to the TPS room and ha~~s a nitrogen~~ve a helium atmosphere. The glovebox atmosphere ~~is continuously~~s are cleaned by the ~~glovebox stripper system~~secondary enclosure cleanup (SEC) to maintain low levels of tritium contamination and oxygen. A detailed physical description of the TPS glovebox is provided in Subsection 9a2.7.1.4.

9a2.7.1.1.5 ~~ATIS Gloveboxes~~

~~There are eight ATIS gloveboxes that provide confinement to process equipment for each ATIS. The gloveboxes are located [ ]^{SRI}. The ATIS gloveboxes are maintained at negative pressure relative to the IF and have a nitrogen atmosphere.~~

9a2.7.1.1.6 ~~Glovebox Stripper System~~Secondary Enclosure Cleanup Subsystem

The ~~glovebox stripper system (GBSS) strips~~SEC removes tritium from the ~~nitrogen~~helium atmosphere of the TPS ~~and ATIS~~ gloveboxes ~~as well as the waste streams from TPS process lines when the lines are evacuated for maintenance~~. The ~~GBSS~~SEC removes tritium in glovebox environments from both chronic sources (leakage and permeation) and accidental releases. The ~~GBSS~~SEC also maintains low levels of oxygen and moisture in the glovebox atmospheres. ~~The GBSS process equipment exhausts to the radiological ventilation zone 1 exhaust (RVZ1e).~~ The SEC uses a combination of cleanup beds to capture elemental tritium and tritiated water. The cleanup beds are periodically replaced to ensure proper SEC function. The SEC recirculates the TPS glovebox atmospheres.

9a2.7.1.1.7 ~~Glovebox Stripper System Hood~~Vacuum/Impurity Treatment Subsystem

~~The GBSS hood is a fume hood that contains the GBSS process equipment. The fume hood draws in zone 2 air from the TPS room and exhausts it to radiological ventilation zone 2 exhaust (RVZ2e) where it combines with the ventilation for the TPS room.~~ The vacuum/impurity treatment subsystems (VAC/ITS) evacuate TPS process lines and remove trace tritium in process waste streams to support normal operations and maintenance operations. Process streams are evacuated through an arrangement of tritium capture beds, and the waste streams are monitored for tritium concentration before exhausting to the facility ventilation.

9a2.7.1.1.8 NDAS Secondary Enclosure Cleanup

The NDAS SEC removes tritium from the atmosphere of the NDAS secondary enclosures. The NDAS SEC removes tritium in NDAS secondary enclosure environments from chronic sources (leakage and permeation) that occur during NDAS operation.

9a2.7.1.1.9 Tritium Purification System Room

The TPS room houses the TPS gloveboxes, ~~GBSS hood, portions of the ATIS header~~VAC/ITS equipment, NDAS secondary enclosure cleanup equipment, TPS fume hoods, SEC equipment, and supporting control and process equipment.

9a2.7.1.2 Design Bases

The TPS maintains the integrity of the TPS confinement boundary by preventing leakage to the IF from the TPS gloveboxes, ~~GBSS~~SEC process equipment, ~~ATIS header, ~~and ~~ATIS gloveboxes~~TPS-NDAS interface lines, which could result in potential off-site exposures to individual members of the public or occupational dose exposures to individual workers in excess of prescribed dose criteria, which are described in Section 11.1. TPS isolation functions are actuated by the engineered safety features actuation system (ESFAS) as described in Section 7.5.

The TPS prevents leakage from primary confinement boundary through isolation of interface process lines between ~~ATIS~~TPS process equipment and NDAS during and after a design basis seismic event which could result in potential off-site exposures to individual members of the public or occupational dose exposures to individual workers in excess of SHINE's dose criteria, which are addressed in Section 11.1. Primary confinement isolation functions are actuated by the target solution vessel (TSV) reactivity protection system (TRPS), as described in Section 7.4.

SHINE design criteria applicable to the TPS are described in Section 3.1.

9a2.7.1.3 Tritium Purification Process Sequence

The TPS isotope separation process begins with ~~the target gas receiving system (TGRS), which consists of vacuum ~~a pair of liquid-nitrogen cooled cryopumps that draw in mixed tritium-deuterium ~~return~~target chamber exhaust gas from NDAS units that interface with the TPS respective train. ~~Gas from TGRS is cleaned in the impurity removal system (IRS) before isotope separation.~~A guard bed in front of the two cryopumps removes moisture impurity before it reaches the cryopumps. The cryopumps are cycled to either capture gas from operating NDAS units or heated to deliver gas to a permeator that provides additional impurity removal of the gas stream.

~~The IRS provides impurity removal through an activated carbon or molecular sieve bed. The impurity removal bed captures chemical impurities to protect more sensitive TPS equipment downstream. The IRS also contains a gas chromatograph to monitor the process stream to confirm functionality of the impurity removal bed and identify if breakthrough on the bed has occurred and if the bed needs to be replaced.~~The permeator inlet receives gas from the target gas receiving cryopumps. As the gas moves through the permeator, impurities are prevented from passing through the permeator wall while hydrogen isotopes permeate across to the permeator outlet, resulting in high purity hydrogen isotopes at the permeator outlet. The permeator outlet is connected to a second set of two liquid-nitrogen cooled cryopumps that cycle between recovering gas from the permeator and delivering gas to the isotope separation process. Impurities that build up on the permeator are periodically evacuated to maintain proper permeator functionality.

After ~~impurity removal~~passing through the permeator, deuterium and tritium isotopes are separated through the ~~t~~Thermal ~~c~~Cycling ~~a~~Adsorption ~~p~~Process (TCAP)~~, which is part of the storage and separation system (SSS)~~. The TCAP separates deuterium and tritium through the thermal cycling of a palladium-based column and a molecular sieve column. By thermally cycling the TCAP columns, pure tritium gas is collected at one end of the palladium-based column and pure deuterium is collected at one end of the molecular sieve column. Tritium is then drawn from the end of the palladium-based column and deuterium is drawn from the molecular sieve column.

TCAP is a batch process. To receive and deliver a continuous supply of gas to and from operating NDAS units, an arrangement of feed, product, and raffinate ~~volume~~tanks ~~are~~is used together with the separation columns. ~~F~~The feed ~~volumes are~~tank is used to supply mixed tritium and deuterium gas to the TCAP separation columns, which separates the two isotopes and fills the product and raffinate ~~volumes~~tank. The product ~~and raffinate volumes are~~tank is used to supply the tritium ~~and deuterium header~~target gas interface line~~s, respectively~~, which ~~are~~is used to supply ~~source and~~ target gas to each operating NDAS. ~~Additional SSS components include a uranium storage bed to hold tritium when not in use and an interface location where fresh tritium may be supplied from a gas cylinder or uranium storage bed. The uranium storage bed allows tritium to be safely stored during maintenance operations on the TPS. A supply volume provides the ability to add measured amounts of tritium to the TPS from either the storage bed or external source.~~ In-process tritium instrumentation monitors the separation process to ensure proper TCAP functionality.

The isotope separation equipment is confined inside the TPS gloveboxes. The TPS gloveboxes provide a tritium confinement boundary along with isolation valves to ensure excessive tritium releases to the facility and environment do not occur. The TPS gloveboxes also provide confinement in the event of a breach in the TPS process equipment.

~~Operating NDAS units deliver and~~To receive new tritium gas ~~from the isotope separation process through the ATIS. Each ATIS is connected to the ATIS header that allows for gas transfer from the main TPS process equipment to an NDAS unit. Tritium and deuterium supplies are provided to the NDAS through mass flow controllers that determine the flow of deuterium into the NDAS ion source and flow of tritium into the NDAS target chamber. The return gas from the NDAS is returned to TGRS through a booster pump to provide proper flow through the ATIS header. The ATIS header tritium lines have jacketed tubing to ensure potential leaks in process lines between the gloveboxes do not result in tritium releases to the facility or environment. Potential leaks in process lines enter the jacket space instead of being released to the facility environment and are detected by tritium monitoring equipment.~~ or store process tritium before entering maintenance, the TPS contains tritium storage vessels, such as depleted uranium beds. The uranium storage beds allow tritium to be safely stored during maintenance operations on the TPS. A supply volume provides the ability to add measured amounts of tritium to the TPS from either the storage bed or an external source.

A VAC/ITS contains the support equipment necessary to evacuate TPS process lines to support normal operations and to prepare for TPS maintenance. The VAC/ITS are capable of removing both elemental and oxide forms of tritium. TPS waste streams are monitored for tritium concentration before exhausting to the facility ventilation. The NDAS may ~~also~~ be evacuated ~~down to vacuum through the TPS which maintains the ability~~before some maintenance operations, so the NDAS evacuation waste streams may also be treated in the VAC/ITS to remove ~~trace~~ tritium before exhausting the NDAS waste stream ~~enters~~to the facility ventilation.

Deuterium source gas is supplied to the NDAS for the NDAS ion source from an external bottle supply. Deuterium source gas exhaust is exhausted to the facility ventilation. NDAS target chamber exhaust consisting of tritium and deuterium gas is returned to the TPS for isotope separation. The NDAS may also be flushed with air and evacuated down to vacuum through the VAC/ITS, which may remove trace tritium before the waste stream enters the facility ventilation.

~~The isotope separation equipment is confined inside the TPS glovebox. The TPS glovebox provides a secondary confinement boundary along with isolation valves to ensure excessive tritium releases to the facility and environment do not occur. The TPS glovebox also provides confinement in the event of a breach in the TPS process equipment. Each instance of ATIS process equipment is confined in an ATIS glovebox.~~

~~In addition to the process equipment for isotope separation, TPS contains multiple supporting systems. To deliver new tritium gas or store process tritium before entering maintenance, the SSS contains tritium supply and storage vessels, such as uranium tritide beds. The SSS will supply new tritium gas to TGRS so that fresh tritium gas passes through the IRS before reaching TCAP. The process evacuation separation system (PESS) consists of the support equipment necessary to evacuate the main process lines before maintenance or component replacement. PESS evacuates process lines to the stripper system to capture any residual tritium before maintenance to reduce loss of tritium inventory and reduce tritium release outside of TPS.~~

~~The GBSS removes hydrogen isotopes and moisture in the TPS and ATIS glovebox nitrogen purge gas before the purge gas enters the facility ventilation system and exhausts to the environment through the facility stack. The GBSS uses a combination of catalytic recombiner and molecular sieve beds to convert tritium to tritiated water and capture the tritiated water before the process stream reaches the facility ventilation. The molecular sieve beds are periodically replaced to ensure sufficient water capture capacity is available. The GBSS samples the process streams from the tritium cleanup process before it enters the facility ventilation system. The GBSS recirculates a portion of TPS glovebox atmosphere and treats the ATIS gloveboxes as a single pass-through before ultimately exhausting to the stack. When process lines are evacuated before maintenance, the streams are directed through GBSS to minimize tritium releases to the environment. The GBSS is contained in a fume hood near the TPS glovebox.~~

Table 9a2.7-1 provides a description of TPS interfaces. Table 9a2.7-2 provides the nominal properties of the tritium supply, return, and raffinate streams. Table 9a2.7-3 provides a listing of process equipment associated with the TPS.

Figure 9a2.7-1 provides a TPS process flow diagram.

9a2.7.1.4 TPS Glovebox Description

The TPS process equipment is enclosed in ~~a central~~three ~~glovebox and eight smaller interface~~ gloveboxes, one for each ~~IU cell~~TPS train. ~~The central glovebox is sized to accommodate the entire demand of the eight NDAS units.~~ The gloveboxes ha~~s~~ve a stainless steel shell with gloveports and windows on both sides for operator access to equipment. The glovebox has feedthrough connections to allow process tubing, electrical power, and instrumentation lines to pass through the gloveboxes to the TPS process equipment. The gloveboxes ha~~s~~ve ~~an~~ antechambers to facilitate the removal and replacement of internal equipment as needed. External lighting fixtures provide light to the glovebox interiors.

The glovebox volume~~ is~~s are sized such that a release of ~~stored~~the tritium and deuterium stored in the glovebox would not result in exceeding the lower flammability limit (LFL) in the glovebox.

~~There is a small interface glovebox [ ]^{SRI}. The interface gloveboxes contain the necessary equipment to regulate flows of tritium and deuterium to each NDAS and return the mixed tritium and deuterium gas to the central glovebox for isotope separat~~ion.

9a2.7.1.5 Glovebox Atmosphere Treatment

Small amounts of tritium are released into the gloveboxes during normal operation, so the gloveboxes each ha~~s~~ve a cleanup system designed to treat the atmosphere to minimize the tritium concentration. The glovebox atmosphere normally has a very low tritium concentration. The most significant releases of tritium to the glovebox atmosphere are expected to occur during maintenance activities (e.g., disconnecting beds or pumps for replacement).

The gloveboxes ha~~s~~ve a recirculating inert atmosphere with minimal ~~nitrogen~~helium makeup. The ~~oxygen~~moisture and tritium content in the glovebox is monitored, and at high concentrations the operator is notified by alarms. The ~~recirculating loop~~SEC cleans the atmosphere to minimize the amount of tritium in the glovebox atmospheres. The glovebox atmospheres exhaust~~s~~ through the ~~GBSS~~SEC into the radiological ventilation zone 1 exhaust (RVZ1e).

The ~~cleanup~~SEC involves ~~a catalytic recombiner and~~ molecular sieve beds and a hydride bed to remove most elemental and oxidized tritium. The ~~molecular sieve~~cleanup beds are replaced as required over the course of operations.

9a2.7.1.6 Radiological Protection

The processes associated with the TPS are performed within gloveboxes to minimize the exposure of individuals to tritium. ~~Outside of the gloveboxes, TPS tritium tubing is double-walled with tritium detection monitors and alarms to alert operators of potential leaks. Additionally, the tritium~~ The TPS equipment outside the gloveboxes that can contain tritium is normally under partial vacuum. Monitors are located near tritium tubing and at glovebox workstations to identify tritium leaks. The TPS is designed to maintain occupational exposures to tritium to within as low as reasonably achievable (ALARA) program goals. Releases of tritium to the facility or environment are within 10 CFR 20 limits.

Process lines that penetrate the ~~central~~ glovebox confinement boundar~~y~~ies have isolation valves that close on high tritium alarm in the glovebox. In the event of a tritium release, the glovebox may be isolated from the rest of the TPS process and IF through actuation of the isolation valves. Isolation valves are also located on process lines at the interface between the TPS and NDAS units that can be closed to support confinement of an irradiation unit (IU) cell.

~~Outside the glovebox boundary, TPS tritium tubing is jacketed. The annular space is monitored to identify potential leaks.~~ TPS process equipment and tubing is designed and fabricated with low leakage rate requirements to ensure low tritium leakage to the glovebox atmosphere or IF.

Tritium is supplied to the NDAS at sub-atmospheric pressure which reduces leakage potential. ~~The tritium within the NDAS is circulated to and from the target chamber by vacuum pumps. A pump is used to aid in returning the mixed tritium and deuterium gas to the glovebox.~~

utilities such as electrical, control, cooling water, and supply gases inside and outside the NSC. The commissioning activities to be carried out in the NSC may include establishing vacuum, helium leak rate testing, filling the pressure vessel with sulfur hexafluoride (SF_6) gas, and beam performance testing.

- Maintenance
  If portions of an NDAS require maintenance or replacement, it may be moved from an IU cell to the NSC. The NDAS is lifted by the IF bridge crane and transferred to the NSC where work can be performed.
- Disposal
  The NSC may also be used to disassemble an NDAS into smaller parts that can fit more easily into containers before sending to an appropriate waste repository.

9a2.7.2.3 Radiological Protection

Gamma radiation monitoring of the NSC is provided to allow for safe operation and interlocking of activities in the NSC. The NSC has a directed airflow system to manage residual tritium contamination of NDAS components. This airflow system maintains the capability to interface with the facility heating, ventilation, and air conditioning (HVAC) through radiological ventilation zone 2 exhaust (RVZ2e). A passive tritium sample collector at the interface to RVZ2e provides a record of tritium content entering RVZ2e from the NSC. The NSC provides a real-time tritium monitor at the interface to the RVZ2e to measure real-time tritium content in exhaust gas from NDAS testing sent to RVZ2e.

The NSC shield walls are made from approximately 24-inch (61 centimeter) thick concrete walls with reinforcing carbon steel bars. Additional local shielding, such as water or polycarbonate blocks, may also be installed during testing in the NSC. Implementation of local shielding in the pit, and around an installed NDAS as necessary, provides radiation shielding during NDAS testing. This local shielding functions in conjunction with the shielding provided by the NSC shield walls and door to maintain occupational exposures to neutron and gamma radiation to within ALARA program goals. Table 11.1-4 provides radiation areas at the SHINE facility, and includes dose rates to the IF general area during accelerator testing in the NSC. Calculated dose rates during accelerator operation in the NSC are approximately 8 mrem/hr outside the NSC walls. The annual average neutron flux to the NSC surrounding soil is expected to be less than 100 n/cm^2-s.

9a2.7.2.4 Instrumentation and Controls

The NSC provides instrumentation and controls to perform testing of an NDAS to verify proper operation before returning to service. Interlocks for safe testing of the NDAS, such as preventing operation of the NDAS while the service cell door is open are provided. A radiation interlock button located inside the NSC prevents or shuts down operation of the NDAS when actuated by personnel in the NSC.

9a2.7.2.5 Technical Specifications

There are no technical specifications associated with the NSC.

Table 9a2.7-1 – Tritium Purification System Interfaces
(Sheet 1 of 2)

Interfacing System	Interface Description
Neutron driver assembly system (NDAS)	Tritium purification system (TPS) interfaces with the NDAS through process tubing connections that allow delivery of tritium and deuterium gas along with return of mixed tritium and deuterium exhaust gas or NDAS evacuation.
Process integrated control system (PICS)	PICS provides normal monitoring and control of all process variables and control components not important to the safe operation of the TPS.
Target solution vessel (TSV) reactivity protection system (TRPS)	The TRPS provides monitoring and indication of the TPS variables important to the safe operation of individual irradiation unit (IU) cells and provides control of all TPS isolation valves into the primary confinement boundary in the event of a design basis event.
Engineered safety features actuation system (ESFAS)	The ESFAS provides monitoring and indication of the TPS variables important to the safe operation of the TPS glovebox and glovebox stripper system. The ESFAS also provides control of all TPS isolation valves out of the TPS and the glovebox stripper system in the event of a design basis event. The ESFAS controls the position of the safety-related actuation components of the TPS.
Facility nitrogen handling system (FNHS)	~~Gaseous nitrogen is supplied to the TPS gloveboxes to establish and maintain the inert environment below atmospheric pressure.~~ Liquid nitrogen is supplied to TPS process equipment to operate ~~impurity removal~~cryopumps and TCAP equipment. Gaseous ~~N~~nitrogen is ~~also~~ used to actuate air-operated valves throughout the TPS process.
Radiological ventilation zone 1 (RVZ1)	TPS interfaces with RVZ1 at ~~two locations:~~ the points of connection from the gloveboxes pressure control exhaust ~~to the zone 1 header duct,~~ and the points of connection from the TPS vacuum/impurity treatment subsystem ~~exhaust sampling tank~~process equipment to the zone 1 header duct.
Radiological ventilation zone 2 (RVZ2)	TPS interfaces with RVZ2 at the exhaust point of the liquid nitrogen cooling lines (in the form of nitrogen gas), TPS fume hoods, and the overall ventilation of the TPS room.
Normal electrical power supply system (NPSS)	TPS interfaces with the NPSS at the following locations: the glovebox electrical penetrations and connections to equipment located external to the glovebox. Electrical power is distributed within the glovebox to operate the various pumps and heaters in the TPS, and other ancillary equipment.
Standby Generator System (SGS)	The SGS provides nonsafety-related backup power to TPS components.

Table 9a2.7-1 – Tritium Purification System Interfaces
(Sheet 2 of 2)

Uninterruptible electrical power supply system (UPSS)	TPS interfaces with the UPSS at the connections to safety-related equipment and instrumentation that require safety-related backup power. Some nonsafety-related portions of the ~~GBSS~~SEC are also on the UPSS.

Table 9a2.7-2 – Nominal Tritium Supply/Return Properties

Parameter	Tritium Supply	External Deuterium Supply	Mixed Tritium-Deuterium Return
Tritium Concentration	[ ]$^{\text{PROP/ECI}}$	~~[ ]$^{\text{PROP/ECI}}$~~ NA	[ ]$^{\text{PROP/ECI}}$
Deuterium Concentration	Balance	~~Balance~~100%	Balance
Flow Rate (per TPS train)	[ ]$^{\text{PROP/ECI}}$	[ ]$^{\text{PROP/ECI}}$	[ ]$^{\text{PROP/ECI}}$
Pressure	< 1 atm	40 psig	< 1 atm

Table 9a2.7-3 – Tritium Purification System Process Equipment (Sheet 1 of 2)

Component	Description	Design/Fabrication Code or Standard
Tritium purification system (TPS) gloveboxes	The TPS gloveboxes provide~~s~~ a ~~secondary~~ confinement barrier that prevents tritium leakage from isotope separation process equipment from releasing to the facility	AGS-G001-2007 is considered as guidance for the design of the gloveboxes. (AGS, 2007)
~~Accelerator TPS (ATIS) gloveboxes~~	~~The ATIS gloveboxes provide a secondary confinement barrier for interface equipment located [ ]$^{\text{SRI}}$ that minimizes tritium leakage from TPS/neutron driver assembly system (NDAS) interface process equipment from releasing to the facility~~	~~AGS-G001-2007 is considered as guidance for the design of the glovebox. (AGS, 2007)~~
~~Impurity removal bed~~Cryopumps	The ~~impurity removal bed captures trace impurities from the TPS process to prevent impurities from reaching the isotope separation columns~~cryopumps recover gas from neutron driver assembly system (NDAS) units and deliver gas to the thermal cycling absorption process (TCAP) feed	Note (a)
Permeator	The permeator removes impurities from the TPS gas stream before it is delivered to TCAP for isotope separation	Note (a)
~~Thermal cycling adsorption process (TCAP) columns~~TCAP	The TCAP columns are a palladium-based column and a molecular sieve column that are thermally cycled to isotopically separate tritium and deuterium	Note (a)
TPS ~~tritium~~secondary enclosure cleanup ~~catalytic recombiners~~beds	The TPS ~~tritium~~ secondary enclosure cleanup ~~catalytic recombiners oxidize~~beds ~~trace~~remove tritium, moisture, and oxygen from the glovebox atmospheres ~~so that it may be captured on the cleanup system molecular sieve beds~~to maintain an inert glovebox atmosphere with minimal tritium contamination	Note (a)
~~TPS tritium cleanup molecular sieve bed~~	~~The TPS molecular sieve beds capture tritiated water to reduce tritium released to the facility ventilation~~	~~Note (a)~~

Table 9a2.7-3 – Tritium Purification System Process Equipment (Sheet 2 of 2)

TPS isolation valves	TPS isolation valves are located on process lines to provide confinement in conjunction with the TPS glovebox and IU cells in the event a radiological release is detected in the IU cell or ~~central~~ TPS gloveboxes	Note (a)

(a) Commercially available equipment designed to standards satisfying system operation.

Figure 9a2.7-1 – TPS Process Flow Diagram

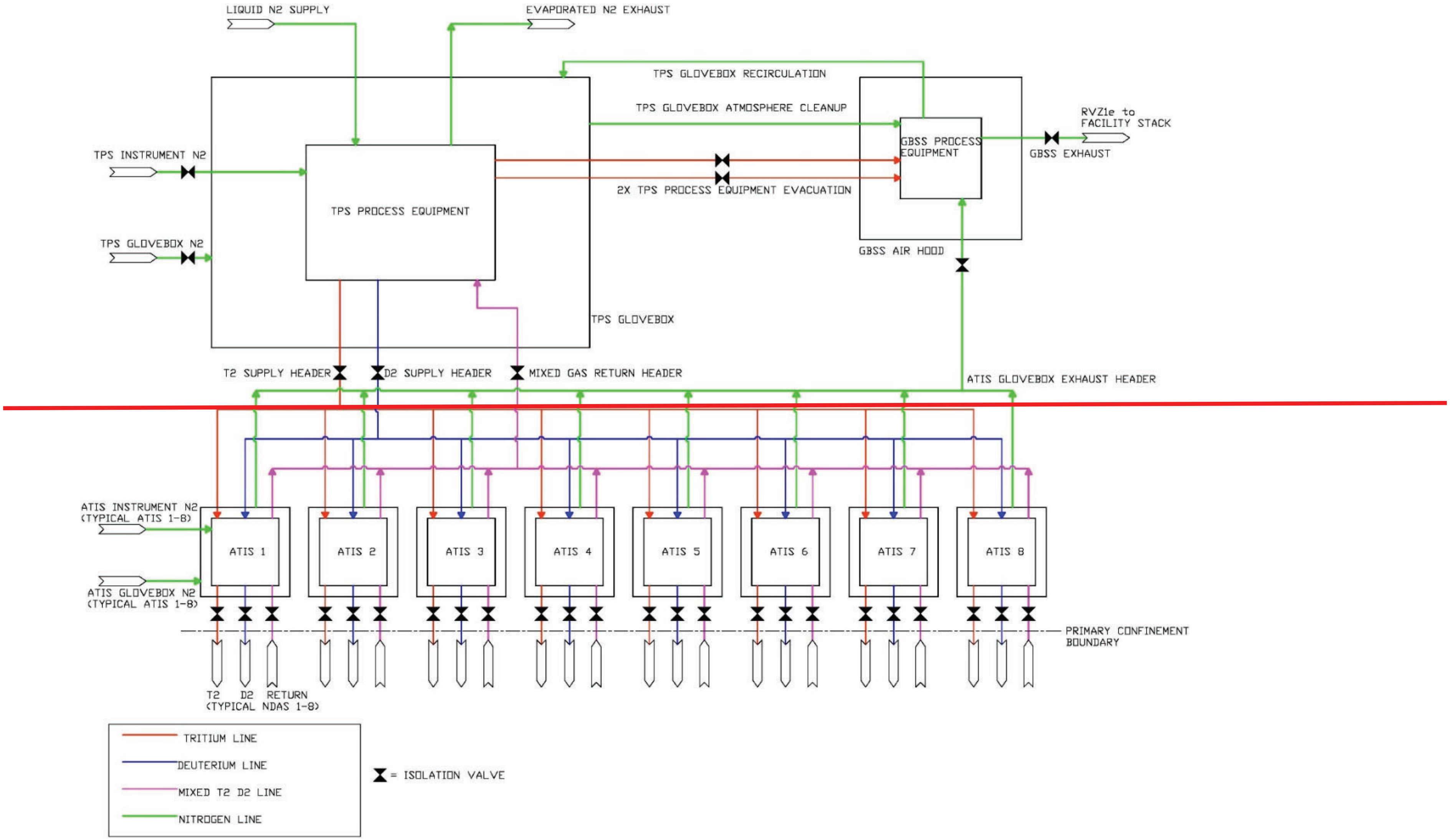
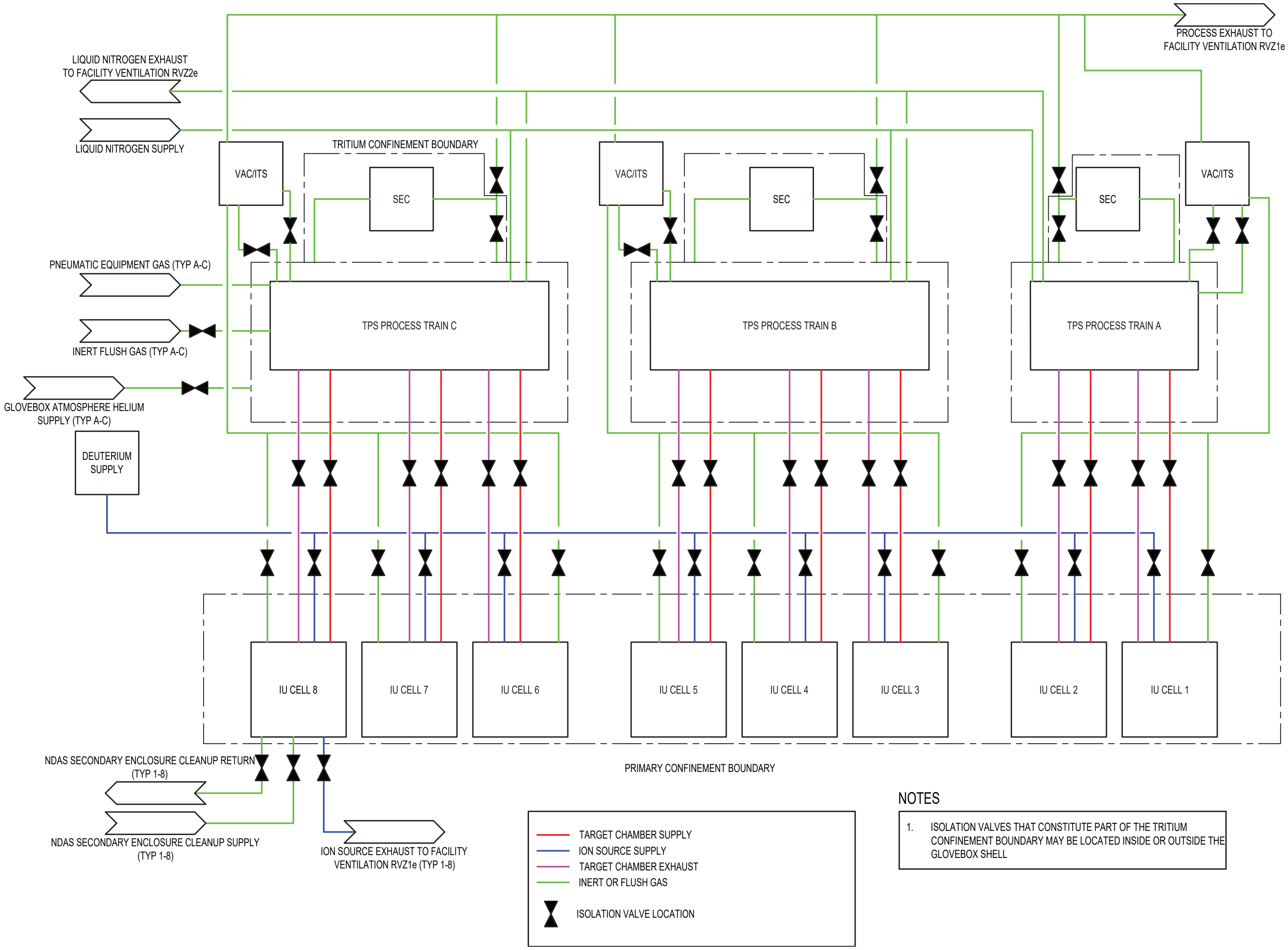


Figure 9a2.7-1 – TPS Process Flow Diagram



The RDS prevents inadvertent criticality through inherently-safe geometrical design of sump, tanks, drain lines, and in-line components that may handle fissile material. A description of provisions for criticality control in the RDS is provided in Subsection 6b.3.2.8.

The RDS is a Seismic Category I, safety-related system.

9b.7.6.4 Instrumentation and Control

The RDS is designed as a passive system, and as such does not use any controls.

The RDS provides liquid detection signals to the engineered safety features actuation system (ESFAS), as described in Subsection 7.5.5.

Nonsafety-related monitoring and control is provided by PICS, as described in Subsection 7.3.3.

9b.7.6.5 Technical Specifications

Certain material in this subsection provides information that is used in the technical specifications.

9b.7.7 FACILITY POTABLE WATER SYSTEM

9b.7.7.1 Design Bases

The design bases function of the facility potable water system (FPWS) is to provide the SHINE facility with potable water. The FPWS piping and system components are designed to the applicable requirements of the Wisconsin Administrative Code, Safety and Professional Services, and the applicable City of Janesville Ordinances.

9b.7.7.2 System Description

The FPWS provides a potable water supply to the SHINE facility and is connected to the City of Janesville water supply. The boundaries of the FPWS include the components from the City of Janesville water main to the fixtures in each of the buildings on the SHINE facility. The fixtures are part of the facility sanitary drain system (FSDS), described in Subsection 9b.7.9. The FPWS ends at the backflow prevention device interfacing with both the facility demineralized water system (FDWS) and facility heating water system (FHWS). The FPWS does not supply water to the facility fire detection and suppression system (FFPS) or any firefighting equipment.

9b.7.7.3 Operational Analysis and Safety Function

Potable water is distributed throughout the SHINE facility through a subgrade piping network. The FPWS site main connects to SHINE facility building mains, which include the main production facility (outside the RCA), the ~~material~~ storage building, and the resource building. The FPWS protects the public water system from contamination due to backflow of contaminants through the water service connection into the public water system using backflow prevention devices.

Shielding and radiological protection is not required for the FPWS and the FPWS contains no SNM.

The FPWS is nonsafety-related.

9b.7.7.4 Instrumentation and Control

The FPWS hot water supply is equipped with automatic temperature controls capable of adjustments.

9b.7.7.5 Technical Specifications

There are no technical specification parameters associated with the FPWS.

9b.7.8 FACILITY NITROGEN HANDLING SYSTEM

9b.7.8.1 Design Bases

The facility nitrogen handling system (FNHS) is designed to supply liquid and compressed gaseous nitrogen to systems inside the RCA. The FNHS gaseous piping is designed, constructed, and tested in accordance with the ASME B31.9, Building Services Piping (ASME, 2011b). The FNHS liquid nitrogen piping is designed, constructed, and tested in accordance with ASME B31.3, Process Piping (ASME, 2013). The FNHS vaporizers, receivers, and bulk liquid nitrogen tanks are designed, constructed, and tested to the ASME Boiler and Pressure Vessel Code, Section VIII, Rules for Construction of Pressure Vessels (ASME, 2010). The balance of the equipment included in the FNHS is commercially available and is designed to standards satisfying the system operation.

The design basis of the FNHS includes:

- Provide nitrogen gas at the pressures and flow rates to operate sampling equipment in the RLWS system, the RDS, the TSSS, the MEPS, and the target solution preparation system (TSPS).
- Provide nitrogen gas for sparging and mixing of tanks in the RLWS, the TSSS, the MEPS, the RDS, and the IXP system.
- Provide liquid and gaseous nitrogen to the TPS. Gaseous nitrogen is used by the TPS to ~~inert glovebox environments and~~ operate pneumatic equipment. Liquid nitrogen is supplied to the TPS ~~impurity removal system~~cryopumps and the thermal cycling absorption process (TCAP) isotope separation columns.
- Provide liquid nitrogen in dewars to the IXP system and the instrument laboratory for equipment cooling.
- Provide nitrogen gas to the TOGS for pressure regulation.
- Provide nitrogen gas to the PCLS and the FFPS for pneumatic control mechanisms.

The FNHS is not relied upon to prevent accidents that could cause undue risk to the health and safety of the workers and the public or to control or mitigate the consequences of such accidents.

Table 9b.7-1 – Radioactive Liquid Waste Immobilization System Interfaces

Interfacing System	Interface Description
Process vessel vent system (PVVS)	The immobilization feed tank cover gas and waste drum vent both discharge via a common header to the PVVS vent header.
Radioactive liquid waste storage (RLWS) system	Immobilization feed tank receives radioactive liquid waste from the RLWS system.
Vacuum transfer system (VTS)	Suction from VTS provides the motive force for waste liquid transfer from the blending tanks to the immobilization feed tank.
Radiological ventilation zone 1 (RVZ1)	The RLWI shielded enclosure is ventilated by RVZ1.
Radiological ventilation zone 2 (RVZ2)	The RVZ2 is the source of air supply to the shielded enclosure through RVZ2 filtration equipment. The RVZ2 is the source of air for the vacuum break between the VTS suction header and the drum fill head vacuum test tank.
Process integrated control system (PICS)	The components of the RLWI system are controlled and monitored by the PICS.
Normal electrical power supply system (NPSS)	The components of the RLWI system are powered by the NPSS.
Facility chemical reagent system (FCRS)	The FCRS pumps dilute sulfuric acid solution from a limited capacity tank to support flushing of the immobilization feed tank, liquid waste drum fill pumps, and the RLWI system piping and valves.
~~Material handling system (MHS)~~	~~The MHS transports the solidified waste drum from the shielded enclosure to the material staging building and imports empty waste drums into the shielded enclosure.~~

Table 9b.7-5 – Facility Nitrogen Handling System Interfaces

Interfacing System	Interface Description
Quality control and testing analytical laboratories (LABS)	The FNHS provides liquid nitrogen to dewars to supply the needs of the instrument laboratory.
Facility fire detection and suppression system (FFPS)	The FNHS provides nitrogen gas to pneumatic actuators for the pre-action fire system.
Iodine and xenon purification and packaging (IXP) system	The FNHS provides a nitrogen gas supply line for product bottle sparging. The FNHS portable dewars, containing liquid nitrogen, interface with the IXP cryotraps to cool system components.
Molybdenum extraction and purification system (MEPS)	The FNHS provides nitrogen gas to sampling equipment maintained by the MEPS.
Primary closed loop cooling system (PCLS)	The FNHS maintains nitrogen gas supply to PCLS nitrogen operated valves in each of the cooling rooms.
Radioactive drain system (RDS)	The FNHS provides nitrogen gas to sampling equipment maintained by the RDS. The FNHS provides nitrogen gas to facilitate sparging and mixing operations in the RDS sump tanks. The FNHS provides a nitrogen gas supply for liquid level detectors in the RDS sump tanks.
Radioactive liquid waste storage (RLWS) system	The FNHS provides nitrogen gas to sampling equipment maintained by the RLWS. The FNHS provides nitrogen gas to facilitate sparging and mixing operations in the uranium liquid waste tanks. The FNHS provides a nitrogen gas supply for liquid level detectors in the liquid waste blending tanks, uranium liquid waste tanks, and liquid waste collection tanks.
Tritium purification system (TPS)	The FNHS provides liquid nitrogen directly piped to the TPS. The FNHS provides nitrogen gas ~~to inert glovebox atmospheres and~~ for the operation of pneumatic equipment.
Target solution vessel (TSV) off-gas system (TOGS)	The FNHS maintains nitrogen gas supply to each of the TOGS skids through a penetration made in each cooling room.
Target solution preparation system (TSPS)	The FNHS provides nitrogen gas to sampling equipment maintained by the TSPS
Target solution staging system (TSSS)	The FNHS provides nitrogen gas to sampling equipment maintained by the TSSS. The FNHS provides nitrogen gas to facilitate sparging and mixing operations in the target solution hold tanks and target solution storage tanks. The FNHS provides a nitrogen gas supply for liquid level detectors in the target solution hold tanks and target solution storage tanks.

9b.8 REFERENCES

ANSI, 1993. Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More, ANSI N14.6-1993, American National Standards Institute, 1993.

ANSI/ANS, 1998. Guide for Nuclear Criticality Safety in the Storage of Fissile Materials, ANSI/ANS 8.7-1998 (R2007), American National Standards Institute/American Nuclear Society, 1998.

ASME, 2009. Code on Nuclear Air and Gas Treatment, AG-1-2009, American Society of Mechanical Engineers, 2009.

ASME, 2010. Rules for Construction of Pressure Vessels, Boiler and Pressure Vessel Code, Section VIII, Division 1, American Society of Mechanical Engineers, 2010.

ASME, 2011a. Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist), B30.2-2011, American Society of Mechanical Engineers, 2011.

ASME, 2011b. Building Services Piping, B31.9-2011, American Society of Mechanical Engineers, 2011.

ASME, 2013. Process Piping, B31.3-2012, American Society of Mechanical Engineers, 2013.

ASME, 2015. Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder), NOG-1-2015, American Society of Mechanical Engineers, 2015.

ASME, 2018. Slings, B30.9-2018, American Society of Mechanical Engineers, 2018.

CMAA, 2004. Specifications for Top Running Bridge & Gantry Type Multiple Girder Electric Overhead Traveling Cranes, CMAA 70-2004, Crane Manufactures Association of America, Inc., 2004.

USNRC, 1980. Control of Heavy Loads at Nuclear Power Plants, NUREG-0612, U.S. Nuclear Regulatory Commission, July 1980.

~~USNRC, 2001. Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants, Regulatory Guide 1.143, Revision 2, U.S., Nuclear Regulatory Commission, November 2001.~~

The design of the SHINE facility maintains airborne radioactive material at very low concentrations in normally occupied areas. Confinement and ventilation systems are designed to protect workers from sources of airborne radioactivity during normal operation and minimize worker exposure during maintenance activities, keeping with the ALARA principles outlined in 10 CFR 20.

Although most process gas systems within the facility are maintained below atmospheric pressure, some leakage of process gases is expected due to the difference in partial pressure between the system and the surrounding environment. A conservative best estimate of airborne releases due to normal operation and maintenance was performed to estimate derived air concentrations (DACs) for the facility.

Leakage from process systems was estimated based on the number of components and fittings, achievable leak tightness per fitting, permeation through equipment, and partial pressures of airborne radionuclides. For processes in hot cells that require routine disconnection of components (e.g., extraction columns) special fittings are used to minimize process leakage.

The effects of the confinement systems are incorporated into the analysis. The results of the evaluation, broken down into particulates, halogens, noble gases, and tritium, are provided in Table 11.1-6. These values provide a conservative best estimate of the facility DACs. Figure 11.1-2 provides the DAC zoning map for the facility, using the following definitions:

- Zone 1 (< 1.0 DAC);
- Zone 2 (1.0 – 10 DAC); and
- Zone 3 (> 10 DAC).

Gaseous activity from the TSV and process operations is routed through the PVVS which includes carbon delay beds to allow for airborne radionuclides to decay to low enough levels such that normal releases are below the 10 CFR 20 limits. Additional airborne release pathways are RVZ1 ventilation of the facility hot cells, flow out of the primary confinement boundary to RVZ1, and radiological ventilation zone 2 (RVZ2) ventilation of any leakage to the general area (material evaluated for the DAC). These additional pathways do not pass through the carbon delay beds but do contain filters as described in Subsection 9a2.1.1. Table 11.1-7 lists key parameters used in the normal release calculation. ~~R~~Tritium releases ~~from the TPS~~ that are treated by ~~the glovebox stripper system (GBSS)~~TPS are negligible in comparison to tritium releases to the general area due to maintenance and leakage and are not included in Table 11.1-7 or Table 11.1-8.

Annual off-site doses due to the normal operation of the SHINE facility have been calculated using the computer code GENII2 (PNNL, 2012). The GENII2 computer code was developed for the Environmental Protection Agency (EPA) by Pacific Northwest National Laboratory (PNNL) and is distributed by the Radiation Safety Information Computational Center (RSICC). Annual average relative atmospheric concentration (χ/Q) values were determined using the methodology in Regulatory Guide 1.111, Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors (USNRC, 1977) with the meteorological data in Section 2.3. The χ/Q values for the maximally exposed individual (MEI), which is the nearest point on the site boundary, and the nearest full-time resident are 7.1E-5 sec/m^3 and 5.3E-6 sec/m^3, respectively.

Table 11.1-5 – Airborne Radioactive Sources

System	Component	Location	Major Sources	Estimated Maximum Activity (Ci)	Exterior Dose Rate (mrem/hr)(a)
TPS	Tritium purification system	TPS gloveboxes	H-3	300,000(b)	< 0.25
NDAS	Driver vacuum hardware	IU cell	H-3	[ ]PROP/ECI(c)	< 0.25
TOGS	Off-gas piping, zeolite beds	TOGS shielded cell	I, Kr, Xe	120,000(d)	< 0.25
RVZ1	IU cell atmosphere and PCLS	IU cell	Ar-41 and N-16	Ar-41: 1E-05 N-16: 10(d)	N/A
RVZ1	Supercell atmosphere	Supercell gloveboxes	I, Kr, Xe, and particulates	3	< 0.2
PVVS and VTS	PVVS and VTS piping	Pipe trenches, valve pits, and PVVS hot cell	I, Kr, Xe	25,000(d)	< 1

a. Dose contribution from listed source in normally occupied area, includes direct dose at 30 cm from the exterior of the shielding surface and contributions from the derived air concentration.
b. Includes inventory in NDAS units.
c. H-3 activity is per NDAS unit.
d. Value is per irradiation unit (IU).

Table 11.1-6 – Estimated Derived Air Concentrations

Source Description	Location	Particulate	Halogen	Noble Gas	Tritium	Total
Primary System Boundary	IF General Area	-	0.~~1~~4%	0.~~4~~1%	-	0.~~5~~4%
Tritium Systems	TPS Room	-	-	-	~~7.0~~1.4%	~~7.0~~1.4%
	IF General Area, Normal Operation	-	-	-	3.2%	3.2%
	IF General Area, Maintenance	-	-	-	5.2%	5.2%
Below-Grade Vaults	RPF General Area	-	0.~~8~~1%	0.0%	-	0.~~8~~1%
PVVS Hot Cell	PVVS Hot Cell	-	12%	1.9%	-	14%
	RPF General Area	-	0.0%	0.0%	-	0.0%
Extraction Hot Cell	Extraction Hot Cell	13%	> 10 DAC	76%	0.0%	> 10 DAC
	RPF General Area	0.0%	2.1%	0.0%	0.0%	2.1%
Purification Hot Cell	Purification Hot Cell	38%	> 10 DAC	220%	0.0%	> 10 DAC
	RPF General Area	0.0%	4.2%	0.0%	0.0%	4.2%
IF General Area Total		-	0.~~1~~4%	0.~~4~~1%	8.3%	8.~~9~~8%
RPF General Area Total		0.0%	~~7.1~~6.4%	0.0%	-	~~7.1~~6.4%

Figure 11.1-1 – Probable Radiation Area Designations Within the SHINE RCA, Ground Floor Level

Figure 11.1-1 – Probable Radiation Area Designations Within the SHINE RCA, Ground Floor Level

Figure 11.1-2 – Estimated Derived Air Concentrations, Ground Floor Level

Figure 11.1-2 – Estimated Derived Air Concentrations, Ground Floor Level

11.2.3.2.1 Consolidated Liquids

Radioactive liquid waste and estimated generated volumes are provided in Table 11.2-1.

Uranium liquid wastes and other radioactive liquid wastes are collected and processed separately, then blended prior to solidification. Uranium liquid wastes may consist of molybdenum extraction column acid wash, extraction column water wash, iodine recovery column [ ]$^{\text{PROP/ECI}}$, VTS knockout pot contents, spent target solution, or decontamination waste. Radioactive liquid waste may consist of [ ]$^{\text{PROP/ECI}}$, purification waste, [ ]$^{\text{PROP/ECI}}$, or PVVS condensate. Blending of wastes is performed without exceeding the maximum uranium concentration applicable to the receiving disposal site. Certain fissile material may be exempted under 10 CFR 71.15.

This waste stream process includes removal of radionuclides, radioactive decay, pH adjustment, blending of uranium and radioactive liquid wastes, and solidification in 55-gallon drums using a solidification agent.

The anticipated disposal site for the solidified liquid waste is Energy*Solutions*.

Requirements for this waste stream are presented in Table 11.2-5.

11.2.3.3 Gaseous Waste Streams

Airborne radioactive sources are identified in Subsection 11.1.1 and Table 11.1-5. The RCA ventilation system filtering and exhaust stack discharge is described in Subsection 9a2.1.1. The exhaust stack location is shown on Figure 1.3-1~~2~~. The stack release monitor provides continuous monitoring of radioactive noble gas stack releases and a means to sample and measure the stack air for particulate, iodine, and tritium concentration to ensure compliance with gaseous effluent regulatory limits. The estimate of annual release of radionuclides is provided in Table 11.1-8. The effect of releases on the surrounding environment is addressed by the Environmental Monitoring Program described in Subsection 11.1.7.

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
ANS	American Nuclear Society
CEO	Chief Executive Officer
COO	Chief Operating Officer
EAL	emergency action level
EDMS	electronic data management system
EPZ	emergency planning zone
GED	general education development
gU/L	grams uranium per liter
I&C	instrumentation and control
~~ISA~~	~~integrated safety analysis~~
IU	irradiation unit
MC&A	material control and accounting
MCNP	Monte Carlo N-Particle Transport Code
NDAS	neutron driver assembly system

12.1.4.2 10 CFR Part 19 Training

Individuals whose assigned duties involve exposure to radiation or radioactive material, and in the course of their employment are likely to receive, in a year, an occupational dose of radiation greater than 100 millirem (mrem) (1 millisievert [mSv]), receive instruction commensurate with their duties and responsibilities, as required by 10 CFR 19.12.

The design and implementation of the radiation protection training program complies with the requirements of 10 CFR 19.12.

12.1.5 RADIATION SAFETY

The RPP is described in greater detail in Subsection 11.1.2. The RPP meets the requirements of 10 CFR Part 20, Subpart B, and is consistent with the guidance provided in Regulatory Guide 8.2, Revision 1, Administrative Practices in Radiation Surveys and Monitoring, and ANSI/ANS 15.11-2016, Radiation Protection at Research Reactor Facilities (ANSI/ANS, 2016b). Development and implementation of the RPP is commensurate with the risks posed by a medical isotope production facility. Procedures and engineering controls are based upon sound RP principles to achieve occupational doses to on-site personnel and doses to members of the public that are as low as reasonably achievable (ALARA).

The organizational structure and responsibilities, including the radiation safety function, are described in Sections 12.1.1 and 12.1.2.

The RP Department is independent of facility operations. This independence ensures that the RP Department maintains its objectivity and is focused only on implementing sound RP principals necessary to achieve occupational doses and doses to members of the public that are ALARA.

RP staff maintain the ability to raise safety issues with the review and audit committee or executive management. The RP staff encompasses the clear responsibility and ability to interdict or terminate licensed activities that it believes are unsafe. This does not mean that the RP staff possesses absolute authority. If facility managers, the review and audit committee, and executive management agree, the decision of the RP staff could be overruled. However, this would be a rare occurrence that would be carefully analyzed and considered.

12.1.6 NUCLEAR SAFETY PROGRAM

The production facility safety program is implemented within the nuclear safety program and developed using ~~Integrated Safety Analysis (ISA)~~ methodologies as described in ~~10 CFR Part 70, Subpart H;~~ Interim Staff Guidance Augmenting NUREG-1537, Part 1, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Format and Content,” for Licensing Radioisotope Production Facilities and Aqueous Homogeneous Reactors (USNRC, 2012a); and Interim Staff Guidance Augmenting NUREG-1537, Part 2, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Standard Review Plan and Acceptance Criteria,” for Licensing Radioisotope Production Facilities and Aqueous Homogeneous Reactors (USNRC, 2012b). The nuclear safety program is described in Chapter 13.

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
AC	alternating current
AECL	Atomic Energy of Canada Limited
AEGLs	Acute Exposure Guideline Levels
ALOHA	Areal Locations of Hazardous Atmospheres
ARF	airborne release fraction
~~ATIS~~	~~accelerator tritium interface system~~
BENM	Best Estimate Neutronics Model
CAMS	continuous airborne monitoring system
CO	carbon monoxide
DBA	design basis accident
DBE	design basis earthquake
DCF	dose conversion factors
DR	damage ratio
ERPGs	Emergency Response Planning Guidelines
ESFAS	engineered safety features actuation system
FCRS	facility chemical reagent system

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
FHA	fire hazards analysis
FMEA	failure modes and effects analyses
ft.	feet
gal	gallons
~~GBSS~~	~~glovebox stripper system~~
gpm	gallons per minute
HAZOP	hazard and operability
HVPS	high voltage power supply
IBC	intermediate bulk containers
IE	initiating event
IF	irradiation facility
IMOD	Iodine Model for Containment Codes
~~ISA~~	~~integrated safety analysis~~
ISG	interim staff guidance
IU	irradiation unit
IXP	iodine and xenon purification and packaging

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
UPSS	uninterruptible electrical power supply system
URSS	uranium receipt and storage system
VAC/ITS	vacuum/impurity treatment subsystem
VTS	vacuum transfer system
χ/Q	atmospheric dispersion factor

13a2 IRRADIATION FACILITY ACCIDENT ANALYSIS

The purpose of this section is to identify the postulated initiating events and credible accidents that form the design basis for the irradiation facility (IF), which includes the irradiation units (IUs) and supporting systems. Section 13b identifies the postulated initiating events and credible accidents within the radioisotope production facility.

Design basis accidents were identified using the following sources of information:

- NUREG-1537 (USNRC, 1996) and the Interim Staff Guidance Augmenting NUREG-1537 (USNRC, 2012a);
- Process hazard analysis method within the ~~integrated~~ safety analysis ~~process~~; and
- Experience of the hazard analysis team.

Each identified accident scenario was qualitatively evaluated for its potential chemical or radiological consequences. For accident scenarios with potential consequences that could exceed the appropriate evaluation guidelines for worker or public exposure, controls were applied to ensure that the scenario is prevented or that consequences are mitigated to within acceptable limits. For accident scenarios which are not prevented, the radiological or chemical consequences were quantitatively evaluated to demonstrate the effectiveness of the selected mitigative controls or shown to be bounded by other quantitative analysis.

The quantitative analysis includes:

1) Identification of the limiting initiating event, initial conditions, and boundary conditions.
2) Review of the sequence of events for functions and actions that change the course of the accident or mitigate the consequences.
3) Identification of damage to equipment or the facility that affects the consequences of the accident.
4) Review of the potential radiation source term and radiological consequences.
5) Identification of safety controls to prevent or mitigate the consequences of the accident.

The results of these analyses are provided in Section 13a3. The analyses identify those safety-related structures, systems, and components (SSCs) and engineered safety features for each accident, and demonstrate that the mitigated consequences do not exceed the radiological accident dose criteria, described in Section 13a2.2.

13a2.1 ACCIDENT-INITIATING EVENTS AND SCENARIOS

The design basis accidents (DBAs) identified in this section are credible accident scenarios that range from anticipated events, such as a loss of electrical power, to events that are still credible, but considered unlikely to occur during the lifetime of the plant. The irradiation facility (IF) maximum hypothetical accident (MHA) is also defined to result in the bounding radiological consequences for the IF.

Based on the guidance provided in the Interim Staff Guidance (ISG) Augmenting NUREG-1537 (USNRC, 2012a), the following accident categories were used to identify potential accident sequences:

MHA based on the maximum consequence to the public. Worker doses are also calculated for the same accident.

Several potential MHA scenarios were considered, including:

- Energetic dispersal of contents of the PSB with bypass of the light water pool scrubbing capacity,
- Failure of the TOGS pressure boundary and release of some or all of the TSV radioactive gases into the TOGS cell,
- Complete loss of target solution inventory (e.g., TSV break),
- Man-made external event that breaches the PSB of more than one IU, and
- Facility-wide external event that breaches various systems containing radioactive fluids.

The main production facility is designed to withstand external events such as tornado, seismic, and man-made external events. The structure protects the equipment inside its seismic envelope from external events. With this protection, it is not credible for an external event such as an aircraft impact, tornado, flood, earthquake, or tornado missile to initiate an accident involving a safety-related SSC on one or multiple IUs within the structure.

Multiple non-seismic SSCs within the structure can still be affected by and initiate an accident due to seismic events. The neutron drivers are nonsafety-related components within the IUs. The neutron drivers do not contain fission products and are not part of the PSB. The failure of multiple neutron drivers during a seismic event is evaluated in Subsection 13a2.1.6.

~~The integrated safety analysis (ISA) process did not reveal potential interaction e~~Events between IUs that could lead to one accident propagating to another unit are not credible because there is no potential interaction between units that supports this propagation. Therefore, scenarios that involve multiple IUs are not analyzed further.

13a2.1.1.1 Identification of Causes, Initial Conditions, and Assumptions

The IF MHA is a failure of the PSB leading to a release of TSV radioactive gases into the TOGS cell. The failure of the TOGS pressure boundary is assumed to cause a failure of the TOGS to function, which initiates the nitrogen purge system (N2PS). The N2PS causes the pressure in the TOGS cell to increase as the nitrogen gas also leaks into the TOGS cell. The MHA assumes that the normal N2PS flow path from the TOGS through the PVVS system is completely blocked, resulting in a higher pressurization of the TOGS cell than would occur for the credible design basis accident. Therefore, the MHA is a pressurized release from the PSB, which sufficiently bounds credible radiological releases.

The selection of this event was determined to be not credible based on a number of factors:

- PSB piping and valves are fabricated and installed according to codes and standards appropriate to their application and safety classification.
- Corrosion allowances on the pressure vessel and piping wall thicknesses ensure that corrosion expected over component lifetime does not impact the pressure retaining capability of the pressure boundary.
- The N2PS flow path from TOGS to the vent release point is designed with redundant valves in parallel to ensure a flow path is available.

13a2.1.2 INSERTION OF EXCESS REACTIVITY

The excess reactivity insertion event during normal operations is identified as a potential initiating event for accidents in the accident analysis. The ~~ISA process also identified the~~ potentials for excess reactivity insertions during the startup process and post-irradiation mode of the TSV were identified as scenarios to be evaluated.

Three operating modes that have potential reactivity impacts were evaluated for the TSV:

- Mode 1 - Startup Mode: filling the TSV
- Mode 2 - Irradiation Mode: operating mode (neutron driver active)
- Mode 3 - Post-Irradiation Mode: TSV dump valves open

Excess reactivity insertion events can challenge the integrity of the PSB by causing increased power density, temperature, and pressure.

The SCAS is designed to operate in a subcritical state without available excess reactivity. Reactors normally have engineered reactivity control mechanisms and load excess reactivity into the core to accommodate power defect, fuel burnup, and uncertainty in k_{eff}. There are no reactivity control systems in the SHINE system. Analyzing the inadvertent withdrawal of the most reactive control element as performed for reactors is not possible. SHINE will not perform experiments with the IUs, so there are no reactivity effects from experiment malfunctions.

For the subcritical assembly being driven by the neutron driver (such as in Mode 2), excess reactivity insertion (i.e., reactivity inserted beyond planned operations) has similar effects to excess reactivity insertions in a reactor, including increases in power, temperature, and gas generation. As substantial power can be generated even if reactivity remains subcritical in a driven system, the effects of excess insertions of reactivity were considered in the safety analysis.

For the subcritical assembly, when it is not being driven by the neutron driver (such as in Mode 1 or Mode 3 prior to dumping), excess reactivity insertion could lead to inadvertent criticality and unplanned fission power generation, temperature increase, and gas generation.

The assembly is designed to be in a subcritical condition during each mode of operation, with multiple safety controls to prevent or mitigate an excess reactivity insertion or inadvertent criticality. The potential for an inadvertent criticality is greater during fill operations. However, as discussed in the following subsections, controls are in place to safely limit excess reactivity insertions.

Inadvertent criticality events outside the IF (i.e., in the RPF) are prevented by the nuclear criticality safety program, as described in Section 6b.3.

13a2.1.2.1 Identification of Causes, Initial Conditions, and Assumptions

The ~~ISA process and guidance in the ISG Augmenting NUREG-1537 (USNRC, 2012a) identified the~~ following postulated initiating events and scenarios that could lead to an excess reactivity insertion or power transient during operation were identified using the guidance in the ISG Augmenting NUREG-1537 (USNRC, 2012a):

Mode 2. For a voiding of 100 percent, the reactivity changed by approximately [ ]$^{PROP/ECI}$ in Mode 1 and [ ]$^{PROP/ECI}$ in Mode 2. The reactivity impact from 5 percent voiding is very small (i.e., approximately [ ]$^{PROP/ECI}$).

Given the inherent design of the and the air-water separator in the PCLS, there is no significant effect from moderator lumping. Additional design features to prevent cooling channel voiding are discussed in Subsection 5a2.2.2. No damage to the PSB occurs and there are no radiological consequences.

Scenario 9 – Inadvertent Introduction of Other Materials into the Target Solution Vessel

The chemical control of the target solution is performed during the preparation and adjustment of the solution in the RPF. Once the target solution is prepared for use in the TSV, there are no additional chemical control additives in the IF.

No significant pH changes are expected during irradiation due to the stability of sulfuric acid under irradiation.

While other materials are not normally added to the TSV, ~~the ISA process has evaluated~~ process upsets that could lead to inadvertent introductions were evaluated. The inadvertent introduction of other materials into the TSV could come from: (1) sources external to the PSB, or (2) sources internal to the PSB itself.

Material Entering the TSV from Sources External to the PSB

The TSV fill lines are isolated once the TSV is filled and ready for irradiation operations. There is no need to add any chemicals to control the chemistry of the target solution during the irradiation cycle.

The only systems that significantly interact with the SCAS during irradiation operations are the TOGS, NDAS, light water pool, and PCLS. The TOGS can adjust pressure and oxygen concentrations through gas removal and additions to the PSB. These gas space changes have no effect on reactivity beyond PSB pressure change reactivity effects, which are discussed in Section 4a2.6. The PCLS and light water pool are unable to add material to the TSV, except for water ingress scenarios, which are described in Subsection 13a2.1.2.2, Scenario 5.

Regarding the target solution itself, uranium solids used in the target solution preparation process are prevented from reaching the TSV by a filter in the TSPS process.

Water could potentially be introduced into the TSV through a leak from the PCLS, light water pool, or from the RPCS-cooled components in TOGS. Dilution of the target solution in the TSV is discussed in Subsection 13a2.1.2.2, Scenario 5.

Material Entering the TSV from Sources Internal to the PSB

T~~he ISA process has identified t~~wo potential sources of uranium solids entering the TSV and resulting in reactivity addition were evaluated: uranyl salt crystal buildup in the TSV or TOGS components and precipitation of uranium solids.

The first two postulated scenarios are a buildup of uranium-bearing salt crystals in the TSV (such as a "bathtub" ring) or in TOGS components. These salt crystals could become rewetted or otherwise dislodged and reenter the TSV. The buildup of salt crystals in the TSV is not expected due to the high humidity of the TSV and the cold walls of the TSV. In addition, periodic inspection of the TSV is performed which would allow for detection of salt crystal buildup.

If salt crystals did accumulate, their release could lead to an unexpected reactivity increase due to the increase in fissile material in the target solution. To quantify reactivity effects, it is postulated that a piece of deposited salt containing 100 grams of uranium is dislodged from the upper TSV surfaces and falls into the target solution. The re-dissolution of the salt adds approximately [ ]$^{\text{PROP/ECI}}$ of reactivity to the system. This reactivity effect does not result in significant consequences and does not lead to an inadvertent criticality. If additional salt pieces were to continue to enter the TSV, they could continue to re-dissolve and lead to further concentration increases, and power could increase in the TSV. The TRPS would dump the target solution on high time-averaged neutron flux, terminating any reactivity increase. The TSV dump tank is favorable geometry at any uranium concentration. No damage to the PSB occurs and there are no radiological consequences.

The second postulated scenario is precipitation of uranium solids from the solution. Precipitation of uranium solids due to uranyl peroxide formation is possible in aqueous reactors. In the SHINE system, chemistry, power density, and temperature limits have been placed on the target solution as described in Subsection 4a2.6.3. Given these limits, no significant precipitation is expected. For transient events, precipitation has not been seen in transient operations of historic uranyl sulfate systems. Therefore, the dump of the target solution by TRPS on high time-averaged or wide range neutron flux occurs prior to significant precipitation developing in the target solution.

The accumulation of small amounts of precipitation over many cycles has been considered. This could lead to chemical effects on the TSV surface, which may have the potential to lead to a failure of the PSB. A failure of the PSB is analyzed in Subsection 13a2.1.4.

Scenario 10 – Concentration of the TSV Target Solution

~~The ISA process identified p~~Postulated scenarios where the uranium concentration of the target solution could increase were evaluated. One identified scenario requiring control was the TOGS pressure control failure leading to excess evaporation. The other identified scenario requiring control was failure of TOGS to return condensate to the TSV.

TOGS pressure control could fail during irradiation operations and cause lower pressure (higher vacuum) in the TSV, which could increase solution evaporation and/or cause boiling. This could result in increased uranium concentrations and a reactivity increase.

TOGS condensate return lines could clog, leading to increased holdup of condensate in TOGS or diversion of condensate to the TSV dump tank. Reduction of condensate return would lead to increased target solution uranium concentration and a reactivity increase.

The pressure control failure scenario is prevented through redundant TOGS vacuum relief valves that prevent excess vacuum in the PSB. Redundant relief valves protect the PSB from damage and results in no radiological consequences. The reduction in condensate return scenario is prevented through the TRPS IU Cell Safety Actuation on high power range neutron flux.

Scenario 11 – Failure to Control Temperature during 1/M Measurement at Startup

~~The ISA process postulates~~Postulation that a failure in the PCLS occurs during the startup process~~, which~~ results in high target solution temperature and errors in the 1/M measurements during the fill process. These errors could be non-conservative and lead to an increase in reactivity during the fill process. This scenario is prevented through the TRPS IU Cell Safety Actuation on high source range neutron flux or high PCLS temperature. Following the TRPS trip, the target solution dumps to the TSV dump tank, decreasing reactivity and resulting in safe shutdown of the TSV.

Because each of these events has preventative measures in place, there are no radiological consequences.

13a2.1.2.3 Accident Consequences

No releases are expected to occur as a result of insertion of excess reactivity events described above. However, additional discussion associated with the most limiting scenario (Scenario 4 – High Reactivity and Power Due to High Neutron Production at Cold Conditions) is provided in Subsection 13a2.2.2.

13a2.1.3 REDUCTION IN COOLING

This subsection discusses the reduction in cooling in the SCAS. The following components were evaluated:

- The neutron multiplier
- The TSV containing uranyl sulfate solution
- The TSV dump tank containing uranyl sulfate solution

These components are cooled by the PCLS during irradiation operations to maintain a target solution average temperature of not more than 176°F (80°C) at 125 kW of heat generation in the TSV. PCLS rejects heat to the RPCS, which in turn is cooled by the process chilled water system (PCHS). Because the PCLS, RPCS, and PCHS cooling pumps are driven by off-site power, a loss of coolant flow occurs due to power failure and could occur due to failure of a pump, inadvertent valve closure, or a pipe break.

If cooling loop circulation flow is lost, the target solution is dumped to the TSV dump tank. The light water pool removes decay heat from the TSV dump tank by passively absorbing the heat in its approximately 14,900 gallons (56,400 L) water volume.

13a2.1.3.1 Identification of Causes, Initial Conditions, and Assumptions

The SCAS is cooled by the PCLS and the light water pool. The PCLS is a closed loop that circulates cooling water through [ ]$^{\text{PROP/ECI}}$ PCLS cooling water also flows around the TSV and neutron multiplier walls to remove heat generated in the target solution and neutron multiplier during normal irradiation and shutdown operations. Section 5a2.2 specifies that the PCLS is designed to remove 580,000 Btu/hr (170 kW).

The light water pool provides a large heat capacity for passively rejecting heat from the TSV dump tank during shutdown operations.

~~The ISA process identified s~~Several potential initiating events were evaluated, including:

- Spills or leakage from the TSV and process tanks
- Excessive cooling of target solution
- Precipitation of the target solution
- Failures of valves, piping, or tanks
- Failure to control pressure which initiates target solution boiling and impacts target solution concentration
- Operator errors or equipment failures resulting in inadvertently overflowing tanks or misdirecting flow

Failure to control pH of the target solution in the IF results in potential excessive corrosion and pressure boundary failure events, as described in this subsection, and potential for precipitation events as described in Subsection 13a2.1.2. Failure to control temperature or pressure of target solution are also described in Subsection 13a2.1.2.

Events involving the failure to control pH during solution preparation or adjustment are discussed in Chapter 13b.

The initial conditions and assumptions associated with mishandling or malfunction of target solution include:

- The PSB does not contain significant sources of pressure. Leakage between the PSB and the light water pool will normally flow from the pool to the PSB should a break occur.
- The primary confinement boundary isolates the PSB from the rest of the facility by robust walls, ceilings, and floors.
- Penetrations for piping, ducts and electrical cables, and shield plugs are sealed to limit the release of radioactive materials from the facility. Integrated leak rate from the primary confinement boundary (see Subsection 6a2.2.1) is less than that assumed in the dose analysis.
- The primary confinement is cooled by a recirculating air ventilation system. The primary confinement is ventilated to RVZ1e through the PCLS expansion tank.
- IF tanks and piping that have the potential to contain fissile material, except the TSV, are designed with passive measures that prevent an inadvertent criticality with the most reactive uranium concentration.
- Drains that lead from the pipe trenches and tank vaults are designed with a geometry that prevents an inadvertent criticality of the leaked target solution.

13a2.1.4.2 General Scenario Descriptions

There are several types of scenarios that are identified as mishandling or malfunction of the target solution within the IF: (1) failure of the PSB below the level of the light water pool, (2) failure of the TSV-to-PCLS pressure boundary resulting in in-leakage to the TSV, (3) failure of the RPCS-to-PSB interface, (4) failure of the TSV-to-PCLS pressure boundary resulting in target solution leakage to the PCLS, (5) failure in the TOGS causes high pressure in the TSV during fill mode, and (6) target solution leakage into a valve pit. Each of these scenarios and their potential causes is discussed below:

Defense-in-depth protections are present to help prevent a failure of the PSB between the TSV and PCLS, which include:

- control of solution pH through target solution sampling in the target solution hold tank;
- a 30-year corrosion allowance in the PSB component design;
- chemistry monitoring of the PCLS to limit corrosion (see Section 5a2.5).

Scenario 3 – Failure of the RPCS-to-PSB Interface

A failure of the RPCS pressure boundary in the TOGS may be caused by excessive corrosion of the PSB in a TOGS condenser. This failure results in water in-leakage to the primary system from the RPCS. The water in-leakage fills the TSV dump tank, TSV, and TOGS with a mixture of target solution and RPCS water. Potential consequences of the flooding of the PSB include an inadvertent criticality in TOGS or deflagration of hydrogen gas in the TSV headspace or TOGS due to insufficient sweep gas flow. Criticality in the TOGS is prevented by the favorable geometry of the TOGS components, as discussed in Section 4a2.8.

Consequences related to hydrogen deflagrations are discussed in Subsection 13a2.1.9.

Scenario 4 – Failure of the TSV-to-PCLS Pressure Boundary Resulting in Target Solution Leakage to the PCLS

Leakage from the primary system into the PCLS due to a failure of the PSB between the TSV and the PCLS is an additional concern. This failure results in: (1) a potential release of target solution into the ~~PCLS~~primary cooling room with potential for higher dose to workers or the public, or (2) a criticality accident in PCLS equipment. Normally the PCLS is at higher pressure than the TSV, so water will flow from the PCLS into the TSV. However, once pressure equilibrium is established, target solution could leak into the PCLS. The protections in place to prevent and mitigate a failure of the PSB between the TSV and PCLS are PCLS isolation supply and return valves, radiation detection on the RVZ1e exhaust from the PCLS expansion tank, and redundant isolation dampers on the RVZ1e exhaust from the PCLS expansion tank. Target solution leakage into the PCLS will result in radioactive gases entering the PCLS expansion tank, flowing past the radiation detection in the RVZ1e exhaust duct, and initiating an IU Cell Safety Actuation including isolation of the PCLS isolation valves and the RVZ1e exhaust duct.

As defense-in-depth, the failure of the pressure boundary may first result in in-leakage and overflow into the TSV dump tank, which is detected with the level detection in the TSV dump tank. The TRPS then closes the PCLS isolation valves and RVZ1e isolation dampers, stopping potential transfer of target solution to the PCLS and reducing the source of water that could enter the PSB, and isolating the ventilation exhaust from the IU cell.

Additional defense-in-depth measures are also in place to avoid a leak and detect leaks, which include:

- control of solution pH through target solution sampling in the target solution hold tank;
- chemistry controls of PCLS to limit corrosion (see Section 5a2.5); and
- conductivity instrumentation in PCLS, which detects intrusion of target solution.

The small amount of target solution that could diffuse into the PCLS cooling water after the pressure between the PCLS and the PSB is equalized, combined with the dilution of the leaked

In addition to the above sequence of events in the IU, the following actions also occur simultaneously:

- In the event that any transfer of uranyl sulfate solution is in progress, VTS transfer operations stop.
- Nitrogen gas sweeps RPF process tank and lift tank headspaces to dilute radiolytic hydrogen. Nitrogen from the N2PS is routed to the PVVS carbon beds for removal of fission product gases before release to the environment. The N2PS has enough capacity for three days, after which the system is resupplied.
- The UPSS supplies essential facility loads their required runtime as provided in Table 8a2.2-1. The 120 VAC UPSS buses automatically maintain power to essential instrumentation and equipment, including radiation monitoring systems.

13a2.1.5.3 Accident Consequences

The accident consequences associated with a LOOP are discussed further in Subsection 13a2.2.5.

13a2.1.6 EXTERNAL EVENTS

This section discusses external events that impact the IF. This class of accident initiators represent natural or man-made events that occur outside the facility and have the potential to impact facility SSCs. Scenario descriptions are provided in this section for the range of accident initiators that were considered during the accident analysis.

13a2.1.6.1 Identification of Scenarios, Initial Conditions, and Assumptions

The ~~ISA process considered the~~ following potential external events were evaluated:

- Seismic event affecting the IF and RPF (see Section 3.4).
- Severe weather events affecting the IF and RPF (see Section 3.2).
- Transportation accidents, including small aircraft crash into the IF or RPF (see Subsection 3.4.5), toxic gas releases (see Subsection 2.2.3), or explosions (see Subsection 2.2.3).
- External flooding affecting the IF and RPF (Subsection 2.4.2).
- External fires from natural sources (see Subsection 2.2.3).

The initial conditions and assumptions associated with these external events include:

- Prior to an external event occurring, the facility is assumed to be running at nominal conditions.
- Unless otherwise noted, these scenarios only consider single failure mechanisms.
- Eight NDAS contain maximum tritium inventory of [ ]$^{\text{PROP/ECI}}$ of tritium gas.
- The facility structure is designed to withstand credible external events including seismic events, severe weather effects, tornado generated missiles, and impact from aircraft.

In addition, seismic events assume that:

- SSCs, including their foundations and supports, that are required to perform their safety function(s) in the event of a design basis earthquake (DBE) are classified as Seismic Category I.
- SSCs that are co-located with a Seismic Category I SSC and that are required to maintain their structural integrity in the event of a DBE to prevent unacceptable interactions are classified as Seismic Category II.
- Seismic Category II SSCs are not required to remain functional in the event of a DBE.

For further details of seismic design criteria refer to Section 3.4.

13a2.1.6.2 General Scenario Descriptions

The following discusses the external event scenarios ~~identified in the ISA process~~ which impact the IF or RPF:

Seismic Events Affecting the IF and RPF

Scenario 1 – Seismic Event causing TOGS Failure

A seismic event may cause the failure of the TOGS. A failure of TOGS in one or more IUs could result in hydrogen deflagrations. Potential consequences of TOGS failure include radiological dose.

To prevent a TOGS failure from an earthquake the TOGS is seismically qualified. The UPSS provides the TOGS with emergency power if normal facility power is lost. The TOGS functions for a short time after the IU cell shutdown until the N2PS can purge TOGS and lower the concentration of hydrogen, reducing the possibility of hydrogen deflagration. Based on this discussion, the TOGS does not fail during a seismic event and no further analysis is required.

Scenario 2 – Seismic Event causing PCLS Failure

A seismic event may cause the failure of the PCLS. A failure of PCLS in one or more irradiation units could result in reduction in or excessive cooling, reactivity insertion, and potential criticality. Potential consequences of PCLS failure include radiological dose.

To prevent these conditions, redundant high power range neutron flux signals initiate a TRPS actuation that opens the redundant TSV dump valves. A TRPS actuation is also initiated on a high PCLS cooling water temperature or low PCLS cooling water flow. Reduction in cooling is discussed in Subsection 13a2.1.3. Reactivity insertions due to excessive cooling are discussed in Subsection 13a2.1.2. Based on this discussion, the loss of PCLS does not result in a radiological release and no further analysis is required.

Scenario 3 – Seismic Event Causing Multiple NDAS Failures

A seismic event may cause the failure of one or more NDAS units. A failure such as a NDAS vacuum boundary failure in one or more irradiation units results in a release of tritium in one or more IU cells. Potential consequences of multiple NDAS failures include radiological dose. The dose analysis conservatively assumes the simultaneous failure of all eight NDAS to bound the maximum allowable operating state in the IF.

To mitigate the impact of such failures of the ~~primary confinement~~NDAS vacuum boundary, ~~accelerator tritium interface subsystem mixed gas~~TPS target chamber supply pressure and TPS target chamber exhaust ~~return line~~ pressure instrumentation~~,~~ and ventilation isolation mechanisms are used to confine released tritium. Accident consequences of this event are discussed in Subsection 13a2.2.6.

A seismic event may also cause the failure of TPS components located in the TPS glovebox. The radiological consequences of a failure of the TPS components due to a seismic event is bounded by the TPS failure due to deflagration, as described in Subsection 13a2.2.12.2.

Scenario 4 – Seismic Event Causing a Single NDAS Failure

A failure of the NDAS in a single IU cell is discussed in Subsection 13a2.1.12.

Scenario 5 – Seismic Event Causing NDAS Tritium Feed Fault

A seismic event may cause the failure of the NDAS tritium feed. A NDAS tritium feed failure results in tritium prematurely entering the NDAS which causes higher power density and potential uranium precipitation. Potential consequences of NDAS tritium feed failure include radiological dose.

To prevent these conditions, redundant high time-averaged power range neutron flux signals initiate a TRPS actuation that opens the redundant TSV dump valves. In addition, the TPS is provided with a passive design feature to limit the flow rate of tritium into the NDAS target chamber. In the event of NDAS tritium feed failure, the primary confinement boundary is used to contain such incidents. Excess reactivity insertions due to high neutron production at cold conditions are discussed in Subsection 13a2.1.2.2, Scenario 4. Based on this discussion, the tritium feed failure does not result in a radiological release and no further analysis is required.

Scenario 6 – Seismic Event Causing Light Water Pool Liner Failure

A seismic event may cause the failure or leak in the light water pool liner. A failure or leak in the light water pool liner could result in a loss of cooling water inventory and result in target solution heat up. Potential consequences of the light water pool liner failure include radiological dose.

To prevent a loss of pool cooling water, the light water pool liner is seismically-qualified, and penetrations through the liner are located above the minimum pool water height to limit out-leakage below this level. Piping penetrations into the light water pool with the potential for siphoning below the minimum acceptable water level contain anti-siphon devices or other means to prevent inadvertent loss of pool water. Because of the limited volume of water available to leak, anti-siphon design features, and the design leak rate of the penetration, no further analysis is required.

Scenario 7 – Seismic Event Causing PVVS/VTS Failure

A seismic event may cause the failure of the PVVS/VTS. The limiting postulated failure occurs during target solution transfer from the TSV dump tank to the molybdenum extraction and

13a2.1.8.2 General Scenario Description

As noted in Subsection 13a2.1.8.1, power oscillations may occur in the TSV during normal operation as a result of target solution reactivity or neutron driver source output variations. Because of the TSV and interfacing system design and operating parameters, the reactivity variations are small at operating power, resulting in a very stable TSV with self-limiting power oscillations.

Large power oscillations that could potentially challenge design limits are prevented by TRPS setpoints on high neutron flux. No operator actions are required to damp power oscillations. When a TRPS high neutron flux setpoint is exceeded, the neutron driver is automatically de-energized, the TSV dump tank valves automatically open, and the target solution is dumped (by force of gravity) into the favorable geometry TSV dump tank. No analyzed power oscillation scenario results in damage to the PSB.

13a2.1.8.3 Accident Consequences

Additional discussion associated with large undamped power oscillations is provided in Subsection 13a2.2.8.

13a2.1.9 DETONATION AND DEFLAGRATION IN THE PRIMARY SYSTEM BOUNDARY

This subsection discusses the effects of a hydrogen deflagration or detonation in the PSB. Irradiation of the target solution produces significant quantities of hydrogen and oxygen and small quantities of fission products. The TOGS is the primary control for mitigating hazards associated with the evolved gases. Functional requirements for the TOGS include maintaining the concentration of hydrogen to less than the lower flammability limit (LFL), recombining the hydrogen and oxygen, and returning the recombined water back to the TSV. The TOGS functions largely as a closed loop during the irradiation process, with gas additions and removals as needed to maintain proper functioning. TOGS is purged as needed to the PVVS via the VTS. Chapter 6 includes a discussion of the facility combustible gas management systems.

13a2.1.9.1 Identification of Causes, Initial Conditions, and Assumptions

The formation and release of hydrogen due to radiolytic decomposition is an inherent result of irradiation of water. ~~The ISA process identified s~~Several potential scenarios that could result in the accumulation of hydrogen and potential deflagration or detonation were evaluated. A deflagration or detonation accident could occur if the TOGS fails, which could allow hydrogen to accumulate in the TSV headspace, dump tank, or TOGS piping. Potential failures that have been identified include a loss of power, failure of the TOGS blowers, blockage or restriction in the TOGS flow path, and water leakage into the PSB that results in reduced sweep gas flow. Hydrogen could also accumulate if there is degraded performance of the TOGS, such as reduced volumetric flow rate due to a partially-obstructed demister or reduced recombiner effectiveness.

Upon loss of TOGS function, hydrogen concentrations in the TSV headspace and TOGS rise. After the neutron driver is shut down on loss of TOGS flow, the voids in the target solution collapse and release hydrogen from the solution. This effect combined with continued radiolysis from delayed fission product decay further increases hydrogen concentration. Hydrogen

The pressure safety limit of the PSB is greater than the maximum credible deflagration pressure and does not fail due to a deflagration within the PSB.

Scenario 2 – PCLS Radiolysis Resulting in Hydrogen Deflagration

Under normal conditions, hydrogen gas generated in the PCLS is ventilated to the facility ventilation system (RVZ1e). A failure of the ventilation system may result in increased hydrogen gas concentration in the PCLS expansion tank. The hydrogen may ignite and cause a deflagration or detonation in the PCLS expansion tank, resulting in a release of radioactive material if the PSB is damaged.

A flame arrestor on the PCLS expansion tank that vents to the primary confinement atmosphere prevents potential ignition sources from causing a deflagration in the PCLS expansion tank. In the event that a release of radioactive material did occur, then the release is mitigated by the primary confinement boundary. Radiation detection instruments on the RVZ1e duct generates an IU Cell Safety Actuation and close redundant isolation valves to RVZ1e. The potential exposures from this event are bounded by the release of target solution to the IU cell, which is discussed in Subsection 13a2.2.4.

13a2.1.9.3 Accident Consequences

Because detonations and deflagrations in the PSB do not result in the failure of the PSB, there are no radiological consequences associated with these accident scenarios. Further discussion is provided in Subsection 13a2.2.9.

Analysis of PSB failures below the light water pool is provided in Subsection 13a2.2.4.

13a2.1.10 UNINTENDED EXOTHERMIC CHEMICAL REACTIONS OTHER THAN DETONATION

Unintended exothermic chemical reactions other than detonation have been evaluated as potential initiating events as part of the accident analysis within the IF. This subsection examines safety aspects of exothermic chemical reactions that challenge the PSB integrity in the IF, other than hydrogen deflagrations or detonations. Hydrogen deflagrations and detonations are addressed in Subsection 13a2.1.9.

13a2.1.10.1 Identification of Causes, Initial Conditions, and Assumptions

The ~~ISA process identified two potential~~ scenario~~s that are~~ evaluated in this subsection~~. The first~~ is the uranium metal-water reaction in the neutron multiplier~~, and the second is an ignition of the activated carbon bed in the TPS system~~.

Scenario 1 – Uranium Metal-Water Reaction in the Neutron Multiplier Assembly

For the uranium metal-water reaction, the IU is operating at normal irradiation conditions. The neutron multiplier, as manufactured, is [
]$^{PROP/ECI}$. The PCLS provides cooling to the TSV and the neutron multiplier and transfers gases produced from radiolysis to the expansion tank.

The neutron multiplier radionuclide inventory is developed assuming 30 years of continuous operation at 137.5 kW.

The uranium metal-water reaction in the neutron multiplier may be caused by an event which breaches the neutron multiplier cladding allowing water to come into direct contact with the uranium metal. Possible causes include corrosion of the cladding, uranium metal-cladding interaction due to radiation-induced growth, or other mechanical damage incurred during maintenance. The breach may occur at any time during the lifecycle of the neutron multiplier allowing water intrusion over an extended period of time.

~~Scenario 2 – Ignition of the Activated Carbon Bed in the TPS~~

~~For the TPS carbon bed fire, the TPS is operating at its maximum normal capacity. There are no additional assumptions for Scenario 2.~~

~~Ignition of the activated carbon bed in the TPS may be caused by air intrusion into the TPS following improper restoration of the system following maintenance.~~

13a2.1.10.2 General Scenario Descriptions

Scenario 1 – Uranium Metal-Water Reaction in the Neutron Multiplier Assembly

A small breach of the neutron multiplier cladding allows PCLS water into the cladding [ ]$^{PROP/ECI}$. The water intrusion results in an exothermic uranium metal-water reaction in the neutron multiplier assembly. The reaction generates hydrogen gas inside the neutron multiplier cladding shell [ ]$^{PROP/ECI}$. An accumulation of hydrogen gas could result in a deflagration under certain conditions. These conditions include sufficient oxygen concentration, an ignition source, or autoignition temperatures being reached. In this scenario, the hydrogen produced mixes with [ ]$^{PROP/ECI}$ inhibits a potential deflagration. Therefore, a hydrogen deflagration in the neutron multiplier from this event is considered unlikely.

Hydrogen gas that migrates into the PCLS stream from the neutron multiplier leak accumulates in the expansion tank, which is vented to the RVZ1e. Therefore, a hydrogen deflagration in the PCLS from uranium metal-water reactions is also unlikely.

~~Scenario 2 – Ignition of the Activated Carbon Bed in the TPS~~

~~Ignition of the activated carbon bed in the TPS may occur due to improper system restoration following maintenance. If air intrusion occurs in the TPS, the activated carbon bed in the impurity removal subsystems may ignite and cause a fire to spread through the TPS system and glovebox. A failure of the TPS pressure boundary may result in a release of stored tritium into the glovebox. The release of tritium is further evaluated in Subsection 13a2.1.12. The protections in place to prevent ignition of the activated carbon bed are the TPS glovebox inert atmosphere and maintenance to maintain the inert atmosphere. Therefore, the ignition of the activated carbon bed and spread of fire in the TPS glovebox is considered unlikely.~~

  - RVZ1r
  - Radiological ventilation zone 2 recirculating subsystem (RVZ2r)

Loss of ventilation

- The ventilation systems (RVZ1, RVZ2) are described in Section 9a2.1.
- Loss of RVZ1 ~~between the TPS glovebox stripper system (GBSS) hood~~flow may result in maloperation of multiple systems in the IF and ~~potentially contaminated areas and systems in the~~ RPF, such as the:
  - TPS glovebox pressure control exhaust and the vacuum/impurity treatment subsystem (VAC/ITS) process vents
  - RLWI shielded enclosure,
  - Individual cells of the supercell,
  - URSS glovebox,
  - TSPS gloveboxes, or
  - Vent exhausts from the PCLS expansion tanks.
- Loss of RVZ2 to common areas of the IF and the RPF.
- Loss of ventilation to the ~~PCLS~~primary cooling rooms.

Spatial Interactions

Spatial interactions are interactions resulting from the presence of two or more systems in locations. Spatial interactions include a single event that could impact the operation of the adjacent systems, or the failure of one system that may impact the operation of another system. The spatial interactions considered include the effects of internal fires, internal flooding, chemical releases, and other dynamic failure effects.

Human-Intervention Interactions

Human-intervention interactions are adverse system interactions caused by human errors in the RPF which can cause adverse system performance in the subcritical assembly during irradiation operations. Human errors are identified as potential causes for other accident sequences and are not explicitly identified in this section. For example, human interactions or errors considered as potential causes for accident sequences include:

- Failure to operate equipment when required
- Inappropriate operation of equipment
- Maintenance error affecting operating equipment
- Testing error affecting operating equipment

Human errors downstream in the RPF processes that are related to mixing or transfer of target solution are considered in Subsection 13b.2.5.

13a2.1.11.1 Identification of Causes, Initial Conditions, and Assumptions

The identification of causes of system interaction events are provided in the subsections in Chapter 13 as referenced below. There are no unique initial conditions or assumptions associated with system interaction events.

13a2.1.11.2 General Scenario Descriptions

The following section discusses the system interactions that can occur at the SHINE facility. System interactions that are already analyzed in other parts of Chapter 13 are referenced to those subsections and not evaluated in this subsection. System interactions that are not described in other subsections are discussed below.

Functional Interactions

Loss of Off-Site Power

LOOP events are described in Subsection 13a2.1.5.

Reduction of Cooling

Events that could cause a reduction of cooling include PCHS or RPCS failure, LOOP, or external events.

- Reduction in cooling due to PCHS or RPCS failure is described in Subsection 13a2.1.3.
- Reduction in cooling following a LOOP is described in Subsection 13a2.1.5.
- Reduction in cooling due to external events is described in Subsection 13a2.1.6.

Loss of Ventilation

A loss of ventilation could be caused by equipment failure, a LOOP, or external events.

Scenario 1 – Loss of Normal Ventilation to the IU or TOGS Cells

A failure of RVZ1 may be caused by failure of a blower or cooler, including loss of cooling water. It may also be caused by a failed-shut or mispositioned damper or other equipment failure. A loss of cooling may cause instrumentation inaccuracies or failures which may lead to TOGS maloperation or loss of function. This can result in a potential deflagration and release of radiological material.

The protections in place to prevent a TOGS failure due to loss of ventilation are redundant and environmentally qualified TOGS instrumentation (e.g., low flow) that initiates a TRPS signal if TOGS failures are detected. The TRPS signal opens redundant TSV dump valves draining target solution to the TSV dump tank and shuts down the irradiation unit. Decay heat from the target solution is removed by the light water pool.

Scenario 2 – Loss of Normal Ventilation to P~~CLS~~rimary Cooling Rooms

A failure of RVZ2 may be caused by failure of a blower or cooler, including loss of cooling water. Loss of ventilation to individual ~~PCLS~~primary cooling rooms may also be caused by a failed-shut or mispositioned damper. A failure of normal ventilation may lead to increased environmental temperatures within the ~~PCLS~~primary cooling room with potential for increased instrument inaccuracies or failure. The consequences of an RVZ2 failure leading to equipment malfunction result in TSV overcooling causing a reactivity insertion in the TSV. Excess reactivity additions are discussed further in Subsection 13a2.1.2.

The protections in place to prevent TSV malfunctions related to ventilation failures are redundant low and high PCLS temperature trip that initiates a TRPS signal (separate from the control system). The TRPS signal opens redundant TSV dump valves draining target solution to the TSV dump tank and shuts down the irradiation unit. Decay heat from the target solution is removed by the LWPS.

Based on the preventive controls the failure of normal ventilation does not have radiological consequences, and no further analysis is required.

Loss of ventilation due to a LOOP is described in Subsection 13a2.1.5.

Loss of ventilation due to external events is described in Subsection 13a2.1.6.

Spatial Interactions

Fires

The fire hazards analysis (FHA) evaluates the fire hazards and fire protection features for each fire area in the SHINE facility. The fire protection features in the IF rely on low combustible loading, fire detection, manual fire-fighting capabilities, and rated fire barriers to limit the potential for fire initiation and spread within the IF. The fire protection program and the FHA are described in Section 9a2.3.

Potential fire scenarios in the IF have been evaluated~~ in the ISA process~~. The principle fire hazards in the IF are: (1) the HVPS used for the NDAS service cell, (2) hydrogen located in the TPS and within the PSB for each IU cell, and (3) the carbon filters in the radiologically controlled area (RCA) exhaust filter room in the mezzanine area. Causes of fires include a catastrophic failure of the HVPS and maintenance activities including hot work.

The consequences of the fire scenarios are the potential release of radioactive materials, including tritium. The release of tritium is evaluated in Subsection 13a2.1.12.

Radioactive materials accumulated in the exhaust filter trains can also be released in the event of a fire. However the exhaust filter trains are monitored and alarmed for buildup and replaced. Therefore, a significant release of radioactive material is not expected to occur.

Additional effects of fire damage on other facility systems include potential loss of TOGS, PCLS, and ventilation system functions. Loss of the TOGS is described in Subsection 13a2.1.4 and Subsection 13a2.1.9. Loss of PCLS is described in Subsection 13a2.1.3 and Subsection 13a2.1.5. Loss of ventilation systems is described in Subsection 13a2.1.11.2.

The protections in place to prevent or mitigate the effects of a fire in the IF include the protection features described above (i.e., detection, rated barriers, manual suppression). Strict administrative controls on combustible materials and maintenance activities, including hot work are also in place. For a fire involving the HVPS, a catchment pan to contain oil leakage or spray limits the potential spread of oil reducing the potential for fire spread from the HVPS. Therefore, a release of radioactive material is not expected to occur.

TPS piping failures resulting in deflagration are discussed in Subsection 13a2.1.12.3.

Hydrogen deflagration within the PSB is discussed in Subsection 13a2.1.9.

Fires caused by external events are discussed in Subsection 13a2.1.6.

Exothermic Chemical Reaction Scenarios

Exothermic chemical reaction scenarios are discussed in Subsection 13a2.1.10.

Internal Flooding

Potential internal flooding scenarios in the IF have been evaluated~~ in the ISA process~~.

There is no potential for widespread internal flooding within the IF. The primary sources of internal flooding are cooling water systems (e.g., PCLS) located in the IF with limited volume and pressure. The primary consequence of a leak in these systems is a loss of cooling to components served by the system. Localized water leaks or spray are contained to the room in which the system resides and would not result in widespread flooding.

One flooding scenario unique to the IF is a leak in a light water pool that serves the IU. A leak in the light water pool liner may result in leakage of water into the pipe trench and subgrade vaults introducing moderator around pipes and tanks containing uranyl sulfate solution. The nuclear criticality analyses for the trench and vaults assumes bounding moderation conditions which includes full reflection. Therefore there is no consequence as a result of this scenario.

A complete drainage of a light water pool due to a large break would also result in a loss of residual heat removal capability from the SCAS. The light water pool liner is designed to remain intact during normal operation as well as during design basis earthquake and design basis accident events. Penetrations through the light water pool liner are above the minimum water level. The light water pool is also equipped with a leak chase system to detect leaks.

Flooding caused by external events is discussed in Subsection 13a2.1.6.

Dynamic Effects

Process systems in the SHINE facility operate at low temperatures (i.e., generally less than 200°F [93°C], except for the TOGS hydrogen recombination components) and low pressures (i.e., less than 100 psig [689 kPa gauge]), which are not subject to dynamic effects as are found in high energy systems. As needed, safety-related systems are protected from the dynamic effects related to equipment failure and external events. No consequences result from dynamic effects interactions in the SHINE facility.

Human Intervention Interactions

Human interventions can cause adverse system interactions because of the single common control room at the SHINE facility. Operators are able to control multiple systems within the IF and the RPF from the control room. Operator errors may occur including performing control operations on the wrong system, failing to perform required actions, or performing actions out of sequence.

Maintenance is performed as a normal scheduled activity and as a response to emergent equipment problems. Maintenance may occur during all modes of operation, including while irradiation or processing activities are in progress. Errors that occur during maintenance activities can cause failures in operating systems such as support systems. Maintenance errors may be detected upon return to service through post-maintenance testing. However, undetected errors may result in system failures at some later point in time.

Human intervention interactions as accident scenario initiating events are described in other sections in this chapter as applicable and are not evaluated further in this section.

13a2.1.11.3 Accident Consequences

The system interactions described in the preceding sections do not result in radiological consequences. Accident consequences resulting from system interactions that are referenced to other subsections in Chapter 13 are evaluated in those subsections.

Further discussion regarding system interaction events described in this section is provided in Subsection 13a2.2.11.

13a2.1.12 FACILITY-SPECIFIC EVENTS

~~The ISA process identified s~~Several accident scenarios that are unique to the SHINE facility and have the potential for inadvertent radiation exposure to workers or members of the public were evaluated. Facility-specific accident scenarios are associated with the NDAS, the TPS, and potential damage resulting from heavy load drops.

13a2.1.12.1 Identification of Causes, Initial Conditions, and Assumptions

General scenario descriptions for events involving the NDAS, TPS, and heavy load drop include causes of each scenario.

For accident scenarios involving the NDAS, the following initial conditions and assumptions apply:

- The NDAS contains the bounding inventory of tritium gas for full power.
- The NDAS pressure vessel contains the maximum inventory of sulfur hexafluoride (SF_6) gas.
- The primary confinement boundary for an affected IU cell is operable, including the RVZ1e radiation detection and isolation valves.

For accident scenarios involving the TPS, the following initial conditions and assumptions apply:

- The TPS glovebox confinement is operable, including the confinement isolation valves.
- The glovebox atmosphere is inerted with ~~nitrogen~~helium.
- Automatic isolation valves are installed in the system to isolate sections of the system to minimize system release.
- Leakage of tritium from the glovebox enclosure or the external piping is detected by the continuous airborne monitoring system (CAMS) or other leakage detection systems to provide alarms for facility personnel evacuation.
- The TPS ~~header~~ NDAS interface lines contain~~s~~ the maximum inventory of tritium gas.

NDAS Scenario 3 – Catastrophic Failure of the NDAS

Catastrophic failure of the NDAS may be caused by a failure of a ceramic component inside the neutron driver. A leak or failure of the ceramic results in a loss of NDAS vacuum inside the SF_6 pressure vessel and subsequent overpressure of the NDAS vacuum boundary causing failure. Failure of the vacuum boundary results in a leak of tritium and SF_6 gas to the IU cell, which causes IU cell pressurization. Pressurization of the IU cell can cause increased leakage rates between the IU cell and the irradiation facility (IF), which results in higher dose to workers and the public due to the release of tritium.

The accident scenario is mitigated by the primary confinement boundary pressure sensors in the ~~NDAS mixed gas return~~TPS target chamber supply lines and TPS target chamber exhaust line~~,~~s and isolation valves on RVZ1e from the PCLS expansion tank. The primary confinement boundary is described in detail in Chapter 6. Multiple catastrophic failures of NDAS units are described in Subsection 13a2.1.6.

NDAS Scenario 4 – NDAS Vacuum Boundary Failure

Release of tritium from the NDAS vacuum boundary may be caused by a weld or vacuum seal failure or improper maintenance. A failure of the NDAS vacuum boundary results in a leak of tritium into the IU cell, causing higher dose to workers and to members of the public. The accident scenario is mitigated by the primary confinement boundary, which is described in detail in Chapter 6.

Tritium Purification System Event Descriptions

There are five scenarios that are specific to the operation of the TPS in the SHINE facility. These scenarios are: (1) TPS piping failure due to deflagration, (2) release of tritium into the IF due to glovebox deflagration, (3) release of tritium to the facility stack, (4) excessive release of tritium from the tritium storage bed, and (5) release of tritium into the IF due to TPS ~~header~~ NDAS interface line mechanical damage.

TPS Scenario 1 – TPS Piping Failure due to Deflagration

Improper system restoration following maintenance allowing air intrusion into TPS piping or by air in-leakage from the NDAS may result in a deflagration within the TPS piping that causes a piping failure and a release of tritium gas into the TPS glovebox. The release of tritium gas into the TPS glovebox results in higher dose to workers and to members of the public.

The release of tritium is confined within the tritium confinement boundary, including the TPS glovebox ~~radiation monitors and GBSS ventilation isolation valves~~and secondary enclosure cleanup subsystem. The tritium confinement boundary is described in detail in Section 6a2.2. Isolation of the TPS room ventilation is also credited for mitigation.

TPS Scenario 2 – Release of Tritium into the IF due to Glovebox Deflagration

Leakage of TPS piping may lead to TPS glovebox failure caused by deflagration that causes the tritium confinement boundary to fail. TPS piping leakage may be the result of improper restoration to operating conditions from maintenance or of liquid nitrogen ingress into the gaseous nitrogen lines which causes embrittlement and failure of the TPS piping. Failure of the tritium confinement boundary releases tritium into the TPS room and results in higher dose to workers and to members of the public.

The TPS glovebox~~ is~~es are designed such that the minimum size prevents the possibility of reaching the lower flammability limit for the quantity of available hydrogen. The TPS glovebox~~ is~~es are also inerted with ~~nitrogen~~helium which prevents the presence of oxygen. Based on the glovebox design and inert atmosphere, a deflagration in ~~the~~a glovebox is not considered credible and is not analyzed further.

TPS Scenario 3 – Release of Tritium to the Facility Stack

A release of tritium directly to the facility stack may be caused by improper restoration to operating conditions from maintenance which results in a leak of tritium into ~~the~~a glovebox and a concurrent misalignment of the ~~GBSS~~VAC/ITS valves following maintenance. A release of tritium to the facility stack results in higher worker and public dose.

The protection in place to mitigate a release of tritium to the facility stack is the tritium monitor on the ~~GBSS~~TPS glovebox pressure control and VAC/ITS process vent exhaust to RVZ1e, which causes an isolation of the glovebox as part of the tritium confinement boundary.

TPS Scenario 4 – Excessive Release of Tritium from the Tritium Storage Bed

Excessive release of tritium from the tritium storage bed may be caused by failure of the storage bed heater control resulting in excessive heat input. Failure of the heater results in an excessive quantity of tritium added to the TPS system, resulting in overpressurization and release of tritium to ~~the~~a TPS glovebox. The tritium release is confined within the tritium confinement boundary, which is described in detail in Section 6a2.2.

The protection in place to mitigate a release of tritium to the facility stack is the tritium monitor on the ~~GBSS~~TPS gloveboxes pressure control and VAC/ITS process vent exhaust, which causes an isolation of the glovebox as part of the tritium confinement boundary.

TPS Scenario 5 – Release of Tritium into the IF due to TPS~~ Header~~-NDAS Interface Line Mechanical Damage

A release of tritium directly to the IF may be caused by mechanical damage to the TPS~~ header~~-NDAS interface lines which results in a leak of tritium to the IF. A release of tritium to the IF results in higher dose to workers and to members of the public. The TPS~~ header consists of jacketed piping~~-NDAS interface lines are in subgrade penetrations which reduces the likelihood of mechanical damage that results in a tritium leak and are protected from mechanical impact between the subgrade penetration and the TPS gloveboxes.

The majority of the length of the TPS-NDAS interface lines are routed in subgrade sleeves and are therefore protected from mechanical damage from external impacts. A small length of the TPS-NDAS interface lines from the point at which they emerge from the subgrade sleeves in the TPS room to the TPS glovebox isolation valves is protected from mechanical damage by external guards. Therefore, TPS-NDAS interface line mechanical damage is not credible.

Heavy Load Drop Scenario Descriptions

With respect to the SHINE facility, a heavy load is defined as a load that, if dropped, may cause radiological consequences that challenge the accident dose criteria described in Section 13a2.2. There are three scenarios that are specific to heavy load drops in the SHINE facility. These scenarios are (1) a heavy load drop into an open IU cell, (2) a heavy load drop onto an in-service IU cell, and (3) a heavy load drop onto TPS equipment.

Heavy Load Drop Scenario 1 – Heavy Load Drop into an Open IU Cell

A crane mechanical failure or operator error during a lift may result in a heavy load drop into an open IU cell. The heavy load can damage the SCAS components and result in a release of radioactive material.

SHINE has applied the applicable guidance from NUREG-0612, Control of Heavy Loads at Nuclear Power Plants (USNRC, 1980), for control of heavy loads at the SHINE facility, as described in Subsection 9b.7.2. Therefore, a heavy load drop into an open IU cell is not credible.

Heavy Load Drop Scenario 2 – Heavy Load Drop onto an In-Service IU Cell.

A crane mechanical failure or operator error during a lift may result in a heavy load drop onto an in-service IU cell. The heavy load can damage the IU cell plug which results in damage to SCAS components and result in a release of radioactive material.

SHINE has applied the applicable guidance from NUREG-0612, Control of Heavy Loads at Nuclear Power Plants (USNRC, 1980), for control of heavy loads at the SHINE facility, as described in Subsection 9b.7.2. Therefore, a heavy load drop into an in-service IU cell is not credible.

Heavy Load Drop Scenario 3 – Heavy Load Drop onto TPS Equipment

A crane mechanical failure or operator error during a lift may result in a heavy load drop onto TPS equipment. The heavy load can damage the equipment and result in a release of radioactive material.

SHINE has applied the applicable guidance from NUREG-0612, Control of Heavy Loads at Nuclear Power Plants (USNRC, 1980), for control of heavy loads at the SHINE facility, as described in Subsection 9b.7.2. Therefore, a heavy load drop onto TPS equipment is not credible.

13a2.1.12.3 Accident Consequences

Neutron Driver Assembly System

The dose consequences of an NDAS failure are evaluated in Section 13a2.2.12.

Tritium Purification System

The dose consequences of a release of tritium from TPS Scenario 1 are described in Section 13a2.2.12. This scenario bounds the dose consequences for the release of tritium from TPS Scenario 3 and TPS Scenario 4.

~~The dose consequences of~~ TPS Scenario 5 is ~~also described in Section 13a2.2.12~~not credible; therefore, accident consequences are not evaluated.

Heavy Load Drop

Heavy load drop scenarios are not credible; therefore, accident consequences are not evaluated.

The public dose was generally calculated over a 30-day interval at the site boundary. The scenario resulting in the release of tritium from ~~the~~ TPS gloveboxes uses a 10-day release interval because it is expected that tritium recovery can be accomplished within this time frame. The χ/Q values are calculated at the nearest point along the site boundary and at the nearest resident location. The maximum calculated value over all directions of the 50th percentile χ/Q was used for both receptor locations. A ground release was used as the release point.

The environmental and meteorological conditions used to develop the atmospheric dispersion factors are discussed in Section 2.3.

Conservatism

Additional areas of conservatism included in the determination of radiological consequences include:

- Conservative TSV power history and operational cycle: The TSV power history was derived from nearly continuous TSV operation over a [ ]$^{\text{PROP/ECI}}$ period at a power level that exceeds the design power level by ten percent. No credit was taken for medical isotope extraction activities that normally occur during the operation of the SHINE facility.
- Conservative statistical bounding of nuclide inventory: Due to inherent uncertainties in MCNP5, multiple unique sets of results were run through ORIGEN-S to determine the nuclide inventories. The nuclide inventories were analyzed such that a 95 percent confident 95th percentile upper bound was determined for each nuclide. These uncertainties on individual nuclides, 0 to 35 percent, were added to the safety basis inventory to account for the uncertainties inherent to the methods used.
- Conservative estimation of nuclide decay (linear interpolation in lieu of exponential decay): Analyses which account for the decay of nuclides between time steps use linear interpolation in lieu of exponential decay, which increases the available radionuclide inventory at the intervening points.
- Condensation was conservatively neglected in the LPF model.

Uncertainties

Uncertainty in the radionuclide inventory was evaluated using statistical modeling to account for uncertainties associated with the use of Monte Carlo N-Particle Transport Code (MCNP) (LANL, 2011) in the SHINE Best Estimate Neutronics Model (BENM). The modeling produced a nuclide-dependent multiplication factor ranging from approximately 0 to 35 percent increase in the nuclide inventory per nuclide. For the radionuclides which were increased, the average increase was approximately 2.5 percent, and the total estimated increase in inventory was approximately 1 percent. The unweighted uncertainty associated with the multiplication factors was approximately 12 percent. Given that the majority of radionuclides either did not receive an increase or received an increase less than 10 percent and that the multiplication factor only increased the inventory this uncertainty is considered to be negligible.

Based on the results of the validation activities for the LPF model, described below, there is no additional uncertainty associated with the LPF model used in the analysis.

The DCFs used in the analysis are well-recognized and are used without consideration of uncertainty in the values.

13a2.2.6.3 Sequence of Events

The accident sequence proceeds as follows:

1. The initiating event is a seismic event that causes the simultaneous vacuum boundary component failure in all eight NDAS units, instantaneously releasing tritium and SF_6 gas into the IU cells.
2. The IU cells become slightly pressurized due to the mass of released SF_6 gas.
3. Some tritium is transported into the IF through penetrations in the confinement boundary.
4. Detection of high ~~accelerator TPS interface system (ATIS) mixed gas return line~~ TPS target chamber supply pressure or high TPS target chamber exhaust pressure actuates the primary confinement boundary isolation valves and irradiation unit trips within 20 seconds of detection. A sufficient time delay is provided by the holdup volume in RVZ1e to prevent radioactive gases from exiting through RVZ1e prior to isolation.
5. Tritium migrates to the IF through the IU cell plugs and is released to the environment.
6. Detection of high radiation in the RCA actuates ventilation dampers between the RCA and the environment and minimizes the transport of radioactive material to the environment.
7. Personal dosimeters, local radiation alarms, and alarms in the facility control room notify facility personnel of radiation leakage.
8. Facility personnel evacuate the immediate area within 10 minutes upon actuation of the radiation alarms.

Radiation transport is driven primarily by barometric breathing between the IU cell and the IF.

The safety-related SSCs in the IU cell do not fail during a seismic event, but the NDAS and its internal components are not safety-related and cannot be relied upon to remain intact following a design basis earthquake.

No operator actions are taken or required to reach a stabilized condition or to mitigate dose consequences.

Safety Controls

The safety controls credited for mitigation of the dose consequences for this accident are:

- Primary confinement boundary
- ~~IU Cell Safety Actuation~~TPS Train Isolation on high ~~ATIS mixed gas return line~~ TPS target chamber supply pressure or high TPS target chamber exhaust pressure
- Ventilation isolation mechanisms
- Holdup volume in the RVZ1e

It is assumed that the primary confinement is intact and performs a mitigation function with respect to radionuclide transport from the IU cells to the IF. The primary confinement boundary components are designed to maintain their integrity under postulated accident conditions and are maintained in accordance with the facility configuration management and maintenance systems.

13a2.2.9.4 Damage to Equipment

If hydrogen deflagration occurs at the peak calculated concentration of 7.7 percent, the PSB remains intact. Damage to other primary system components internal to TOGS in the affected train may occur; however, such damage will not result in any release of radiological material.

13a2.2.9.5 Radiological Source Terms

Because the PSB remains intact, there is no radiological source term for this accident sequence.

13a2.2.9.6 Radiological Consequences

Because the PSB remains intact, there are no radiological consequences for this accident sequence.

13a2.2.10 UNINTENDED EXOTHERMIC CHEMICAL REACTIONS OTHER THAN DETONATION

As discussed in Subsection 13a2.1.10, the potential for an unintended exothermic chemical reaction within the IF is unlikely. Therefore, there is no radiological consequence to the workers or the public.

Accident scenario consequences associated with the release of tritium gas are discussed in Subsection 13a2.2.12.

13a2.2.10.1 Initial Conditions

Initial accident conditions are described in Subsection 13a2.1.10.1.

13a2.2.10.2 Initiating Event

Scenario 1 – Uranium Metal-Water Reaction in the Neutron Multiplier Assembly

The initiating event is a small breach of the neutron multiplier cladding, allowing PCLS water into the cladding [ ]$^{\text{PROP/ECI}}$.

~~Scenario 2 – Ignition of the Activated Carbon Bed in the TPS~~

~~The initiating event is improper TPS system restoration following maintenance, allowing air intrusion into the impurity removal subsystem.~~

The initiating events associated with unintended exothermic chemical reactions other than detonation are further discussed in Subsection 13a2.1.10.1.

13a2.2.10.3 Sequence of Events

Scenario 1 – Uranium Metal-Water Reaction in the Neutron Multiplier Assembly

The accident sequence proceeds as follows:

1. A small breach of the neutron multiplier cladding occurs, allowing PCLS water to enter the cladding [ ]PROP/ECI.
2. The water intrusion results in an exothermic uranium metal-water reaction, generating hydrogen.
3. The presence of [ ]PROP/ECI inhibits a potential deflagration.
4. Small amounts of hydrogen gas migrate into the PCLS and travel to the PCLS expansion tank, along with hydrogen normally generated in PCLS itself via radiolysis. The expansion tank is vented to RVZ1e to prevent hydrogen accumulation in that tank.
5. Small amounts of fission products from the multiplier migrate into the PCLS water. The presence of fission products in excess of normal operating levels is detected via in-line radiation monitoring installed in the exhaust of the PCLS expansion tank.

Safety Controls

- The design of the neutron multiplier to inhibit deflagration is a safety control (including [ ]PROP/ECI).

~~Scenario 2 – Ignition of the Activated Carbon Bed in the TPS~~

~~The accident sequence proceeds as follows:~~

1. ~~The TPS is improperly restored after maintenance, and air is allowed to enter the TPS impurity removal subsystem.~~
2. ~~The presence of air in the activated carbon bed causes an exothermic reaction.~~
3. ~~The presence of an inert nitrogen atmosphere within the glovebox prevents any fire from damaging the TPS glovebox or causing a release.~~

~~Safety Controls~~

- ~~The presence of an inert nitrogen atmosphere and pre-operational and post-maintenance procedures to verify the atmosphere is within limits.~~

The sequences of events associated with unintended exothermic chemical reactions other than detonation are further discussed in Subsection 13a2.1.10.2.

13a2.2.10.4 Damage to Equipment

As discussed in Subsection 13a2.1.10, no damage beyond the initiating events is anticipated to occur as a result of unintended chemical reactions other than detonation.

13a2.2.10.5 Radiation Source Terms

Scenario 1 – Uranium Metal-Water Reaction in the Neutron Multiplier Assembly

Because a gross failure of the multiplier cladding is unlikely based on its design and a deflagration due to small leaks in the cladding is unlikely (as described in Subsection 13a2.1.10.2), a uranium metal-water reaction in the neutron multiplier assembly does not result in consequences to the worker or the public.

~~Scenario 2 – Ignition of the Activated Carbon Bed in the TPS~~

~~The radiation source term created by the release of tritium due to ignition of the activated carbon bed in the TPS is evaluated further in Subsection 13a2.2.12.~~

13a2.2.10.6 Radiological Consequences

Scenario 1 – Uranium metal-water reaction in the neutron multiplier assembly

Because a gross failure of the multiplier cladding is unlikely based on its design and a deflagration due to small leaks in the cladding is unlikely, there are no radiological consequences to the worker or the public from this event sequence.

~~Scenario 2 – Ignition of the activated carbon bed in the TPS~~

~~The radiological consequences resulting from the release of tritium due to ignition of the activated carbon bed in the TPS is evaluated further in Subsection 13a2.2.12.~~

13a2.2.11 SYSTEM INTERACTION EVENTS

As discussed in Subsection 13a2.1.11, no releases are expected to occur as a result of system interaction events. There are no consequences to the workers or the public from system interaction events, as discussed below. Accident consequences resulting from system interactions that are referenced to other subsections in Chapter 13 are evaluated in those subsections.

13a2.2.11.1 Initial Conditions

There are no unique initial conditions associated with system interaction events.

13a2.2.11.2 Initiating Event

Potential causes for system interaction events are described in Subsection 13a2.1.11.

13a2.2.11.3 Sequence of Events

Functional Interactions

Loss of Off-Site Power

LOOP events are described in Subsection 13a2.2.5.

13a2.2.12.1.3 Sequence of Events

It is assumed that the primary confinement is intact and performs a mitigation function with respect to radionuclide transport from the IU cell to the IF. The primary confinement is designed to maintain its integrity under postulated accident conditions and is maintained in accordance with the facility configuration management and maintenance programs.

1. The initiating event is a vacuum boundary component failure in the NDAS, which instantaneously releases tritium and SF_6 gas into the IU cell.
2. The IU cell becomes slightly pressurized due to the mass of released SF_6 gas.
3. Tritium is transported into the IF through penetrations in the confinement boundary.
4. Detection of high ~~ATIS mixed gas return line~~ TPS target chamber supply pressure or high TPS target chamber exhaust pressure actuates the primary confinement boundary isolation valves and an irradiation unit trip within 20 seconds of detection. A sufficient time delay is provided by the holdup volume in RVZ1e to prevent radioactive gases from exiting through RVZ1e prior to isolation.
5. Tritium migrates to the IF through penetrations in the primary confinement boundary and is released to the environment.
6. Detection of high radiation in the RCA actuates ventilation dampers between the RCA and the environment and minimizes the transport of radioactive material to the environment.
7. Personal dosimeters, local radiation alarms, and alarms in the facility control room notify facility personnel of radiation leakage.
8. Facility personnel evacuate the immediate area within 10 minutes upon actuation of the radiation area monitor alarms.

Radiation transport is primarily driven by barometric breathing between the IU cell and the IF.

Safety Controls

The safety controls credited for mitigation of the dose consequences for this accident are:

- Primary confinement boundary (IU cell plugs and seals)
- ~~IU Cell Safety Actuation~~TPS Train Isolation on high ~~ATIS mixed gas return line~~ TPS target chamber supply pressure or high TPS target chamber exhaust pressure
- IU cell ventilation isolations
- Holdup volume in the RVZ1e

13a2.2.12.1.4 Damage to Equipment

Failure of the NDAS vacuum boundary does not cause subsequent damage to equipment.

After the initial IU cell pressurization has reached equilibrium, leakage between the IU cells and the IF is driven primarily by barometric breathing. The leakage paths between the cells and the IF are not impacted by the accident sequence.

13a2.2.12.1.5 Radiation Source Terms

The initial MAR for this scenario is [ ]PROP/ECI of tritium from the neutron driver assembly in the IU cell.

The accident source term development is discussed in Section 13a2.2. The LPF model values used in the source term development for the public and worker doses are provided in Table 13a2.2-1 and Table 13a2.2-2, respectively.

13a2.2.12.1.6 Radiological Consequences

The radiological consequences of this accident scenario are determined as described in Section 13a2.2.

The radiological consequences of this accident scenario are provided in Table 13a3-1 and meet the accident dose criteria.

13a2.2.12.2 Tritium Release into the Tritium Purification System Glove Box

A release of the tritium inventory from the TPS is analyzed as a DBA. This accident is described in Subsection 13a2.1.12.3 as TPS Scenario 1. This analysis establishes bounding radiological conditions for a release of tritium due to a TPS process deflagration, release of tritium to the facility stack, and release of tritium from the tritium storage bed.

13a2.2.12.2.1 Initial Conditions

Initial conditions for facility-specific events are described in Subsection 13a2.1.12.1.

13a2.2.12.2.2 Initiating Event

An event causes a break in the tritium piping and vessels such that the uncontrolled release of the entire tritium in-process inventory occurs within the tritium confinement boundary. The tritium confinement boundary is described in detail in Section 6a2.2. Potential causes of the initiating event are discussed in Subsection 13a2.1.12.3.

13a2.2.12.2.3 Sequence of Events

It is assumed that the tritium confinement boundary is intact and performs a mitigation function with respect to radionuclide transport from the TPS to the IF. The tritium confinement boundary components are designed to maintain their integrity under postulated accident conditions and are maintained in accordance with the facility configuration management and maintenance programs.

1. The initiating event is a break in the tritium piping and vessels which instantaneously releases the entire tritium inventory of the TPS system into ~~the~~a TPS glovebox.
2. For the first 20 seconds, tritium escapes from the glovebox to the IF ~~at 10 percent of the maximum GBSS flow rate~~through the glovebox pressure control exhaust process vent to RVZ1.
3. The glovebox ventilation shuts down after 20 seconds due to the glovebox tritium monitors.
4. During the 30 seconds after the initiating event, the TPS room vents to the IF at an elevated rate due to the facility RVZ2 ventilation system.
5. The RVZ2 ventilation damper from the TPS room isolates after 30 seconds due to the glovebox tritium monitors.

6. The radioactive material is then dispersed throughout the IF and exits the facility to the environment through building penetrations.
7. Personal dosimeters, local radiation alarms, and alarms in the facility control room notify facility personnel of radiation leakage.
8. Facility personnel evacuate the immediate area within 10 minutes upon actuation of the radiation area monitor alarms.

Throughout the accident sequence, the leakage rate between the TPS glovebox and the TPS room is constant. After the TPS room ventilation is isolated, radiation transport is driven by air exchange between the TPS glovebox and the IF. Transport to the environment occurs through RCA boundary leak paths. The accident duration used in this analysis is 10 days, after which it is assumed that recovery actions will have occurred to stop further release and dispersion of radioactive material.

Safety Controls

The safety controls credited for mitigation of this accident are:

- TPS room ventilation isolations
- ~~GBSS~~Glovebox pressure control and VAC/ITS ventilation isolations
- TPS glovebox tritium radiation monitors
- Tritium confinement boundary, as described in Section 6a2.2

In addition, TPS glovebox deflagration is prevented by:

- TPS glovebox gas space inerted with ~~nitrogen~~helium
- TSP glovebox minimum volume prevents deflagration conditions

13a2.2.12.2.4 Damage to Equipment

Failure of the TPS piping and vessels does not cause subsequent damage to other equipment.

13a2.2.12.2.5 Radiation Source Terms

The initial MAR for this scenario is ~~236~~300,000 curies of tritium from the TPS equipment in the TPS glovebox.

The accident source term development is discussed in Section 13a2.2. The LPF model values used in the source term development for the public and worker doses are provided in Table 13a2.2-1 and Table 13a2.2-2, respectively.

13a2.2.12.2.6 Radiological Consequences

The radiological consequences of this accident scenario are determined as described in Section 13a2.2. The radiological consequences of this accident scenario are provided in Table 13a3-1 and meet the accident dose criteria.

13a2.2.12.3 ~~Tritium Release into the Irradiation Facility~~

~~A release of tritium from a tritium header outside of confinement is analyzed as a DBA. This accident is described in Subsection 13a2.1.12.3 as TPS Scenario 5. This analysis establishes the bounding radiological conditions for the direct release from the tritium header to the IF.~~

13a2.2.12.3.1 ~~Initial Conditions~~

~~Initial conditions for facility-specific events are described in Subsection 13a2.1.12.1.~~

13a2.2.12.3.2 ~~Initiating Event~~

~~An event causes a break in the tritium header, releasing the header inventory directly to the IF.~~

13a2.2.12.3.3 ~~Sequence of Events~~

1. ~~The initiating event is a break in the tritium header, which instantaneously releases the entire tritium inventory of the header into the IF.~~
2. ~~Personal dosimeters, local radiation alarms, and alarms in the facility control room notify facility personnel of radiation leakage.~~
3. ~~Facility personnel evacuate the immediate area within 10 minutes upon actuation of the radiation area monitor alarms.~~
4. ~~The radioactive material is then dispersed throughout the IF and exits the facility to the environment through building penetrations.~~

~~Safety Controls~~

~~No safety controls are credited for mitigation of the dose consequences for this accident.~~

13a2.2.12.3.4 ~~Damage to Equipment~~

~~Failure of the TPS header does not cause subsequent damage to equipment.~~

13a2.2.12.3.5 ~~Radiation Source Terms~~

~~The initial MAR for this scenario is 3000 curies of tritium from the tritium header.~~

~~The accident source term development is discussed in Section 13a2.2. The LPF model values used in the source term development for the public and worker doses are provided in Table 13a2.2-1 and Table 13a2.2-2, respectively.~~

13a2.2.12.3.6 ~~Radiological Consequences~~

~~The radiological consequences of this accident scenario are determined as described in Section 13a2.2. The radiological consequences of this accident scenario are provided in Table 13a3-1 and meet the accident dose criteria.~~

Table 13a2.2-1 – Summary of Radiation Transport Terms (Public)

Accident Category	ARF x LPF Nobles (30-day)	Iodine (30-day)	Non-volatiles (30-day)	Tritium (10-day)	Tritium (30-day)
Maximum Hypothetical Accident (Subsection 13a2.2.1)	9.98E-01	9.98E-01	0	N/A	N/A
Mishandling or Malfunction of Target Solution (Subsection 13a2.2.4)	9.98E-01	1.22E-01	8.39E-07	N/A	N/A
External Events (Subsection 13a2.2.6)	N/A	N/A	N/A	N/A	3.66E-01
Mishandling or Malfunction of Equipment (Subsection 13a2.2.7)	9.98E-01	5.72E-01	0	N/A	N/A
Facility-Specific Events (Subsection 13a2.2.12)					
• Tritium Release into an IU Cell	N/A	N/A	N/A	N/A	3.66E-01
• Tritium Release into the Tritium Purification System Glovebox	N/A	N/A	N/A	~~1.57~~1.78E-01	N/A
~~• Tritium Release into the Irradiation Facility (Header Release)~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~1.00E+00~~

Table 13a2.2-2 – Summary of Radiation Transport Terms (Worker)

	ARF x LPF (10-minute)			
Accident Category	**Nobles**	**Iodine**	**Non-volatiles**	**Tritium**
Maximum Hypothetical Accident (Subsection 13a2.2.1)	1.19E-02	1.19E-02	0	N/A
Mishandling or Malfunction of Target Solution (Subsection 13a2.2.4)	8.24E-03	4.03E-05	9.69E-11	N/A
External Events (Subsection 13a2.2.6)	N/A	N/A	N/A	1.47E-01
Mishandling or Malfunction of Equipment (Subsection 13a2.2.7)	1.19E-02	1.17E-02	0	N/A
Facility-Specific Events (Subsection 13a2.2.12)				
• Tritium Release into an IU Cell	N/A	N/A	N/A	1.47E-01
• Tritium Release into the Tritium Purification System Glovebox	N/A	N/A	N/A	~~2.89~~8.03E-04
~~Tritium Release into the Irradiation Facility (Header Release)~~	~~N/A~~	~~N/A~~	~~N/A~~	~~1.00E+00~~

Table 13a3-1 – Irradiation Facility Accident Dose Consequences

Accident Category (Bounding Scenario)	Public Dose TEDE (mrem)	Worker Dose TEDE (mrem)
Maximum Hypothetical Accident (Subsection 13a2.2.1)		
• TOGS failure with complete PVVS blockage	366	4800
Insertion of Excess Reactivity (Subsection 13a2.2.2)	No consequences	
Reduction in Cooling (Subsection 13a2.2.3)	No consequences	
Mishandling or Malfunction of Target Solution (Subsection 13a2.2.4)		
• Primary system boundary leak into an IU cell	65	1480
Loss of Off-Site Power (LOOP) (Subsection 13a2.2.5)	No consequences	
External Events (Subsection 13a2.2.6)	106	4930
Mishandling or Malfunction of Equipment (Subsection 13a2.2.7)	234	4760
Large Undamped Power Oscillations (Subsection 13a2.2.8)	No consequences	
Detonation and Deflagration affecting the Primary System Boundary (Subsection 13a2.2.9)	No consequences	
Unintended Exothermic Chemical Reactions other than Detonation (Subsection 13a2.2.10)	No consequences	
System Interaction Events (Subsection 13a2.2.11)	No consequences	
Facility-Specific Events (Subsection 13a2.2.12)		
• Tritium Release into an IU Cell	13	616
• Tritium Release into the Tritium Purification System Glove Box	~~335~~482	~~71~~252
~~Tritium Release into the Irradiation Facility (Header Release)~~	~~27~~	~~3140~~

13b RADIOISOTOPE PRODUCTION FACILITY ACCIDENT ANALYSES

13b.1 RADIOISOTOPE PRODUCTION FACILITY ACCIDENT ANALYSIS METHODOLOGY

The accident analysis process for the radioisotope production facility (RPF) was conducted using the same methodology as the accident analysis in the irradiation facility (IF), described in Section 13a2.1. The radiological consequences were evaluated using the same methodology described in Section 13a2.2 for the IF.

13b.1.1 PROCESSES CONDUCTED OUTSIDE THE IRRADIATION FACILITY

The production of molybdenum-99 (Mo-99) and other fission products occurs in the IF. After the irradiation of the target solution is completed, the solution is transferred from the IF to the RPF and processed for radioisotope extraction and purification. Other processes occurring within the RPF include target solution processes for reuse, waste handling, and product packaging. These processes that occur within the RPF are evaluated via ~~an Integrated Safety Analysis (ISA) process, involving~~ hazard identification and a process hazard analysis (PHA). The hazard identification process includes a review of potential radiological hazards, chemical hazards, and other facility hazards that might be present.

Process that are conducted in the RPF ~~and are analyzed in the ISA~~ fall into the following categories:

- Operations with special nuclear material (SNM)
  - Irradiated target solution processed for radioisotope extraction
  - Irradiated target solution processed for reuse or for waste disposal
  - Operations with unirradiated SNM
- Radiochemical operations
- Operations with hazardous chemicals

The operations involving SNM include the uranium receipt and storage system (URSS), target solution preparation system (TSPS), the molybdenum extraction and purification system (MEPS), the iodine and xenon purification and packaging (IXP) system, the quality control and analytical testing laboratories (LABS), the target solution staging system (TSSS), the vacuum transfer system (VTS), the radioactive liquid waste storage (RLWS) system, the radioactive liquid waste immobilization (RLWI) system, and the radioactive drain system (RDS). The operations that do not involve SNM but pose a radiological or chemical hazard from radiochemical operations and operations with hazardous chemicals include the molybdenum isotope packaging system (MIPS), the process vessel vent system (PVVS), and the facility chemical reagent system (FCRS). Other systems in the RPF that do not have direct radiological or chemical hazards are evaluated in the ISA for impact on the systems listed above.

The URSS receives, thermally oxidizes (if needed), repackages, and stores low-enriched uranium prior to target solution preparation in the TSPS. The URSS is classified both as an operation with unirradiated SNM and as an operation with hazardous chemicals. Because of the presence of uranium, the URSS poses a criticality, radiological, and chemical hazard.

The TSPS prepares low-enriched uranyl sulfate solution, which, once qualified for use, is referred to as target solution. The TSPS is classified both as an operation with unirradiated SNM or transferred to the RLWS for disposal. The RDS involves operations with irradiated target solution processed for reuse or for waste disposal. Because of the presence of uranium, the RDS has the potential for a criticality as well as radiological and chemical exposure hazards.

The PVVS handles the off-gas resulting from the processes of the IF and the RPF. The PVVS is classified as a radiochemical operation and poses a radiological hazard. This process contains radionuclides removed from the off-gas.

The FCRS stores and supplies reagents to the processes of the RPF. The FCRS is classified as an operation with hazardous chemicals and poses a chemical hazard. The system contains no SNM or radionuclides.

13b.1.2 ACCIDENT INITIATING EVENTS

The design basis accidents (DBAs) identified in this section are initiating events (IEs) followed by credible accident scenarios that range from anticipated events, such as a loss of electrical power, to events that, while still credible, are considered unlikely to occur during the lifetime of the facility. The maximum hypothetical accident (MHA) is an accident scenario defined to result in the worst-case (bounding) radiological consequences for the facility. Although the MHA is an accident scenario, it does not define a credible initiating event or accident progression, except for what is necessary to evaluate the consequences. Its purpose is to provide the most limiting consequence for the facility that bounds all credible DBAs.

DBAs were identified using the following sources of information:

- IEs and accidents identified in the Interim Staff Guidance Augmenting NUREG-1537 (USNRC, 2012)
- Hazard and operability (HAZOP) studies, failure modes and effects analyses (FMEA), and the PHA methods ~~used as part of the ISA process~~
- Experience of the hazard analysis team

The DBA identification process resulted in a series of accident sequences that were then categorized into the following accident types:

- MHA
- External Events
- Critical Equipment Malfunction (i.e., Malfunction or Mishandling of Equipment)
- Inadvertent Nuclear Criticality in the RPF
- RPF Fire
- Hazardous Chemical Accidents

The effects of a loss of off-site power (LOOP) and operator errors were considered as initiating events within the scope of the PHA and were not classified as separate accident types. Qualitative evaluations are performed on the DBAs to further identify the bounding or limiting accidents and scenarios, including the partial loss of systems or functions that could result in the highest potential consequences. These evaluations are based on a review of identification of causes, the initial conditions, and assumptions for each accident.

Using the range of accident scenarios identified, each scenario was qualitatively evaluated for its potential chemical or radiological consequences. Scenarios that presented potential sequence is prevented. The RLWI enclosure damage scenario is further described in Subsection 13b.2.4.5.

Scenario 19 - Heavy Load Drop onto a Tank Vault or Pipe Trench Cover Block

A crane failure or operator error resulting in a heavy load drop on a tank vault or pipe trench cover block causes a damage to the cover block and internal equipment. Potential consequences of a heavy load drop include radiological dose. To prevent damage to a cover block, the cover blocks have been designed to withstand a heavy load drop. This scenario was evaluated qualitatively and is not described in Section 13b.2 because the accident sequence is prevented.

13b.1.2.4 RPF Inadvertent Nuclear Criticality

Nuclear criticality safety (NCS) in the RPF is accomplished through the use of criticality safety controls to prevent criticality during normal and abnormal conditions. Each process that involves the use, handling, or storage of SNM is evaluated by the SHINE nuclear criticality safety staff under the requirements of the NCS program. ~~The results of the criticality safety evaluations are incorporated into the ISA.~~ Radiological consequences of criticality accidents are not included in the accident analysis because preventative controls are used to ensure criticality events are highly unlikely. Further discussion of the criticality safety bases for RPF processes is included in Section 6b.3.

13b.1.2.5 RPF Fire

The RPF was evaluated for internal fire risks based on the fire hazards analysis (FHA). The FHA documents the facility fire areas and each area was individually evaluated for fire risks. Internal facility fires are generally evaluated as an initiating event for the release of radioactive material and are included in the scenarios evaluated in Section 13a2.1 and this section. Two unique scenarios are described below and evaluated in detail in Section 13b.2.

The main production facility maintains a facility fire protection plan to reduce the risks of fires, as described in Section 9a2.3.

Scenario 1 - PVVS Carbon Delay Bed Fire

An upset or malfunction in the PVVS (high moisture or high temperature) results in ignition of the carbon media in a delay bed. A fire in the carbon delay bed results in a release of the captured radioactive material into the PVVS downstream of the delay bed and to the environment via the facility exhaust stack. A release to the environment results in radiological exposure to the public. Release of radioactive material in excess of acceptable levels is prevented by the carbon delay bed carbon monoxide (CO) detectors, which provide a signal to ESFAS to close the PVVS carbon delay bed isolation valves for the affected carbon delay bed group and bypass the affected group in the event of high CO concentration indicative of a fire in a bed. Releases to the RPF are further mitigated by the process confinement boundary (carbon delay bed vaults). This scenario is further described in Subsection 13b.2.6.1.