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Tritium Glovebox Stripper System Seismic Design Evaluation

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EXECUTIVE SUMMARY

The use of glovebox confinement at US Department of Energy (DOE) tritium facilities has been discussed in numerous publications.[1-4] Glovebox confinement protects the workers from radioactive material (especially tritium oxide), provides an inert atmosphere for prevention of flammable gas mixtures and deflagrations, and allows recovery of tritium released from the process into the glovebox when a glovebox stripper system (GBSS) is part of the design. Tritium recovery from the glovebox atmosphere reduces emissions from the facility and the radiological dose to the public. Location of US DOE defense programs facilities away from public boundaries also aids in reducing radiological doses to the public.[5]

Tritium is also used outside of US DOE defense programs for fusion research[6] and other pending applications.[7] Many times these facilities are closer to public boundaries than defense programs facilities and operating licenses may be based on Nuclear Regulatory Commission (NRC) requirements instead of DOE requirements. These differences will require a different approach to glovebox and GBSS designs and requirements – especially under design basis accident (DBA) seismic events.

Tritium releases to the public from US DOE tritium facilities are many times mitigated by the facilities being located kilometers away from facility boundaries. Glovebox confinement systems are typically designed to maintain mechanical integrity after a DBA seismic event, but not maintain its tritium confinement function. For NRC regulated facilities located close to the public, glovebox designs that maintain some degree of tritium confinement and fitted with a GBSS that also remains functional after a DBA seismic event may be required. This report is to discuss the design considerations and components of a GBSS to survive a DBA seismic event.

To minimize radiological doses to the public, the NRC imposes certain design criteria to Safety Related (SR) components and systems. The NRC requires a defense-in-depth practice that requires independence of components and systems to avoid common mode failures. A Single-Failure requirement states that systems and components required to perform their intended safety function are designed to include sufficient redundancy and independence such that failure of any active component does not result in a loss of the capability of the system to perform its safety function. After the initiating event (i.e. the DBA seismic event), a single failure is assumed to be a random event. An active component is a device that is expected to change state or position to perform its safety related function upon demand.

This is a study based upon design concepts to identify issues and considerations for design of a Seismic GBSS. Safety requirements and analysis should be considered preliminary. Safety requirements for design of GBSS should be developed and finalized as a part of the final design process.

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LIST OF ABBREVIATIONS

AE	Analytical Element
AMSB	Ambient Molecular Sieve Bed
ANS	Analytical System
Ar	Argon
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COTS	Commercial Off The Shelf
D	Deuterium (^2H)
DBA	Design Basis Accident
DBE	Design Basis Event
Decon	Decontamination
DI	Diffuser
E	Evacuation pump
FC	Flow Controller
FCV	Feed Calibrated Volume
FE	Flow Element
FPR	Functional Performance Requirements
FSAR	Final Safety Analysis Report
GB	Glovebox
GBPC	Glovebox Pass Chamber
GBSS	Glovebox Stripper System
GC	Gas Chromatography
GPPC	Glove Port Pass Chamber

H	Hydrogen (protium, ^{1}H)
HAZOP	Hazard and Operability Study
HCl	Hydrogen chloride
He-3	Helium-3 (^{3}He)
HF	Hydrogen Fluoride
HOLD	Term used when requirements are given a temporary value without a firm technical basis.
HTV	Hydride Transport Vessel (for shipping tritium)
HVAC	Heating Ventilation and Air Conditioning
IC	Ionization Chamber
ICD	Interface Control Document
I/O	Input/Output
IRS	In-structure response spectrum
L	Liter (volume)
LFL	Lower Flammability Limit
LMSB	Low-temperature Molecular Sieve Bed
LOC	Limiting Oxidant Concentration
LOCA	Loss of Cooling Accident
MB	Metal Bellows pump
MCR	Main Control Room
MDP	Molecular Drag Pump
ME	Moisture Element (i.e. moisture probe)
MFC	Mass Flow Controller
Mo-99	Molybdenum-99 (^{99}Mo)
MS	Molecular Sieve

MSB	Molecular Sieve Bed
N_2	Nitrogen
Na	Sodium
NA	Not Applicable
NBI	Neutral Beam Injector
NEG	Non-Evaporative Getter
NQ_3	Ammonia (Q = any hydrogen isotope)
NQA-1	Nuclear Quality Assurance-1
NRC	Nuclear Regulatory Commission
O_2	Oxygen
OGM	Open Glovebox Maintenance
P&ID	Process and Instrument Diagram
PCV	Product Calibrated Volume
Pd	Palladium
Pd/k	Palladium deposited on kieselguhr
PdM	Predictive Maintenance
PE	Pressure Element
PFD	Process Flow Diagram
PFP	Product Feed Pump (also called Tritium Feed Pump)
PGS	Purge Gas Stripper
ppm	Parts Per Million
PPP	Pressure Protection Plan
PSAR	Preliminary Safety Analysis Report
PTFE	Polytetrafluoroethylene (e.g. Teflon®)
PV	Product Vessel (for shipping tritium)

PvM	Preventive Maintenance
Q	Any hydrogen isotope (^{1}H = protium, ^{2}H = deuterium, ^{3}H = tritium)
Q_2O	Water
RAMI	Reliability, Availability, Maintainability, and Inspect ability
RE	Radiation Element (i.e. ionization chamber)
RGA	Residual Gas Analyzer
RH	Relative Humidity
RIP	Repair in Place
R&R	Remove and Repair
sccm	Standard Cubic Centimeters per Minute flow rate
SDD	System Design Description
SDC	Seismic Design Category
SIL	Safety Integrity Level
SLPM	Standard Liters per Minute (flow rate) (STP: 0°C and 1 atmosphere)
SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions LLC
SRS	Savannah River Site
STP	Standard Temperature and Pressure (0ºC, 1 atmosphere)
T	Tritium (^{3}H)
TBD	To Be Determined
TCV	Tritium Calibrated Volume
TCVG	Thermocouple Vacuum Gauge
TE	Temperature Element
TF	Tritium Fluoride
TFP	Tritium Feed Pump (also known as Product Feed Pump)

TFS	Tritium Feed Supply
TFTR	Tokamak Fusion Test Reactor (former PPPL fusion experiment)
TMP	Turbo-Molecular Pump
TRS	Tritium Recovery System
UPS	Uninterruptible Power Supply

1.0 INTRODUCTION

The use of glovebox confinement at US Department of Energy (DOE) tritium facilities has been discussed in numerous publications.[1-4] Glovebox confinement protects the workers from radioactive material (especially tritium oxide), provides an inert atmosphere for prevention of flammable gas mixtures and deflagrations, and allows recovery of tritium released from the process into the glovebox when a glovebox stripper system (GBSS) is part of the design. Tritium recovery from the glovebox atmosphere reduces emissions from the facility and the radiological dose to the public. Location of US DOE defense programs facilities away from public boundaries also aids in reducing radiological doses to the public.[5]

Tritium is also used outside of US DOE defense programs for fusion research[6] and other pending applications.[7] Many times these facilities are closer to public boundaries than defense programs facilities and operating licenses may be based on Nuclear Regulatory Commission (NRC) requirements instead of DOE requirements. These differences will require a different approach to glovebox and GBSS designs and requirements – especially under design basis accident (DBA) seismic events.

2.0 BACKGROUND

Tritium releases to the public from US DOE tritium facilities are many times mitigated by the facilities being located kilometers away from facility boundaries. Glovebox confinement systems are typically designed to maintain mechanical integrity after a DBA seismic event, but not maintain its tritium confinement function. For NRC regulated facilities located close to the public, glovebox designs that maintain some degree of tritium confinement and fitted with a GBSS that also remains functional after a DBA seismic event may be required. This report is to discuss the design considerations and components of a GBSS to survive a DBA seismic event.

It is assumed in this report the glovebox still retains a level of tritium confinement after the DBA seismic event that allows stripping of tritium released into the glovebox. Since most tritium gloveboxes operate at negative pressure relative to the room, it is assumed the total air in-leakage of the glovebox after the DBA event is still within the design capacity of the GBSS. The design capacity of the GBSS may be different for normal operations than for post-seismic DBA events.

For this report, it will be assumed the tritium stripping technology used is catalytic oxidation of Q2 to Q2 oxide followed by water capture. The components of a typical GBSS using this technology are illustrated in Figure 2-1. A single-stage of tritium stripping typically contains a pre-heater for the catalyst bed used to convert molecular tritium compounds to tritiated water. The catalyst bed operates at temperatures above ambient and is followed by a chiller so water can be absorbed on an ambient molecular sieve bed (AMSB). Stripper efficiencies of this type are typically greater than 99% efficient[8] and higher efficiencies are obtained with recirculating and/or multi-stage stripper systems. A typically recirculating GBSS is illustrated in Figure 2-2: a second AMSB is included for system maintainability and a system purge for oxygen control of the glovebox atmosphere.

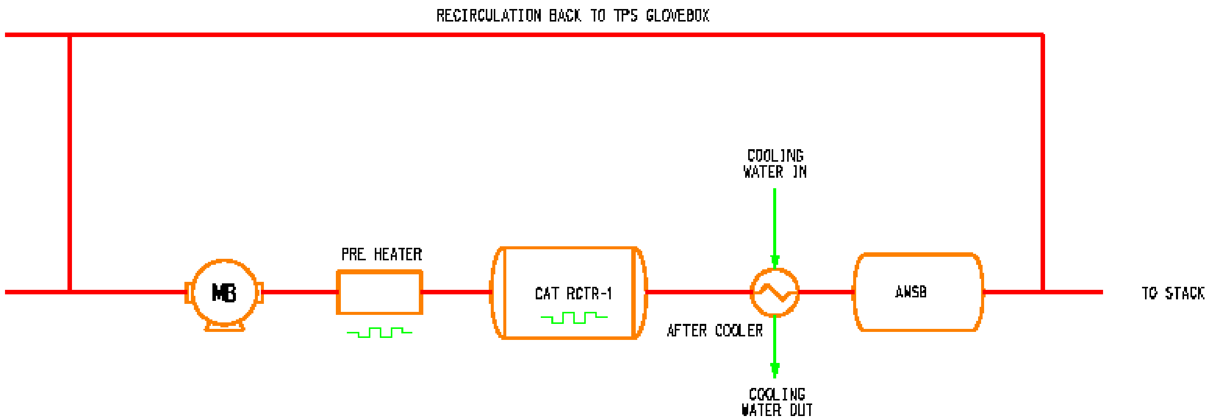

Figure 2-1 Single-Stage Catalytic Oxidation/Absorption Stripper System

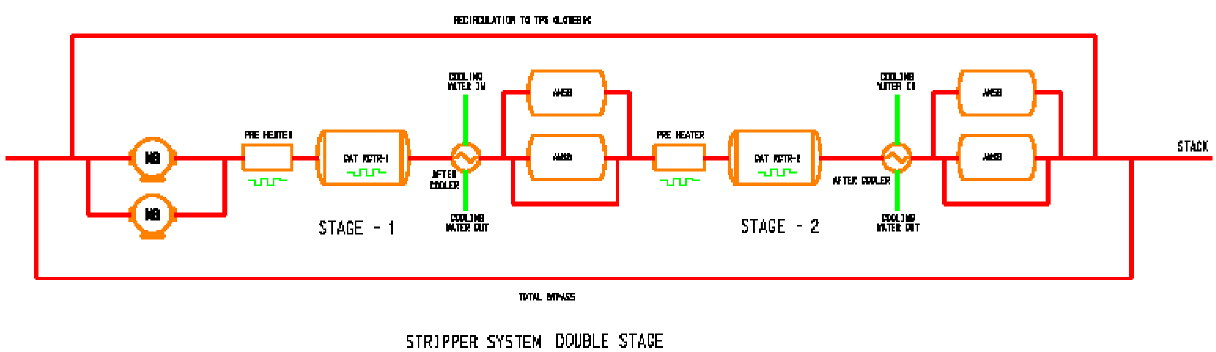

Figure 2-2 Glovebox with Recirculating GBSS

To minimize radiological doses to the public, the NRC imposes certain design criteria to Safety Related (SR) components and systems. The NRC requires a defense-in-depth practice that requires independence of components and systems to avoid common mode failures. A Single-Failure requirement states that systems and components required to perform their intended safety function are designed to include sufficient redundancy and independence such that failure of any active component does not result in a loss of the capability of the system to perform its safety function. After the initiating event (i.e. the DBA seismic event), a single failure is assumed to be a random event. An active component is a device that is expected to change state or position to perform its safety related function upon demand.

To satisfy the Single-Failure requirement, Figure 2-1 is redrawn in Figure 2-3 to include redundant pre-heaters, and two catalytic reactors since the power supply to the pre-heaters and the catalytic reactors are considered active components while an AMSB is considered a passive component. It is assumed that one AMSB when initially installed has enough water absorption capacity to not only absorb the tritiated water generated from combusting tritium containing compounds to water, but also the ambient water ingress into the glovebox during the duration of required stripper operations post-DBA.

Figure 2-4 shows that same components in Figure 2-3 in an alternate arrangement where there are effectively two independent stripper systems in series. Design of a GBSS which can function after the DBA is discussed in the next section.

The NRC requires these systems to meet the requirements of: 10 CFR70.64 "Requirements for New Facilities or New Processes at Existing Facilities" and Appendix A of 10 CFR 50 "General Design Criteria for Nuclear Power Plants.

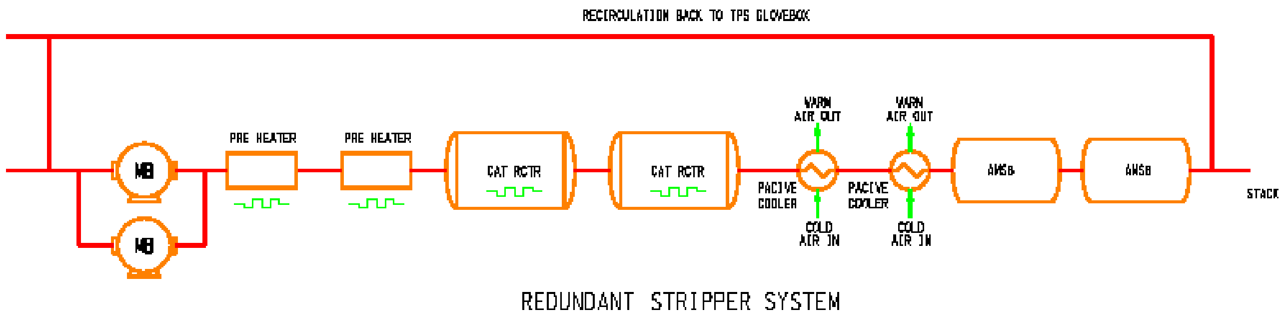

Figure 2-3 Redundant GBSS Component

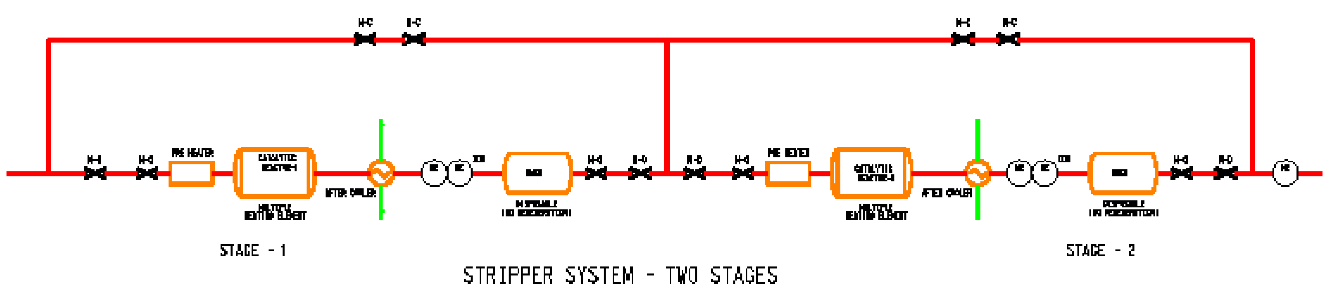

Figure 2-4 Redundant GBSSs: Independent Stripper Systems in Series

3.0 SCOPE OF DOCUMENT

The confinement system (glovebox) function to provide a barrier between the atmospheres inside and outside and the stripper system function to oxidize isotopes of hydrogen and absorb water are intimately linked to achieve overall goals of providing non-hazardous environments, worker protection and public safety. Ideally a glovebox would be leak-tight and the stripper system would only need the capacity to capture leaked tritium. A leak tight glovebox is unrealistic and an oxidation/absorption system can't distinguish between isotopes of hydrogen. Therefore, the stripper system capacity must be sufficient to capture all isotopes of hydrogen leaking from the process systems and in leakage into the glovebox from the outside atmosphere, with sufficient efficiency to meet the overall goals. A large source of hydrogen is atmospheric moisture that enters the glovebox through leaks or diffuses through gloves.

Additionally, since a stripper system is inherently a feed and bleed process, time is important and the glovebox atmosphere is maintained slightly negative, i.e., a vacuum, so tritium is less likely to leak out before it is removed or stripped out. The stripper system, in conjunction with the source of inert gas for the glovebox atmosphere, also maintains the glovebox atmosphere slightly negative.

A glovebox atmosphere is "inerted" to avoid a hazardous situation when a tritium or deuterium leak occurs. More accurately, the glovebox atmosphere is maintained such that the oxygen concentration is less than the minimum oxidant concentration for hydrogen. The source of inert gas, typically nitrogen, is provided and controlled by the confinement system.

This is a study based upon design concepts to identify issues and considerations for design of a Seismic GBSS. Safety requirements and analysis should be considered preliminary. Safety requirements for design of GBSS should be developed and finalized as a part of the final design process.

4.0 GBSS SAFETY REQUIREMENTS

4.1 Listing of Safety Requirements

The following pages contain a listing of the safety requirements and their functions, failure effects, critical characteristics and verification methods. These represent the major equipment for the Glovebox Stripper System (GBSS). With a number of the following equipment alternate designs or equipment will be discussed.

This is a study based upon design concepts to identify issues and considerations for design of a Seismic GBSS. Information including safety requirements, discussion of component and vendor identification should be considered preliminary. Safety requirements for design of GBSS should be developed and finalized as a part of the final design process.

NOTE: All notes are contained on the pages immediately following the Safety Requirements charts.

1. EVENT/ACCIDENT	• Natural Phenomena Hazard (NPH) most challenging of which is a Seismic Event. • Design Basis Accident (DBA) which includes: o Design Basis Earthquake (DBE) is most demanding o Breach of Primary confinement (TBD quantity of Tritium) o Fire -Deflagration o Loss of Power (single train, TBD duration of both trains)
2. SAFETY FUNCTION STATEMENT	• Minimize the release of Tritium from the tritium facility to the public at less than regulatory limit • Eliminate deflagration hazard.
3. SYSTEM SAFETY FUNCTION	• System designed at all times to keep tritium in a safe state even during and after design basis accidents (DBA) • Keep any process Tritium that leaks from getting into the process facilities or up the stack to the general public during a Seismic Event • Tritium containment, if required, secondary confinement and tritium stripping (removal) • Provide inert environment in the tritium gloveboxes (Ref. section 5)
4. SYSTEM LEVEL DESIGN CRITERIA	• Primary Confinement –confine sufficient amount of T2 in the tanks such that capacity of GBSS is not exceeded, with a single failure. • Secondary Confinement- prevent out leakage of T2 • Secondary Confinement- maintain Oxygen content less than NFPA requirement. • Tritium Removal – Capable post DBE
5. REQUIRED SAFETY INTEGRITY LEVEL (SIL)	• Primary Confinement- Post DBE : To Be Determined, Likely SIL-3 (require analysis to justify) • Secondary Confinement, pressure boundary- N/A • Secondary Confinement, Inert atmosphere To Be Determined, Likely SIL-3 (require analysis to justify) • Tritium Removal- To Be Determined, Likely SIL-3 (require analysis to justify)
6. SAFETY FUNCTION PERFORMANCE REQUIREMENTS	• Primary Confinement- (TBD) g of T2 post DBE confined in qualified vessels isolated by STCS • Secondary Confinement- Leak rates Post DBE: 100 times higher than Pre DBE. • Tritium Removal -.Post DBE: DF>100
7. SAFETY SYSTEM DIAGRAM/ DESCRIPTION REFERENCE DOCUMENTS	• Primary Confinement- (Tank, First Valve, Solenoids(2), Motion Sensor (3), 2/3 voting logic, welded piping plus process value that is not credited) • Secondary Confinement- See Figure 3-2, 5-1 • Secondary Confinement- See Figure 3-2, 5-1 • Tritium Removal – See Figure 3-2, 5-1
8.INTERFACING / SUPPORTING SYSTEMS / STRUCTURES	• The GBSS will interface with the facility (stack exhaust and support systems) and with the tritium processing glovebox and any other equipment that is handling or processing tritium.

9. SYSTEM / COMPONENT / PART	10. COMPONENTS SAFETY FUNCTION	11.COMPONENT FAILURE MODES	12. FAILURE EFFECTS ON SAFETY FUNCTION	13. FUNCTIONAL RELIABILITY OF SAFETY COMPONENT	14. COMPONENT'S CRITICAL CHARACTERISTICS /DESIGN REQUIREMENTS TO SUPPORT SAFETY FUNCTION RELIABILITY	15. VERIFICATION METHOD FOR ACCEPTANCE (CGD)
All Glovebox Components – (Including appendages)	Secondary Confinement • Worker and Public protection (minimize T2 leaks to the environment)	Leak	• Exposure of Worker and Public to T2	At all times when T2 (and D2) is not in a safe state (including before, during, and after DBA)	Design loads include responses to all NPH, overpressure/vacuum: • Shell: ASCE 7 • Windows: (See Note 1 & 2) • Gloves: (See Note 1) • Bulkhead Fittings: (See Note 1,3 &6) • Jacket for Pipe: B31.3, Design Only	Design: Analyze per-ASCE-7, shake test per IEEE 344 as necessary Leak per leak test per AGS-G001 & G006 (See Note 3) Glovebox Overpressure/Vacuum relief device (bubbler) flow test
	Secondary Confinement • Prevent Deflagration		• Flammable Atmosphere			

9. SYSTEM / COMPONENT / PART	10. COMPONENTS SAFETY FUNCTION	11.COMPONENT FAILURE MODES	12. FAILURE EFFECTS ON SAFETY FUNCTION	13. FUNCTIONAL RELIABILITY OF SAFETY COMPONENT	14. COMPONENT'S CRITICAL CHARACTERISTICS /DESIGN REQUIREMENTS TO SUPPORT SAFETY FUNCTION RELIABILITY	15. VERIFICATION METHOD FOR ACCEPTANCE (CGD)
GBSS Components, Passive (Pressure Boundary) (Note 9)	Secondary Confinement • Worker and Public Protection (minimize tritium leak to environment	Leak	Exposure of Worker and Public to tritium	At all times when Tritium is not in a safe state (before, during and after a DBA) (See Note 10)	• Piping and unlisted components – ASME B31.3 • Vessel - B&PV Code	Analysis and code leak test (See Notes 2 & 3)
	Secondary Confinement • Prevent Deflagration		Flammable atmosphere	At all times when Tritium is not in a safe state (before, during and after a DBA) (See Note 10)		

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GBSS Manual Valves – (See Note 11)	Secondary Confinement –	**(See GBSS Components above)**		**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**
	Pressure boundary (Passive)	Leak (through Valve Seat)	**(See GBSS Components above)**	When Isolation is required (e.g. removal of AMSB)	Valve Seat leak tightness	Sensitive leak test (See Note 5)

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Remotely Operated Process and Isolation Valve (Actuator & Valve)	Secondary Confinement - Pressure boundary (Passive)	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**
	Prevent leak of tritium and in-leakage of air (Active)	Leak (through Valve Seat)	See GBSS Components	When isolation is required (post DBA)	Pressure boundary (Active)/ ASME	Analysis and code leak test (See Note 5)
	Maintain stripper system efficiency for the GBSS process equipment (Active)	Flow Restriction	Unmitigated release of T2 Flammable Atmosphere	At all times when T2 (and D2) is not in a safe state (including before, during, and after DBA)	• Pressure boundary (Active)/ ASME • Provide Alternate/redundant flow path	By Design (Independent Review)
	Open/Close as commanded (prevent out-leakage of air, control process flow)	Leak (through valve seat)	See GBSS Components		Valve seat leak tightness	Sensitive leak test
		Fails to open	Reduction in GBSS performance		• Operator reliability, as commanded • Provide redundant isolation valve	• Test per IEEE323 (Shake Table Test) • By Design (Independent Review)
		Fails to close	See GBSS Components		• Operator reliability, as commanded • Provide redundant isolation valve	• Test per IEEE323 (Shake Table Test) • By Design (Independent Review)

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Automatic Pressure Control Valve (Actuator & Valve)	Secondary Confinement **-** Pressure boundary (Passive)	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**
	Pressure control in glovebox	Fails to control vacuum in glovebox (none or too low)	Unmitigated release of T2	At all times when T2 (and D2) is not in a safe state (including before, during, and after DBA)	• Operates reliably • Provide redundant control	• Test per IEEE323 (Shake Table Test) • By Design (Independent Review) (See Note 12)
		Fails to control vacuum in glovebox (too high)	Unmitigated release of T2 Flammable Atmosphere		• Glovebox vacuum relief or • Limit vacuum pumping capability	• Analysis and performance test • Analysis and performance test
Alternate Design	Secondary Confinement **-** Pressure boundary (Passive)	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**

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Automatic Flow Control Valve (Actuator & Valve)	Secondary Confinement - Pressure boundary (Passive) (See Note 13)	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**
	Pressure control in glovebox	Flow too low (pressure control valve unable to control pressure in glovebox) vacuum	Unmitigated release of T2 Flammable Atmosphere	At all times when T2 (and D2) is not in a safe state (including before, during, and after DBA)	• Operates reliability • Provide redundant flow control	• Test per IEEE323 (Shake Table Test) (See Note 14) • By Design (Independent Review)
	Prevent process leaks (tritium out) (Active)	Flow too high	Stripper System efficiency is reduced		Same as flow too low	Same as flow too low
Threaded Piping and Fittings	Secondary Confinement - Pressure boundary (Passive)	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**

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O2 Monitor Outside of Glovebox **(**Monitoring Glovebox atmosphere**)**	Secondary Confinement **-**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**
	Monitor glovebox for breach of secondary confinement	Failure to detect oxygen concentration above LOC	Unaware of potential flammable condition (glovebox leak) • Appropriate responsive actions not taken	At all times when tritium (deuterium) is not in safe condition. Not required post-DBA (confinement is assumed to be breached)	Detection w/sufficient sensitivity and margin	• Initial Calibration Testing • Periodic Calibration Testing
		False alarm	• Unnecessary responses			
O2 Monitor Inside of Glovebox **(**Monitoring Glovebox atmosphere**)**	Monitor glovebox for breach of secondary confinement	Failure to detect oxygen atm above LOC	Unaware of potential flammable condition (glovebox leak) • Appropriate responsive actions not taken	At all times when tritium (deuterium) is not in safe condition. Not required post-DBA (confinement is assumed to be breached)	Detection w/sufficient sensitivity and margin	• Initial Calibration Testing • Periodic Calibration Testing
		False alarm	• Unnecessary responses			

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Ambient Molecular Sieve Beds (AMSB)- Zeolite Bed (Z-Bed) .	Secondary Confinement - Pressure boundary (Passive)	**(See All Process Components)**	**(See All Process Components)**	**(See All Process Components)**	**(See All Process Components)**	**(See All Process Components)**
	Tritium Stripping from the tritium glovebox effluent paths	• Saturation – moisture on zeolite exceeds design capacity	Tritium release exceeds limits due to reduction in Stripping performance	At all times when Tritium is not in a safe state (including before, during, and after DBA)	• Design capacity • Available Stripping capacity (sufficiently dry to maintain reserve capacity for postulated accident)	• Weigh contents • Measurement (Moisture meter) operations response and administrative control
		• Poison/Aging – zeolite unable to adsorb moisture due to offending chemical or particulate and/or due to polymer breakdown or similar mechanism				
		• Channeling or bypassing within AMSB			• molecular sieve material • Bed Design (to avoid channeling)	• Verify/certify correct material • Design review
Alternate Design: Three AMSB Configuration (See Section 10.4 for details)	Tritium Stripping from the tritium glovebox effluent paths	• Saturation – moisture on zeolite exceeds design capacity			• Design capacity • Available Stripping capacity (sufficiently dry to maintain reserve capacity for postulated accident)	• Weigh contents • Measurement (Moisture meter) operations response and administrative control

9. SYSTEM / COMPONENT / PART	10. COMPONENTS SAFETY FUNCTION	11.COMPONENT FAILURE MODES	12. FAILURE EFFECTS ON SAFETY FUNCTION	13. FUNCTIONAL RELIABILITY OF SAFETY COMPONENT	14. COMPONENT'S CRITICAL CHARACTERISTICS /DESIGN REQUIREMENTS TO SUPPORT SAFETY FUNCTION RELIABILITY	15. VERIFICATION METHOD FOR ACCEPTANCE (CGD)
Preheater	Secondary Confinement **-** Pressure boundary (Passive)	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**
	Heat GBSS Process	GBSS Process temp too low (Not all T2 will combined with O2 to become water	Tritium release exceeds limits due to reduction in Stripping performance	At all times when T2 (and D2) is not in a safe state (including before, during, and after DBA)	Redundant heaters Redundant power supply	Analysis and testing for all components (including controls) (See Section 12.0)
	Heat GBSS Process	GBSS Process temp too high (May damage Cat Rx)			Independent heater, independent controller and high temp interlock	Independent Temp Control (See Figure 12.1) Analysis and testing for all components (including controls)
Ion Chamber and Components	Secondary Confinement **-** Pressure boundary (Passive)	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**
	Detect high concentrations of T2	Fails to detect	Unmitigated release of T2 or T2 release exceeding limits	At all times when T2 (and D2) is not in a safe state (including before, during, and after DBA)	Detection sensitivity	Test (See Note 5)

9. SYSTEM / COMPONENT / PART	10. COMPONENTS SAFETY FUNCTION	11.COMPONENT FAILURE MODES	12. FAILURE EFFECTS ON SAFETY FUNCTION	13. FUNCTIONAL RELIABILITY OF SAFETY COMPONENT	14. COMPONENT'S CRITICAL CHARACTERISTICS /DESIGN REQUIREMENTS TO SUPPORT SAFETY FUNCTION RELIABILITY	15. VERIFICATION METHOD FOR ACCEPTANCE (CGD)
Catalytic Reactor (Cat Rx) .	Secondary Confinement - Pressure boundary (Passive)	**(See All Process Components)**	**(See All Process Components)**	**(See All Process Components)**	**(See All Process Components)**	**(See All Process Components)**
	Tritium Stripping from the tritium glovebox effluent paths	• Poison/Aging – Cat Rx unable to provide oxidation due to offending chemical or particulate and/or due to polymer breakdown or similar mechanism	Tritium release exceeds limits due to reduction in Cat Rx Oxidation performance	At all times when Tritium is not in a safe state (including before, during, and after DBA)	• Design capacity	• Weigh contents
		• Channeling or bypassing within Cat Rx			• Catalytic material • Bed Design (to avoid channeling)	• Verify/certify correct material • Design review

9. SYSTEM / COMPONENT / PART	10. COMPONENTS SAFETY FUNCTION	11.COMPONENT FAILURE MODES	12. FAILURE EFFECTS ON SAFETY FUNCTION	13. FUNCTIONAL RELIABILITY OF SAFETY COMPONENT	14. COMPONENT'S CRITICAL CHARACTERISTICS /DESIGN REQUIREMENTS TO SUPPORT SAFETY FUNCTION RELIABILITY	15. VERIFICATION METHOD FOR ACCEPTANCE (CGD)
Exhaust Blower	Secondary Confinement **-** Pressure boundary (Passive) (See Note 13)	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**
	Prevent in-leakage of air (Active)	Leak	Unmitigated release of T2 Flammable Atmosphere	At all times when T2 (and D2) is not in a safe state (including before, during, and after DBA)	Pressure boundary (Passive)/ ASME	Analysis and code leak test (See Note 3)
	Pressure control in glovebox Alternate Design: Shown in Figure 10.2 Section 10.5	Flow to low (Pressure control valve unable to control vacuum in glovebox)	Unmitigated release of Tritium		• Operates reliability	• Test per IEEE323 (Shake Table Test)

9. SYSTEM / COMPONENT / PART	10. COMPONENTS SAFETY FUNCTION	11.COMPONENT FAILURE MODES	12. FAILURE EFFECTS ON SAFETY FUNCTION	13. FUNCTIONAL RELIABILITY OF SAFETY COMPONENT	14. COMPONENT'S CRITICAL CHARACTERISTICS /DESIGN REQUIREMENTS TO SUPPORT SAFETY FUNCTION RELIABILITY	15. VERIFICATION METHOD FOR ACCEPTANCE (CGD)
Met-bel pumps	Secondary Confinement **-** Pressure boundary (Passive)	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**
	Glovebox atmosphere flow to AMSB	Flow too low	Unmitigated release of T2	At all times when T2 (and D2) is not in a safe state (including before, during, and after DBA)	• Operates reliability For Alternate Design: Shown in Figure 10.2 Section 10.5	• Test per IEEE323 (Shake Table Test) For Alternate Design: Shown in Figure 10.2 Section 10.5
Moisture Meters	Secondary Confinement **-** Pressure boundary (Passive)	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**	**(See GBSS Components above)**
	Detect loaded Z-Bed Prevent process leaks (tritium out) (Active)	Fails to detect moisture	T2 release exceeding limits (reduction in GBSS performance)	At all times when T2 (and D2) is not in a safe state (including before, during, and after DBA)	Detection Sensitivity	Test
		False Alarm	N/A		For Alternate Design: Shown in Figure **10-2** Section 10.5	For Alternate Design: Shown in Figure **10-2** Section 10.5

4.2 List of Notes:

1. In leakage of air after a DBE may exceed purging and stripping capabilities to limit oxygen to below LFL due to damaged window, loss of one or more gloves (due to fire), and leaks through bulkhead fitting seals. Fire could be prevented by isolating all electrical power sources or isolating T2 and D2 supply bottles outside the glovebox provided the quantity of T2 and D2 released to the gloveboxes yield a concentration below the LFL.
2. If FHA (Fire Hazards Analysis) permits, glove box windows made of a polycarbonate are less likely to leak after a DBA.
3. Shake table test – Some components, especially those not designed and manufactured to a recognized standard relevant to resisting seismic loads, may require subjecting representative samples, arranged to reflect bounding loads, to a shake table test. For example, glovebox penetration plates with bulkhead, feed-through fittings for cables and tubing may need to be mocked up and subjected to shaking and subsequently tested and inspected for leaks.
4. A safe state of T2 is stored in a credited storage apparatus, such as a HTV or manually isolated, seismically qualified storage bed.
5. A Glovebox and Airlock Proof Test for a typical tritium facility glovebox has the acceptable leak rate for an individual leak shall not exceed 1×10^{-6} atm cc/sec. This is different from AGS-G001 & G006 which only requires 1×10^{-4} atm cc/sec (AGS-G006) or 1×10^{-3} atm cc/sec (AGS-G001).
6. Typical commercially available Bulkhead fittings are not designed for DBE. However some manufacturers design connectors for marine and deep sea oil rig applications. They are more robust and would likely to survive a DBE. They are design to MIL Spec 167 "Mechanical Vibrations of Shipboard Equipment". In order to evaluate them fully they will need to be tested (shake table).
7. When valves are used to isolate Z-Bed (AMSB) they must not leak through the valve seat or any internal parts.
8. When valves are used to isolate they must not leak through the valve seat or any internal parts
9. Applies to any component providing a "safety" (credited confinement) function, i.e., all GBSS components and, possibly, the seismically qualified storage bed.
10. Safe State – stored on the seismically qualified storage bed and isolated by manual values, is designed to survive all DBA's and safely contain Tritium.
11. Any manual valve providing a "safety" function when, by design, the closed valve is a barrier between Tritium and atmosphere. This includes maintenance valves at removable equipment, e.g. GBSS AMSB's and the seismically qualified storage bed isolation valves.
12. Refer to Alternate Design in section 10.4 (Figure 10-2) which shows a system with normal stripping components and the stand-by safety system. The stand-by system vacuum pumps would be designed to provide a vacuum without pressure control valve.
13. Air leaking into the valve that does not challenge the downstream pumps ability to provide necessary flow to the valve would not be a concern.
14. See Alternate Design in section 10.4 (Figure 10-2) with a normal train and safety train (AMSB & Pumps). The safety trains pumps could be selected or controlled possibly to provide necessary flow without flow control valve.

15. Shake table testing should not be required if post DBA (Earthquake) confinement is assumed to be breached.

5.0 SEISMIC DESIGN CRITERIA FOR STRUCTURES & COMPONENTS

The Seismic Design Basis (SDB) is established based on ASCE/SEI 43-05 (Seismic Design Criteria for Structures, Systems, and Components on Nuclear Facilities). The SDB is the combination of Seismic Design Category (SDC) and Limit State. ASCE 43-05 refers to ANSI/ANS-2.26-2004 (American National Standard Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design) guidance in establishing the SDC and Limit State for Structures, System, and Components (SSC).

Tables 1 and A.3 of ANS-2.26 define SDC Categories based on unmitigated consequences of SSC failure. The following used to select the SDC Categories and Limit States:

1. SDC-3 is an appropriate categorization for safety related SSCs, and non-safety related that could adversely impact safety related SSCs, at any tritium facility; because, the emphasis to prevent or mitigate releases at a tritium facility is similar to commitments, at nuclear facilities per ANS 2.26, for releases that would result in 25 to 100 rems exposure to workers and 5 to 25 rems to the public.

2. Appendix B of ANS-2.26 provides guidance for the Limit State. For a tritium facility safety related SSCs depended upon to mitigate releases it was deemed appropriate to select Limit State C, minor damage no impacting performance (e.g. gloveboxes used a confinement barrier may experience a few small cracks, not impacting functionality for post-accident demands).

3. Non-safety related SSCs whose failures (releases) are mitigated by safety related SSCs, the appropriate Limit State is B, the safety related glovebox stripper system mitigates releases from non-safety related process system components.

ASCE 43-05, Table 1.1 establishes the corresponding Seismic Design Criteria to be used in the evaluation. Both SDB-3C and SDC-3B require the seismic analysis to follow the procedure stated in ASCE 43-05. Figure 1-1 establishes the ASCE 43-05 procedure. This procedure requires establishing the Design Basis Earthquake Ground Motion for the site or the Seismic Response spectrum. A response spectrum (RS) analysis is performed on the glovebox using the In-structure response spectrum (IRS) at the glovebox location in the structure. If the glovebox is located at ground level, then the site RS can be used in lieu of the IRS. The total Inelastic Seismic Demand is calculated and compared to the Capacity to establish the Demand to Capacity Ratios.

5.1 Conclusion:

To ensure the tritium facility gloveboxes meet seismic requirements for a DBE it will need to meet design standards. A tritium facility will need to have all gloveboxes designed to meet the ANSI/ANS-2.26-2004

SDC-3 criteria. The gloveboxes will also need to be designed to select ANSI/ANS-2.26-2004 Limit State C to mitigate releases. The contents of the glovebox will need to be designed to ANSI/ANS-2.26-2004 SDC-3 and also meet ANSI/ANS-2.26-2004 Limit State B. The components in the glovebox are at a lower Limit State since the stripper system mitigates releases from the non-safety related process system components.

6.0 BULKHEAD FITTINGS

6.1 Glovebox/ Hood Application

For this equipment we use many of these bulkhead fittings for electrical, instrument and pneumatic pass thru to the inside of the Glovebox or Hood. The most challenging situation is the Seismic DBA event which will put stress on the sealing surface between the Bulkhead fitting and the wall of the Glovebox/Hood

6.2 Bulkhead Vendor Option

After discussion with a vendor (Seacon) about the application of these connectors for Seismic on a Glovebox/Hood, the vendor stated that their connectors were easily robust enough to handle these loads. The vendor stated that the best way to mount it was to use a welded flange as shown below (see Figure 6-1 and 6-2)

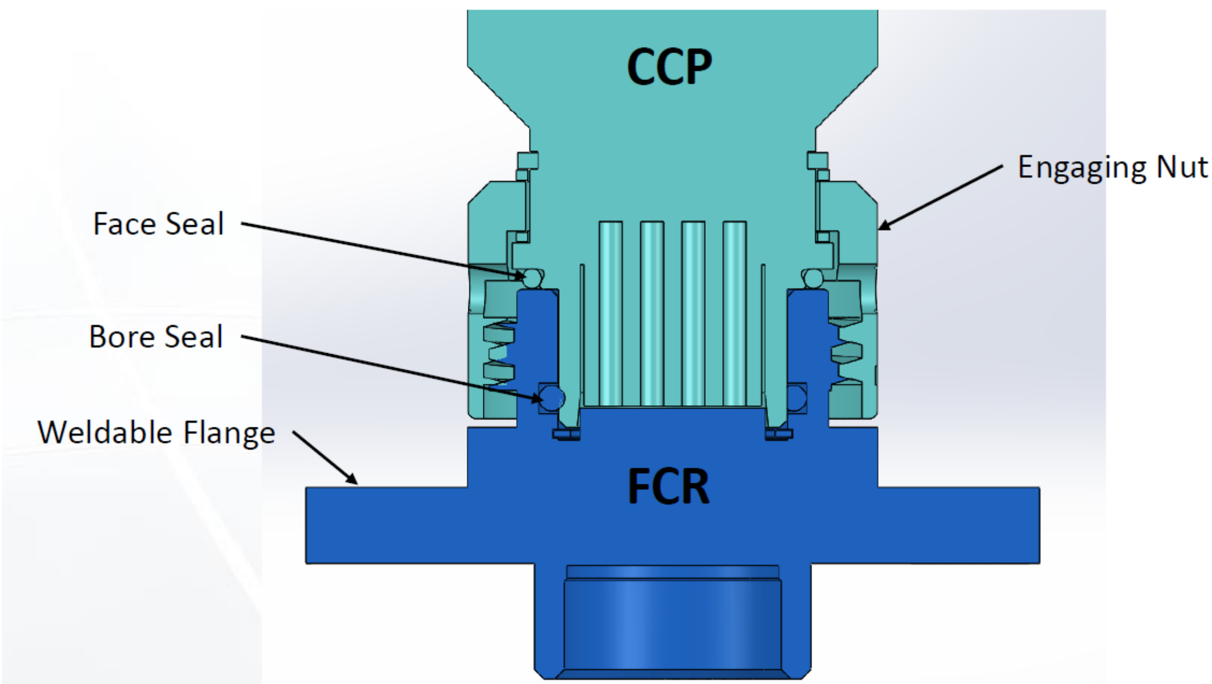

Figure 6-1 Section of a Typical Welded Flange

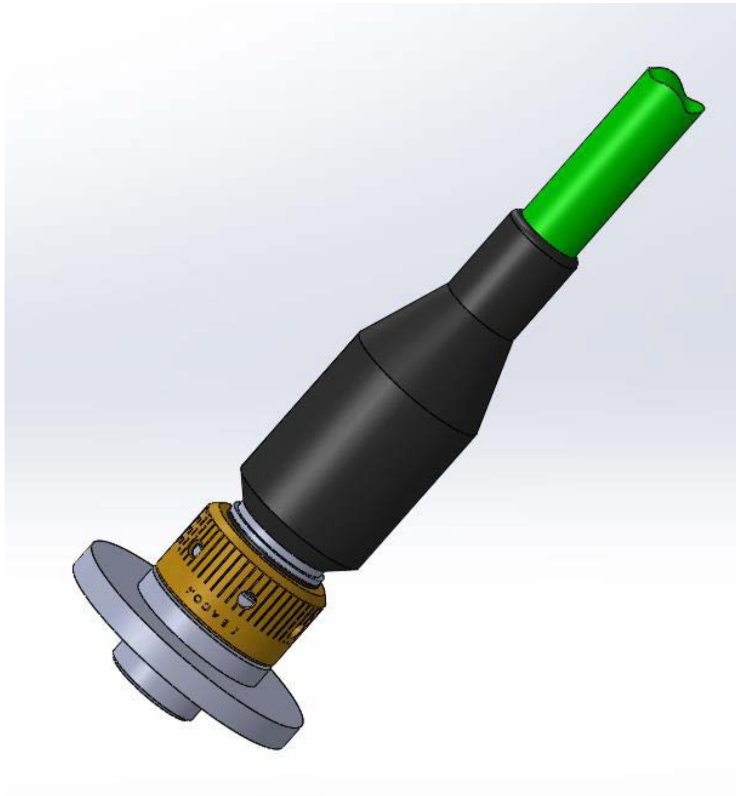

Figure 6-2 Section of a Typical Welded FlangeIf

6.3 Testing Requirements

For these connectors the vendor did some under water testing where an explosive was detonated near the connector and it continued to fully function. The engineering group from SEACON stated that their connectors are very robust and would easily handle the Seismic stresses from a DBA event. They provided a copy of the test to us. It may be prudent to test these connectors again but focus on the sealing attributes after a seismic event.

7.0 AFTER COOLERS

7.1 After Cooler Application

GBSS consists of several components (Preheater, Catalytic Reactor, After cooler Ambient Molecular Sieve Bed) and pumps to process glovebox atmospheric gases to remove stray or fugitive tritium during normal and upset conditions. It is imperative to design the components to provide a reliable robust system under all operating conditions including Design Basis Accident (DBA).This requirement can be achieved with redundancy and / or passive design.

The after cooler which is to cool the hot gases leaving the catalytic reactor at about 850 ^{o}F, needs to be cooled down to about 80 – 100 ^{o}F. This cooling requirement is to optimize the effectiveness of the AMSB where the catalytically formed Q_2O (Q- any hydrogen isotope) is absorbed. The conceptual water cooled after cooler, as the name depicts, uses a source of cooling water. For reliability sake, the water source needs to be designed with redundancy to assure the availability of the cooling water source.

7.2 Alternate Design –Air Cooled After Cooler

Alternately, if the after cooler can be designed with a passive atmospheric air cooled device, the required cooling mechanism does not need any redundancy. The hot gas to be cooled passing through finned tubes within a shroud creates buoyancy in the air and induces a draft. This will increase the heat transfer coefficient and improve cooling. This concept will eliminate the need for not only the cooling water which is undesirable where tritium gas is being processed, but eliminate the need for the redundancy.

Figure 7-1 Typical Air Cooled Finned Tubing (Cain Industries)

An air cooled heat exchanger is a very common concept for cooling liquids such as cooling tower, automobile radiator etc. Gas to gas heat exchanger, however, is not common specifically without the use of an electric fan. The concept proposed here is to use the high temperature difference to develop a turbulent cooling air flow across a finned tube bank using buoyancy and induced draft by placing the tube bank within a shroud with decreasing cross sectional area at the top of the conical shroud to enhance this concept.

7.3 After Cooler Testing

One option is the Cain Industrial Spiral Finned Tubing shown in Figure 7-1. If needed, a prototype design may need to be developed and tested or analyzed to assure the required effectiveness and meet other requirements. This cooling equipment is not seismically qualified but could be tested using the parameters in section 8.3.1.

8.0 MET BEL PUMPS (METAL BELLOWS)

It was speculated the service life of the Edwards pump, due to its use of Teflon, would be around three to six months before the pump would fail and need replacement so the use of this pump would require an installed spare in the process along with the ability to replace the failed pump while NDAS unit operations were occurring. The maintenance strategy would require only one Metal Bellows pump since its expected replacement frequency was estimated to be three years.

8.1 Pump Application

These Metal Bellows pumps will be used in the Stripper System to move the internal atmosphere through the pre-heater, heater, after cooler and the Zeolite Beds (Z-beds or AMSB). It will be moving primarily gaseous atmosphere. These pumps were chosen for this application because all “wetted” parts are stainless steel or steel. The process gas would not need to contact any other materials like plastic or rubber which can be an issue for Tritium.

8.2 Met Bel Pump Vendor

One vendor that manufactures Metal Bellows pumps is Senior Aerospace (Figure 8-1)

Figure 8-1 Senior Aerospace Brand Met Bel Pump Configurations

8.3 Met Bel Pump testing

The manufacturer of this pump did not have any seismic test data but was willing to do a seismic (shake table) test for an additional cost.

8.3.1 Typical testing parameters

The equipment should be seismically tested or qualified to IEEE 323-74/83 and/or IEEE C37.98-1987. From previous testing of Tritium equipment the following parameters were used:

a. Reference 1 A SEISMIC QUALIFICATION TEST used the following info:
   i. Frequency range : 1 to 50 Hz
   ii. Damping Value: 5% OBE 5% SSE
   iii. Max Octave Freq Intervals : 1/6
   iv. See Figures 5.2, 5.3, & 5.4 for sample configurations
b. Reference 2: A Seismic Tritium Confinement System Test used the following
   i. Natural Frequency: 4Hz
   ii. Actuating Acceleration: 0.005g to 0.05 g
   iii. 1.5 critical, 1 Hz to 10 Hz seismic event
   iv. Power Input: 12 VDC
   v. Output Contact Rating; 10 Watt (DC)

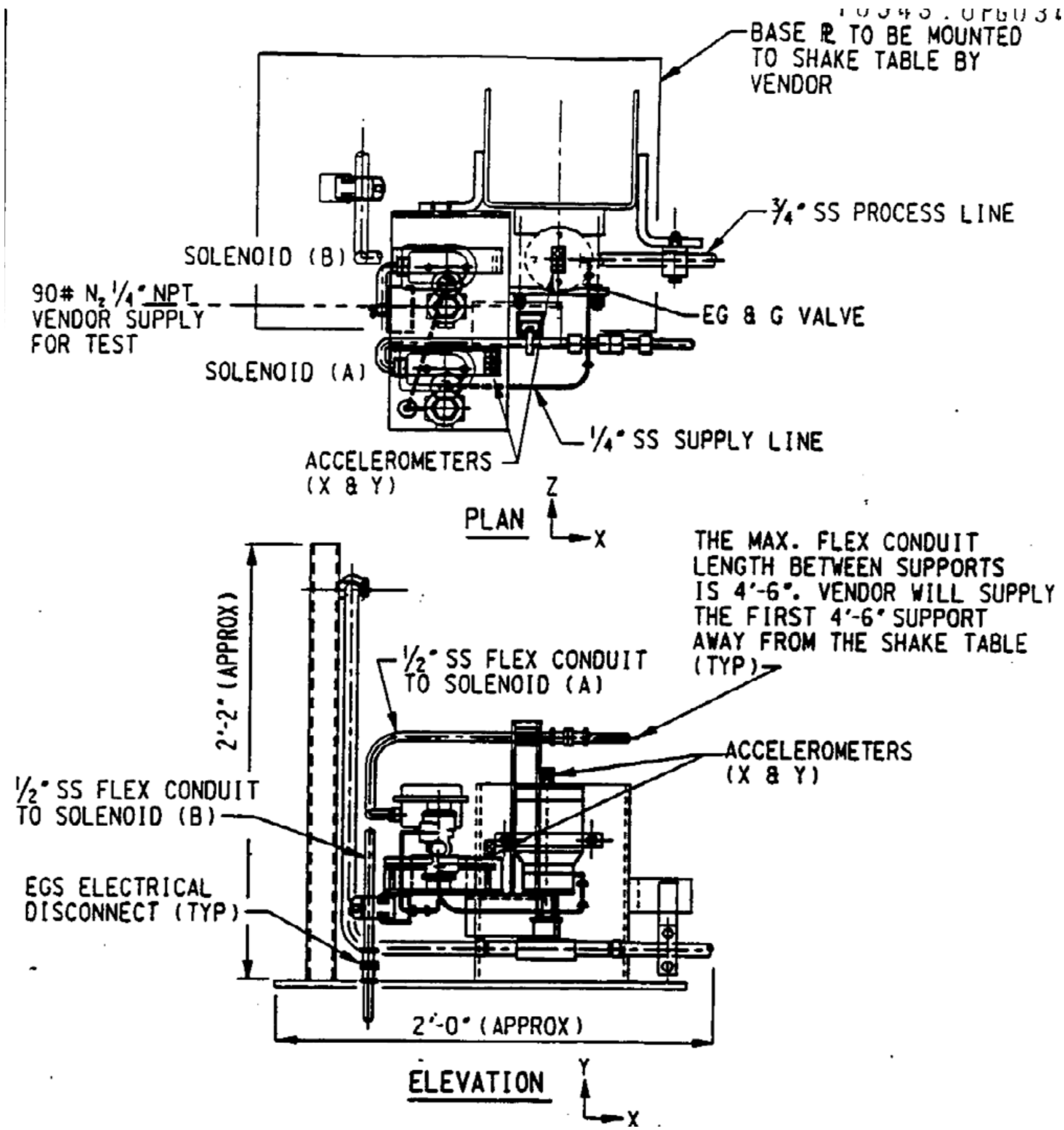

Figure 8-2 Sample Test Configuration EG & G Valve

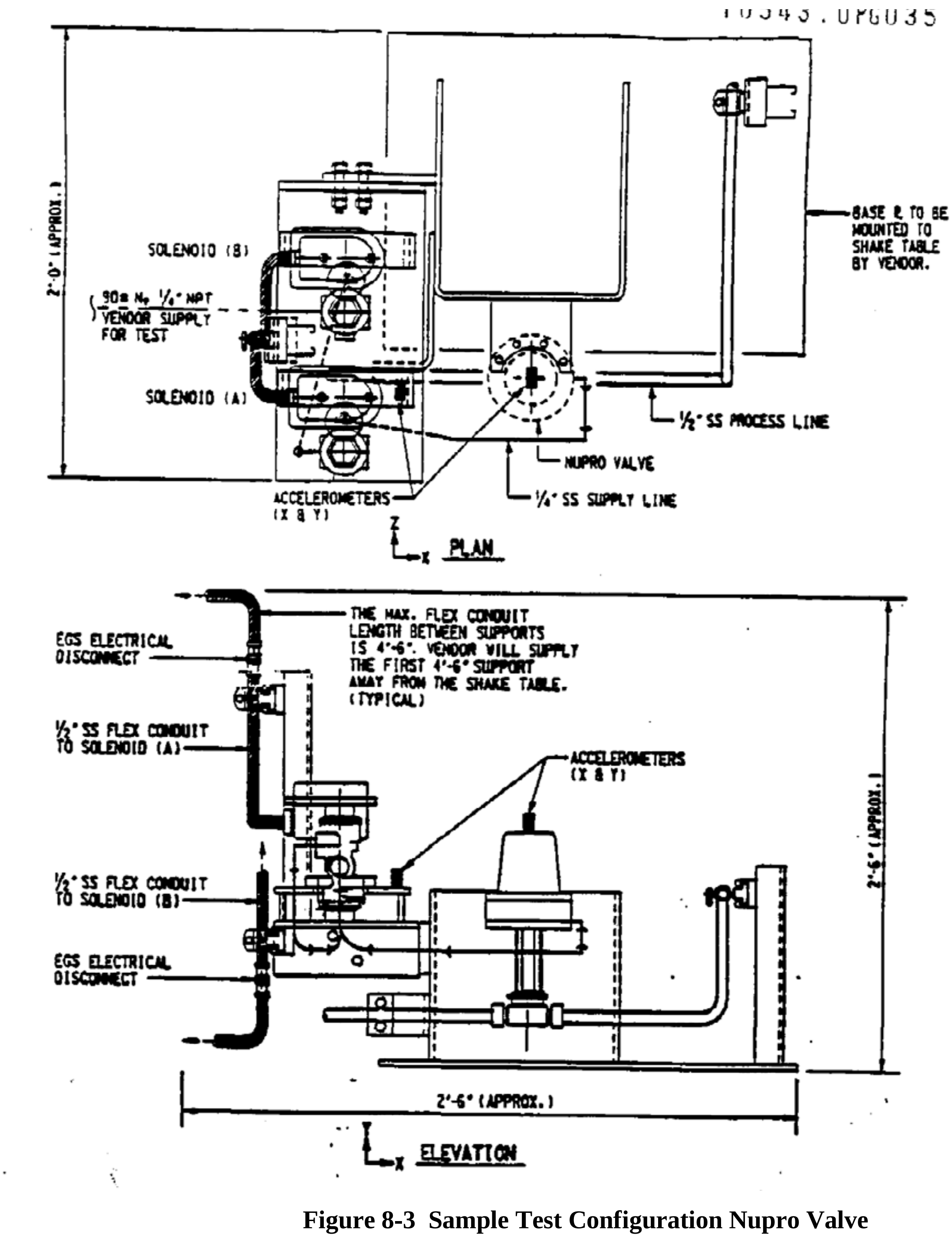

Figure 8-3 Sample Test Configuration Nupro Valve

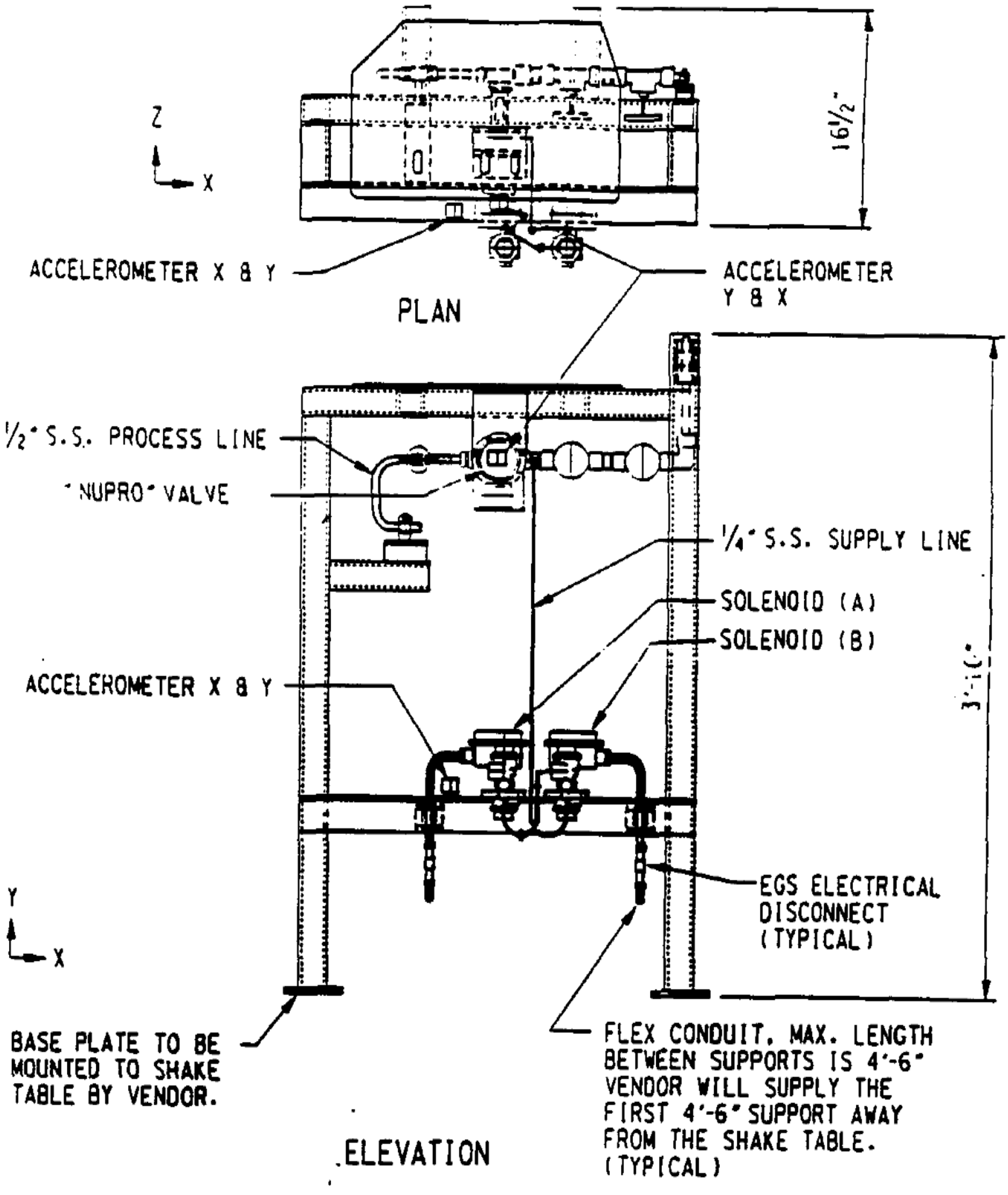

Figure 8-4 Sample Test Configuration Nupro Valve

9.0 VCR FITTINGS

9.1 VCR Application

These fittings are used in many locations especially in gloveboxs and hoods to make for a quick to connect/disconnect and tight non-leaking connections. To facilitate this it is not inherently a strongly supported connection.

9.2 VCR Vendor

The major vendor used for these fittings is Swagelok. Some typical fittings are shown in Figure 9-1. These are not seismically tested or qualified to IEEE 323-74/83 and/or IEEE C37.98-1987.

Figure 9-1 Typical Swagelok VCR Fitting

9.3 VCR Testing

These fittings or piping sections are not seismically qualified but could be tested using the parameters in section 8.3.1. It is likely that the seismic forces will allow at least temporary leaks or permanent deformations of the tubing and sealing surfaces.

10.0 AMBIENT MOLECULAR SIEVE BED (AMSB)

10.1 AMSB Application

AMSB Stripper beds (also called Zeolite or Z-beds) are used to remove water that could contain one or two Tritium molecules (T2O, DTO, or HTO). They will reach a saturation level and have to be removed and replaced. They can be used again after being heated to remove and capture the water which may contain Tritium.

10.2 AMSB Vendor

One possible vendor is American Boiler Works which has experience manufacturing AMSB Stripper Beds (see Figure 10-1)

10.3 AMSB Testing

With Electrical and Process connections being the weakest point testing may be required unless they are manufactured to be very robust. The vendors that manufacturer these AMSB do not make them seismically qualified and tested to meet requirements of IEEE 323-74/83 and/or IEEE C37.98-1987.

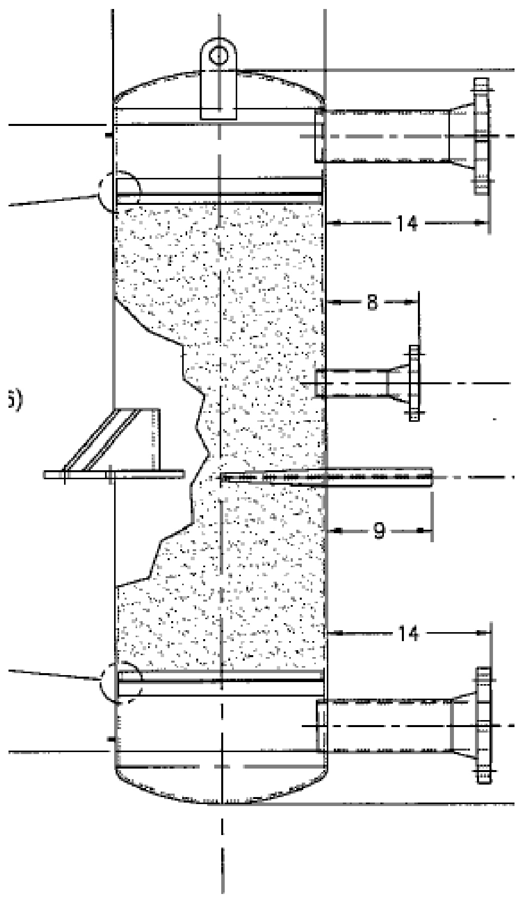

Figure 10-1 Typical AMSB Stripper Bed

10.4 AMSB Alternate Design

In Figure 10-2 we present an option where there are three AMSB (Z-beds) in which the first two are used for normal service. The Back-Up AMSB (Z-beds) is always kept ready for use immediately after a seismic event. This third or back up AMSB (Z-beds) is the only safety one since it has to be available for the seismic event.

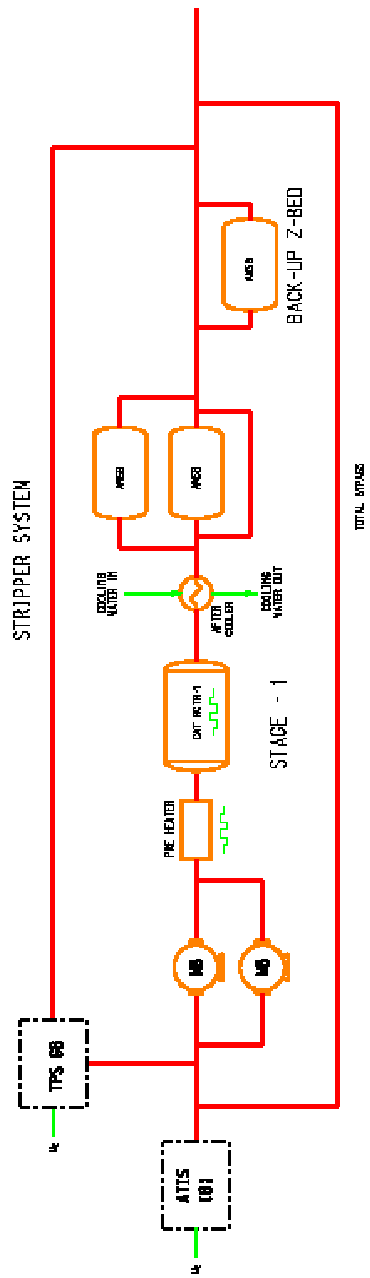

Figure 10-2 Alternate Design Back-Up AMSB Stripper

Bed

11.0 GLOVEBOX/HOOD GASKETS, GLOVEPORTS AND GLASS

11.1 Glovebox/Hood Gasket Application

These gaskets are used in the GBSS in a hood and with interfaces to tritium process gloveboxes. Per the AGS-G001(American Glovebox Society- Guideline for Gloveboxes) and AGS-G006 (Standard of Practice for the Design and Fabrication of Nuclear Application Gloveboxes).These gaskets will need to maintain a seal during and after a Seismic event. If there is a fire they will likely fail. See Figure 11-1 for Typical Glovebox window installation with gaskets.

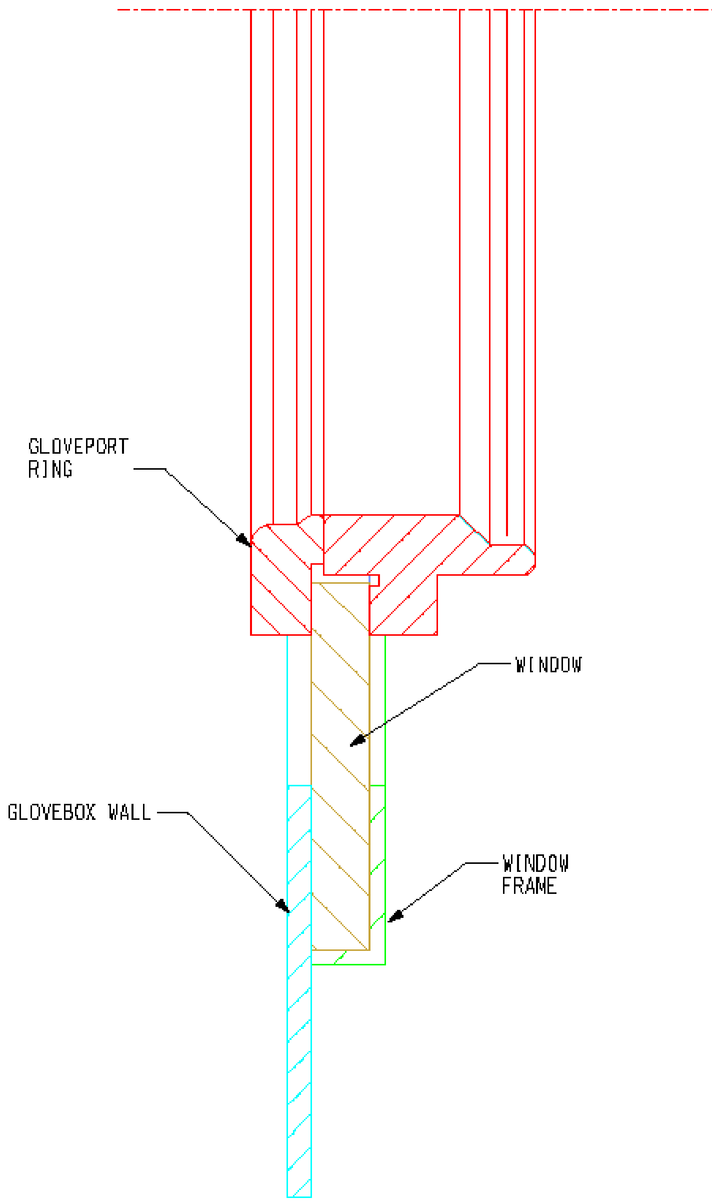

Figure 11-1 Typical Window and Gloveport Installation

11.2 Glovebox Gloveport Application

These gloveports are in tritium Gloveboxes to allow access for operations and maintenance of the internal equipment. In a Seismic Event it is expected that the Gloveports and Gloves would continue to seal. This could be disrupted if the glass cracks or breaks do to stress or by impact of a foreign object. This would allow the free flow of the room atmosphere into the gloveboxes. This could overwhelm the GBSS system.

11.3 Glovebox Glass Application

Structural Engineers normally don't design glass but glass like any other material has known properties and can be analyzed with a certain degree of confidence. The plastics family offer superior performance with regard to physical properties such as strength and the ability to deform without cracking and failure. Below is a compiled table listing the main physical properties of glass, Plexiglas™ and Lexan™: As can be seen from the table, glass is very brittle and easily fails with small displacement.

Glass/Plastics Properties Table			
Property Type	Glass	Plexiglas™	Lexan™
Unit weight (pcf)	139.0	74.0	75.0
Poisson's Ratio	0.20	0.35	0.38
Tensile Strength (ksi)	1.0	10.2	10.2
Flexure Strength (ksi)	1.0	15.0	13.0
Flexure Elasticity Modulus (ksi)	9.2	450.0	333.5

For any tritium glovebox application, the glovebox can be analyzed either with or without the plastic window part of the finite element model. If the plastic window is in the model, the stresses in the plastic are determined directly. However, if the plastic window is not included in the model but only its mass and the glovebox framing, then the glovebox framing displacement must be calculated in order to determine stresses in the plastic window. If the stresses are exceeded, the glovebox framing must be stiffened and another cycle of analysis is required. The glovebox is SDC-3 and therefore must be in designed per ASCE 43-05 which requires a dynamic analysis.

11.4 Gasket, Gloveport and Glass testing

Gaskets would be dependent on the window glass and glovebox wall retaining its shape. For the gloveports, one possible vendor is Central Research Labs. This manufacturer doesn’t have seismic testing results available.

It may be advisable to test this equipment as well. This would require setting up a test for the shake table based on the criteria in 8.3.1 as required.

12.0 EQUIPMENT REQUIRING POWER DURING AN DBE (SEISMIC EVENT)

There will be a need for independent power trains for some of the equipment that is being used in the GBSS such as the Pre-Heater. Also some systems may require a diesel back-up generator in case of a DBE. It may be possible to do maintenance of equipment when the plant is in an outage. Any electric item required to function after DBE which requires power to operate will need equal redundant equipment as well as separate power supplies for each train of equipment. The design will need to have two separate power circuits to supply two redundant trains of electrical equipment. Also one of the trains will have a diesel generator as a back-up power supply. To accomplish this will require an Automatic Transfer System to get the power from the back-up generator to the equipment.

13.0 REFERENCES

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