C-A Unreviewed Safety Issue (USI) Form

Title of USI: Changes to ODH Protection

Description of USI (use attachments if necessary):

See attached calculation by L. Snydstrup, "Calculation of Oxygen Deficiency Hazards for TVDG", Rev Ø dated 11/5/01

Title and Date of Relevant SAD: SAD for the TVDG Facility, 11/28/95

Committee Chair or ESHQ Division Head must initial all items. Leave no blanks:

ITEM	APPLIES	DOES NOT APPLY
Decision to not revise the current SAD and/or ASE at this time:	RK	
The hazard associated with the proposed work or event is covered within an existing SAD and/or ASE.	RK	
SAD Title and Date: SAD for the TVDG Facility 11/28/95	RK	
This Form and attachments, if necessary, shall be used to document the USI until the next revision of the appropriate SAD.	RK	
Decision to submit a revised SAD and/or ASE to the BNL ESH Committee:		RK
The hazard associated with the proposed work is not appropriately included in an SAD.		RK

Ray Karol ______ 11/5/01 ______

Signature of C-A Committee Chair or C-A ESHQ Division Head   Date

Edward T Lessard ______ 11-5-01 ______

Signature of C-A Associate Chair for ESHQ   Date

Calculation of Oxygen Deficiency Hazards for TVDG

Table of Contents

1.0 Introduction

This report contains the study of oxygen deficiency hazard (ODH) at the Tandem Van de Graaff, Building 901A, in the following areas:

- Accelerator Room (A.R.)
- Mechanical Equipment (ME) Room
- Electrical Equipment (EE) Room
- Target Rooms
- Building Basement
- Gas Storage Area (remote)
- TTB Tunnel

The ODH hazard in the MP Accelerator Room (A.R.) affects other contiguous areas in Building 901A. The floor plan for the A.R. is shown in Figure 1. The Accelerator Room is a common space with two MP Tandem Van de Graaff machines, beam line components, and the MP gas handling system. Part of the gas system for each MP resides in the lower level below the accelerator. During operation, each MP accelerator pressure vessel contains11,250 cubic feet of insulation gas pressurized to 180 psig with a gas mixture of approximately 45% sulfur hexaflouride, 45% nitrogen, and 10% carbon dioxide. The insulation gas has a high density of about 2.85 specific gravity and a low diffusion rate in air. At 180 psig there is about 35,000 pounds of gas in each MP, which is equal to 160,000 cubic feet of gas at atmospheric pressure. A diagram of the MP Gas System is shown in Figure 2.

The method for analysis generally follows the SBMS 'ODH Calculation and Control Measures' for determining the 'F' factor based on oxygen concentration and for determining equipment failure rates. In many cases failure rates are based on operator experience of actual failure events and known running times. The method of calculating oxygen concentration as a result of equipment failure does not follow the SBMS procedure, which is intended for the leakage or spills of low-density cryogenic gases. The SBMS procedure assumes instantaneous and complete mixing of leaked gas with air in the space, which is not the case if the heavier insulation gas leaks into a room. The method of analysis does not account for the low occupancy rate of the space.

The results of the analysis are given in the following table:

TVDG Building ODH Classifications and Recommendations					
Building Space	Current ODH Class	Upgraded ODH Class	Purge Fan Disabled		Recommendation
			Prior to Upgrade	After Upgrade	
A.R. Room	0	-	-	1	1. Classifications reflect recent upgrade to auto purge fan. 2. For this classification purge fan flow must be reduced to 20,000 scfm from the existing 25,000 to handle heavier gas from a leakage event. 3. During leak testing of gas dryers (prior to pressurization of the MP), the area around the dryers should be clear of personnel during pressurization. Leak checking to be conducted in pressure steps only after pressure has stabilized.
ME Room	1	0	3	2	1. Classifications reflect recent upgrade to auto purge fan. 2. Upgrade: Vent overpressure devices at vacuum pump outlet (item 8, App. D) to outside or to AR Room. 3. Room classifications apply during gas transfer operations; room to be a minimum '0' classification at all other times. 4. Recommend ODH Escape Pack requirement to be waived. 5. Mark clearly control panel valves that isolate ME Room from Gas Storage and MP pressure vessels.
EE Room	0	-	-	1	1. Same remarks as Accelerator Room above 2. Restrict occupancy of room if purge fan becomes disabled.
Target Rooms	U	-			
Building Basement	0	U	-	1	Same remarks as Accelerator Room above.
Gas Storage	0	-	-	-	Implement procedure to secure Gas Storage Room door in open position during occupancy of room.
TTB Tunnel	0	-	-	1	1. Same remarks as Accelerator Room above. 2. In order to safeguard personnel in the TTB tunnel either of the following measures should be implemented: Install alarm in the tunnel to notify personnel of ODH condition occurring in AR Room <u>or</u> install barrier to preclude flow of insulation gas into tunnel.

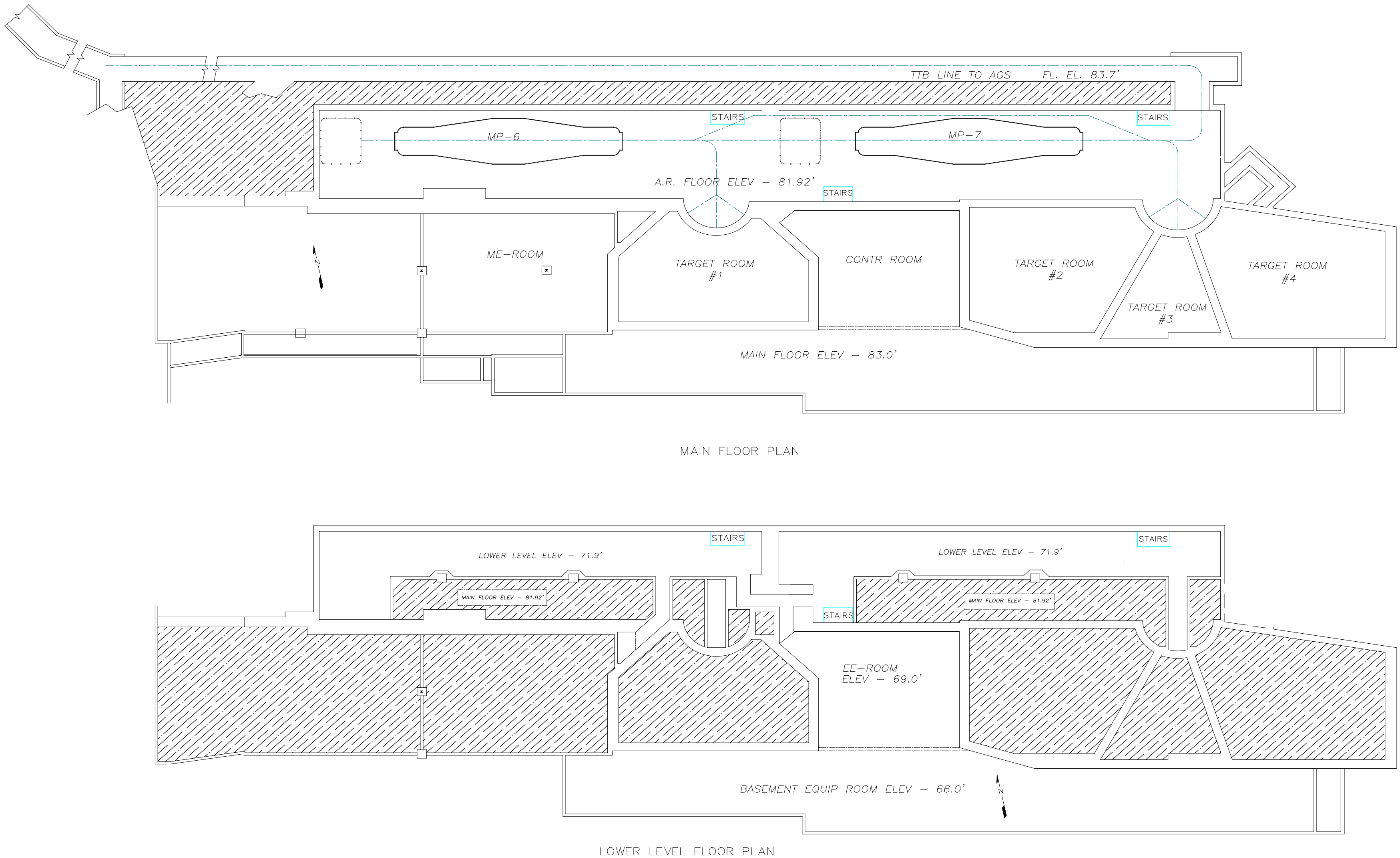


FIGURE 1: BUILDING 901A FLOOR PLAN

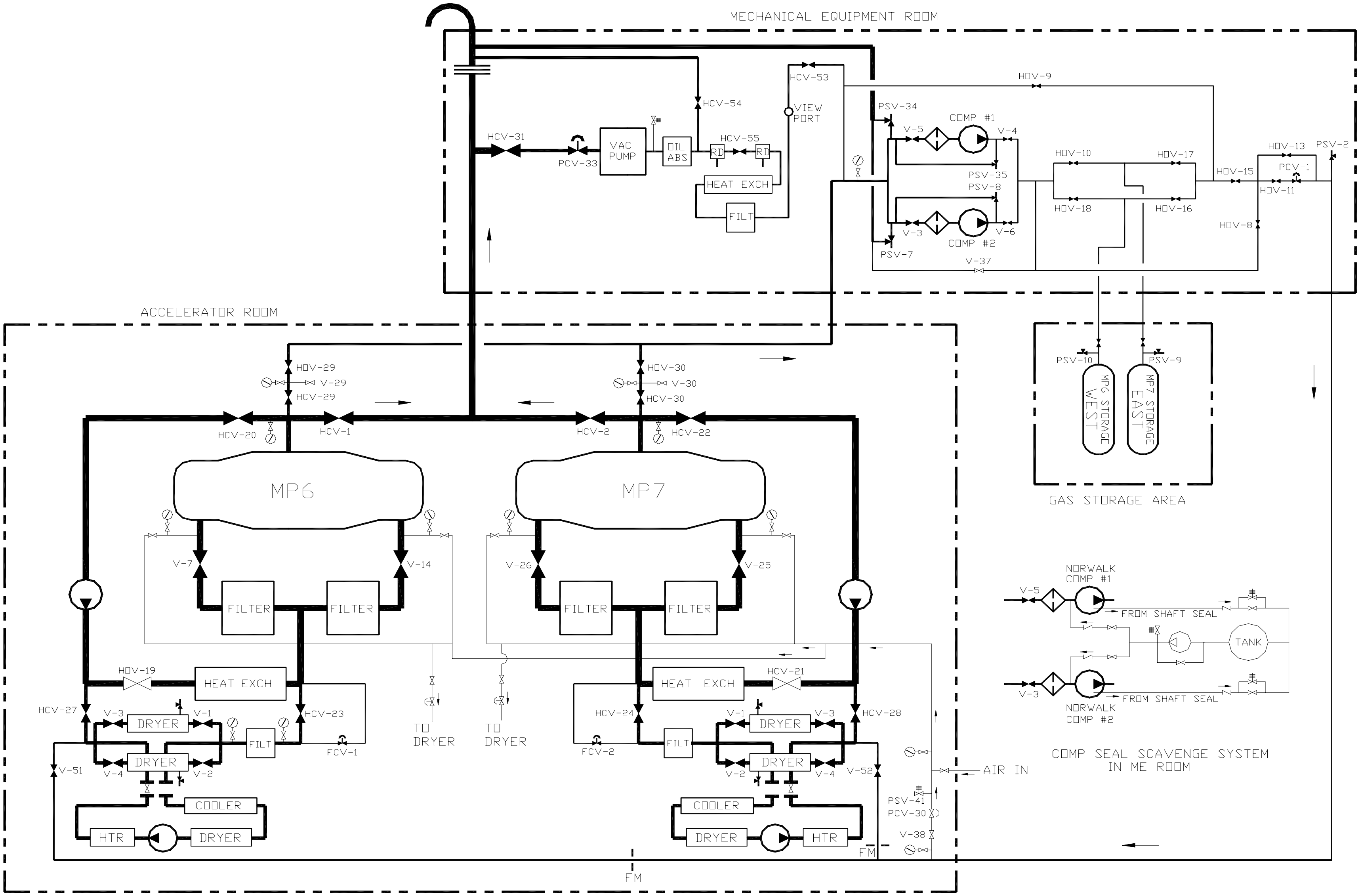


FIGURE 2: TVDG GAS SYSTEM

2.0 Accelerator Room(s)

2.1 Facility:

Accelerator Room (A.R.) Volume	280,000 cu. ft.
MP6 Lower Level Volume	31,000 cu. ft.
MP7 Lower Level Volume	31,000 cu. ft.
A.R. Main Level Elevation	81.9’
A.R. Lower Level Floor Elevation	71.9’
MP6 Ventilation Unit:	11,170 cfm, 15 hp, 10-15% new air
MP7 Ventilation Unit:	11,170 cfm, 15 hp, 10-15% new air
Emergency Purge Fan:	21,000 cfm, 20 hp

The lower level areas beneath each MP are separated by a passageway of 6’6” high by 5’ wide by 35’ long. This passageway is about 60% filled with piping and cable tray. The two lower level areas constitute about 40% of the gas volume of one MP pressure vessel.

There are six oxygen monitors in the Accelerator Room, one Lumidor type and one Delta F type in each lower level and one Delta F type near each MP pressure vessel on the main level. The Delta type has two set points at 19.5% and 20%; the Lumidor is set at 19.5% only. The Delta type monitors alarm in the control room when the oxygen content drops to 20%. If either the Lumidor or Delta measure 19.5% or lower, the following actions result: Activation of siren in A.R., MCR notification, and purge fan now operates. There are also portable Gastech monitors that are used when work is being done inside the MP vessel. These energize a horn on the MP and an alarm in the control room if an ODH condition in the MP occurs.

2.2 MP Gas System Failure Modes:

The following failure modes of the gas system or MP could result in insulation gas entering the Accelerator Room:

1. Rupture of 3-inch diameter pressure vessel window. The existing configuration of the two MP accelerators has been in operation for a period of 30 years[1]. It is estimated that 1.5 accelerators have been running during this period. There has been no window failure during this time. See Appendix A for ODH Analysis of Accelerator Room due to Window Failure.

2. Failure of the vacuum beam line inside the MP pressure vessel while under external pressure of 180 psig. Normally closed ball valves at each end of the vessel automatically close if there is a loss of vacuum, preventing gas from flowing out of the MP. The ball valves have a flow diameter of 2.5 inches. There has been no failure of this type at the TVDG. See Appendix B for ODH Analysis of MP Beam Line Failure.

3. Relief valve opening. Relief valves on the gas dryers have opened during gas handling operations with an operator present. The relief valves exhaust into the Accelerator Room. There are two relief valves on each dryer; these valves have a set pressure of 250 psig. Each valve has a flow diameter of 1.25 inches. See Appendix C for ODH Analysis for Gas Dryer

Relief Valves. Other relief valves in the A.R. besides the dryer relief valves include two small 1" valves on each MP. Also, there is a 2" relief valve on an insulation gas supply line to the dryers that was used during regeneration, but is no longer used (replaced with air line).

4. Access door gasket failure. Each MP has a main access door of 42 inches diameter and four smaller doors of about 24 inches diameter. The failure modes for the access doors include the following: door not secured properly prior to pressurization, gasket not installed, improperly installed, or damaged during maintenance, and gasket failure during operation.

The probability of access doors not being closed properly is very low. There was one failure of the main access door gasket during nitrogen gas operations (no SF6), due to an incorrectly implemented procedure for closing. In order to preclude this type of failure the door mechanism has since been modified to include a power door locking mechanism and interlock switches[1]. The smaller access doors are not closed until a large locking pin is slid into place opposite the door hinge. This pin cannot be installed until the door is fully bolted down and the gasket compressed. A limit switch to an indicator light on the gas panel in the ME Room shows that the tank doors have been closed properly. Furthermore, significant gas leakage from gasket failure will be detected prior to pressurization when air in the MP vessel is pumped out with the vacuum pump.

5. Gas System Failures in M.E. Room will result in gas overflow into the lower level of the AR Room. This is described in Appendix D. The maximum flow rate is 750 scfm, which is less than the scenarios described above.

6. Slow leaks from piping flange gasket or valve packing leakage are less serious than the above modes. Yearly leakage testing detects and corrects these leaks. The oxygen deficiency monitors have detected relatively small leaks in many cases. Non-threatening leaks, not detected by gas monitors, are eventually noticed by gradual pressure decay in the MP.

The above incidents represent the only potentially significant leakage failures. [1]

2.3 ODH Classification

The ODH classification is based on window failure mode and the assumption that the emergency purge fan is upgraded to be suitable for the heavier gas. The classification of the Accelerator Room depends on the method of operation of the emergency purge fan: manual operation or automatic.

> Manual Operation. The purge fan is manually operated upon detection of an ODH condition in the Accelerator Room. ODH classification is '0' for manual operation mode.
>
> Automatic Operation. The purge fan is configured to come on automatically upon detection of an ODH condition by the ODH monitor. For automatic mode the ODH classification is '0'.

In the event that the emergency purge fan is disabled, the ODH classification is '1'.

3.0 Mechanical Equipment Room

3.1 Facility:

Mechanical Equipment (ME) Room Area	3,250 sq. ft.
ME Room Volume	40,000 cu. ft.
ME Room Pit Volume (NE Corner)	2,000 cu. ft.
ME Room Floor Elevation	83.0’
ME Room and Basement Ventilation Unit:	12,500 cfm – 6,470 basement, 6.030 ME Rm
Emergency Purge Fan:	About 50% of Purge Fan Capacity-See below

The Mechanical Equipment Room is a multiple purpose space, containing gas system equipment, cooling water equipment, and machine shop. The gas system equipment includes the gas distribution panel, 150 hp gas compressors rated for 146 scfm at 250-600 psig, vacuum pump to pump down the 11,250 cu. ft. MP volume, and piping and valves.

A/C Ventilation Unit #4 serves both the ME Room and the basement. Ventilation dampers to the ME Room may be closed to isolate the room by a pushbutton located on the control panel in the ME Room. In the emergency purge mode Ventilation Unit #4 is isolated and the purge fan pumps out the ME Room and the basement simultaneously at about 10,500 scfm flow through each space.

A Delta F type oxygen monitor in the ME room senses oxygen deficiency.

3.2 Failure Modes

The ODH hazard in the ME Room is due to the potential of personnel working in close proximity to leakage sources. Since the ventilation system serves both the ME Room and the basement, gas that leaks will eventually dilute in this large volume space. The following failure modes would result in local gas leaks in the equipment room space:

1. Safety Overpressure Devices. There are several relief valves and safety devices that protect the gas system from overpressure.
2. Compressor Seal Failure
3. Piping flange gaskets or valve packing leakage

Appendix D covers gas leakage rates into the ME Room that may occur during various operating modes.

3.3 ODH Classification

The ODH classification of the ME room with a manually operated purge fan is ‘2’ during gas transfer operations, and ‘0’ at all other times. If the purge fan operates automatically the room is class ‘1’. A system upgrade to vent the vacuum pump relief device outside the room will improve the classification to ‘1’ for manual operation of fan and ‘0’ for automatic. If the purge fan is disabled, the classification is ‘3’ prior to the upgrade and ‘2’ after. It is recommended that the room have a minimum classification of ‘0’ at other times.

4.0 Electrical Equipment Room

4.1 Facility:

Electrical Equipment (EE) Room Area	2,600 sq. ft.
EE Room Volume	36,000 cu. ft.
EE Room Floor Elevation	slab 67.7’ sub-floor 69.0’
EE Room and Control Room Ventilation Unit	14050 cfm-7100 cfm CR 6950 cfm EE
Emergency Purge Fan	Flow to Control Room and EE Room

4.2 Oxygen Depletion

The EE Room is connected to the lower level of the A.R. by a passageway through which cable trays are routed. The floor of the room is at a lower elevation (elev 69.0’) than the A.R. lower level (elev 71.9’). Since the cable entranceway to the EE Room from the A.R. is not sealed, any gas that leaks into either MP6 or MP7 lower level, and is not pulled into the ventilation ducting, will gravitate into the EE Room.

There is no supply of insulation gas and no ODH monitor in the EE Room.

4.3 ODH Classification

The classification of the EE Room is the same as the Accelerator Room. It is recommended that the occupancy of the EE Room be restricted if the purge fan is disabled, since the room is at a lower elevation than the lower level of the A.R.

5.0 Target Rooms

5.1 Facility:

There are four target rooms. The rooms are isolated from the Accelerator Room by shielding walls, but are connected by openings for cable tray that passes from the top of the A.R. lower level into the target room trenches. The elevation of the floor in each target room is 83’, the main level of the building.

5.2 Oxygen Depletion

The target rooms are connected to the Accelerator Room by cable passageways. Trenches in the target room are 3 feet deep by 4 feet wide. A cable tray passage of 2-foot width and 1-foot depth connects the Accelerator Room to the bottom of the target room trench. An insulation gas leak in the Accelerator Room will begin to enter the target room trench if gas fills the A.R. lower level to a height of about 7 feet above the floor. The target room floors are about 1 foot above the elevation of the Accelerator Room main level (elevation 81.9’). Insulation gas that reaches the main level of the Accelerator Room will enter the target room trenches and then overflow into the connecting basement area before filling the room.

There is no supply of insulation gas in the Target Room.

5.3 ODH Classification

The Target Rooms is not considered an ODH area, since a major gas leak would empty the MP into the A.R. lower level and basement prior to reaching the target room elevation.

6.0 Building Equipment Area – Basement

6.1 Facility:

Basement Floor Area	7,000 sq. ft.
Basement Volume	120,000 cu. ft.
Basement Floor Elevation	66.0'
Basement Ventilation Unit and ME Room	12,500 scfm, 15 hp, 10-15% new air
Emergency Purge Fan	Flow to ME Room and Basement

The ventilation rate for the basement is 6,470 scfm, or about 50% of the Ventilation Unit capacity.

6.2 Oxygen Depletion

The basement is connected to the target rooms and to the electrical equipment room by cable passageways. The insulation gas can enter the basement area the following ways:

Target Room Trenches. If insulation gas accumulates in the lower level of the Accelerator Room to an elevation of 3' below the main level, it will then start to enter the target room trenches. Any gas that enters the target room trenches will flow through the trenches and overflow into the cableways leading to the basement. The flow path area is restricted to 1' by 2' between the A.R. and the target room. Although the flow area entering the basement is somewhat restricted, it is larger than the 1' by 2'.

Gas entering the EE room can enter the basement through an opening for cable tray near the stairwell. This flow area is restricted.

The large floor area and room volume and the restricted flow paths available for gas flow make the possibility of insulation gas accumulation and oxygen deficiency in the basement much lower than the other primary areas.

There is no supply of insulation gas in the basement area.

6.3 ODH Classification

The classification of the basement is the same as the Accelerator Room.

7.0 Remote Gas Storage Area

7.1 Facility:

There are two high-pressure banks of insulation gas, one dedicated to each MP accelerator. Each bank has 36 active, 220 cubic foot cylinders (7,920 cu. ft. total). The cylinders in each bank are stacked in three horizontal layers and covered with earth. An enclosed room 8 feet wide by 30 feet long separates the two banks. Outlet pipes with valves from each of the gas cylinders are manifolded together inside this room between the berms covering the cylinders. There is a single entrance door at one end of the room. A 22-inch square louvered vent at the bottom of the door and a 24-inch square louvered vent in the far wall allow for natural ventilation. The storage pressure is about 375 psig when all the MP gas is pumped into the storage cylinders. There is a relief valve on each storage bank set for 575 psig to protect the cylinders and piping from overpressure.

Floor Area		240 sq. ft.
Volume		2100 cu. ft.
Vent Area	Door	1.5 sq. ft.
	Vent	2.0 sq. ft.

7.2 Failure Modes and Oxygen Depletion

Insulation gas leakage into the Gas Storage Area could result from either relief valve opening during filling operations or by valve packing failure.

The relief valves cannot be pressurized to the set pressure with the existing gas inventory. The set pressure can be reached only by increasing the gas inventory or by pumping the gas of both accelerators into one storage bank. In the latter case the relief valve flow rate would equal the rated flow rate of two compressors, or 290 scfm. This flow would be adequate to fill the room when the door is closed at a rate of 1 foot per minute. If the door is held open, there will be no accumulation.

It is expected that any failure of valve packing would not be adequate to accumulate insulation gas in the room, due to the existing high natural ventilation rate of the fixed louvers. Significant packing leakage would also be audible and eventually detected by pressure loss.

7.3 Failure Rates

Loss of insulation gas through the relief valves is a low probability. There is no known incident where the relief valves have lifted or valves have failed in the history of the tandem. The failure rate is then estimated to be one incident in 30 years of operation, or $1x10e\text{-}6/hr^2$. The rate at which operations are conducted in the gas storage room with the door closed is estimated at 1x10e-2 per demand, which corresponds to a general human error of omission. This represents a failure condition rate of 1x10e-8/hr.

7.4 ODH Classification

The ODH classification of the Gas Storage Area based on a conservative 'F' factor of 1.0 and 'F' rate of 1x10e-8/hr is '0'.

Valve operation or any maintenance performed in the Gas Storage Area should follow a procedure that requires the door to be held open.

8.0 TTB Tunnel

8.1 Facility:

The entrance to the TTB Tunnel is at the northeast corner of the Accelerator Room. The floor elevation of the tunnel is about 10 inches above the main level of the Accelerator Room.

8.2 Oxygen Depletion

There is no source of insulation gas in the tunnel. Insulation gas will enter the tunnel only when the main level of the Accelerator Room fills to a level of 10 inches above the main level elevation.

8.3 ODH Classification

The ODH Classification of the TTB Tunnel is the same as the Accelerator Room. Personnel working in the tunnel will not be aware of an ODH condition occurring in the Accelerator Room. For this reason an alarm should be installed in the tunnel to notify workers to evacuate the area.

References:

1. Conversations with C. Carlson, TVDG
2. Memo from R. Karol to W. Glenn, dated 16 December 2000
3. Conversations with H. Abendroth, TVDG
4. Memo from R. Karol to L. Snydstrup, dated 6 March 2001

Appendix A: ODH Analysis of Window Failure

A.1 Leakage Rate, Air-Gas Mixing, and Oxygen Depletion.

Window failure assumes full opening of the 3-inch diameter window. The calculations for window leakage are shown in Appendix E. The flow rate at the normal pressure of 180 psig, 20degC is calculated to be 11,000 scfm. This is 52% of the capacity of the emergency purge fan. The flow rate decays exponentially. The calculations are done for two conditions: the gas temperature in MP is constant (isothermal) and the adiabatic case in which the gas temperature drops isentropically (i.e., there is no heat transfer into the gas from the vessel walls). The actual condition is somewhere in between, but both calculations show similar flow rates. Based on the worst case condition, 90% of the gas exits the vessel in about 35 minutes.

There are different scenarios that may result from a leak:

1. The insulation gas exits with minimal mixing with the room air. This may occur if the gas jet is deflected downward. Unmixed tank gas is much denser then room air, having a specific gravity of 2.85 at room temperature. Since the purge fan capacity exceeds the leak rate, the insulation gas will enter the ventilation ducting with room air, resulting in an air-gas mixture with a specific gravity of about 2.0 entering the fan.

2. The insulation gas exits and mixes with room air. The resultant mixture will be a larger volume than that of the insulation gas escaping the tank and it will be heavier than air. At the same time the air component of the mixture increases its oxygen content. If room air comprises an average of 60% or more of the mixture, the rate that the mixture is generated will exceed the purge fan capacity. Initially, the fan will not be able to pump out all of the gas that settles in the lower level. As the leak rate diminishes, the purge fan will exceed the rate at which the gas mixture is formed. Eventually the area is cleared of gas by the fan. The following chart shows average mixing ratios of tank gas with air that may be possible, the ‘F’ factor associated with the resulting oxygen content, and the maximum gas level that may accumulate in the lower level:

Case	%Tank Gas	% Air	Specific Gravity	%O2 in Mix	‘F’ Factor	Max LL Gas Level, feet
1	100	0	2.85	0	1.0	0
2	40	60	1.74	13	4.1e-4	1.5
3	30	70	1.56	15	1.3e-5	4.4
4	20	80	1.37	17	3.8e-7	7.2

3. The insulation gas exits the tank and the purge fan fails to run. In this case the gas from the leak will fill the lower level area, overflow into the adjacent lower level, and then fill part of the upper level and flow into the TTB tunnel. The following chart shows the volumetric flow rate of the higher density mixture and the rate at which the 10 foot deep lower level fills:

Case	%Tank Gas	% Air	Flow Rate, scfm	Time to Fill, sec**
1	100	0	11,000	170
2	40	60	28,000	65
3	30	70	37,000	50
4	20	80	55,000	34

** Fill rate ignores the possible flow of gas to adjoining lower level through passageway due to the low expected flow rate.

A.2 Gas System Failure Rates

Two scenarios of operation are considered: Automatic purge fan operation and the manual operation of purge fan by the operator. The failure modes for each are as follows:

Operation	Failure Mode
Automatic	1. Window fails, purge system runs
	2. Window fails, purge system fails to run
Manual	1. Window fails, purge system runs after turned on by operator
	2. Window fails, purge system is not turned on, it is turned on only after delay, the fan fails to run after successful start, or dampers fail.

1. Failure of Purge Fan to Run in Automatic Mode (excluding ventilation damper failure rate). The probability of window failure based upon the past running history at the BNL Tandem and also the running experience of the tandem at the University of Minnesota is estimated to be 3x10e-7/hr[4]. The failure of the purge fan to automatically come on may be due to two possibilities: Control system failure or failure of the continuously operating ODH monitor. There are a few components that can contribute to the automatic control system failure after the ODH monitor detects a leak: a PLC system and relay, motor starter, motor, or power system failure. The probability of the purge fan to fail to come on automatically then is estimated to be 1x10e-3/demand, as shown below. A conservative estimate of the ODH sensor failure is once every 1000 hours (these sensors alarm when they fail). Whether the control system fails or there is a simultaneous failure of the ODH monitor and a leak, the failure rate is 3x10e-10/hr. The failure rate for automatic mode is the sum of the two, or 6x10e-10/hr.

Gas Leak → 3x10e-7/hr	ODH Monitor → Operates	Auto Circuit → Fails on ODH	-PLC/relay	1x10e-4 per demand	
			-Motor Starter	1x10e-4/d	
			-Motor	3x10e-4/d	
			-Power	3x10e-4/d	
		Continuously Operating ODH Monitor Fails	TOTAL EST.	1x10e-3/d	→3x10e-10/hr
Gas Leak	+	1x10e-3/hr	→		→3x10e-10/hr
				TOTAL	6x10e-10/hr

2. Failure of Purge Fan to Run in Manual Mode (excluding damper failure). The probability of failure of an operator to manually turn the emergency fan on is estimated to be 2-3 times out of 10 for general human error at very high stress levels (SBMS), or 3x10e-1/demand.

			→ Fan Runs	→ 2.1x10e-7/hr
Gas Leak → 3x10e-7/hr	→ Fan On by Operator .7/d	→	→ Fan Fails 7x10e-4/d (from above data)	→ 1.5x10e-10/hr
	→ Fan Not Turned On by Operator .3/d			→ 9x10e-8/hr

3.Damper Failure Rate. Finally, the possibility of the failure of the dampers in the ventilation ducting is considered. There are three dampers in each A/C unit that must be correctly positioned for the emergency purge to occur: return air (RA) damper, exhaust air (EA) damper, and the outside air (OA) damper. There is also a set of four inlet dampers located in each lower level of the A.R. Room that must be open during purging. The failure rates for dampers to operate are made up of the following components: a relay, a 3-way solenoid pilot valve, and one or more pneumatically operated damper. In the purge mode the relays and solenoid valves for the four dampers are de-energized, and the failure rate for both to de-energize and go to the normally open position is estimated to be 1x10e-3 per demand. The failure rate for the normally closed air operated dampers (spring to close) to open is estimated to be 3x10e-4 per demand (i.e., considered to be the same as an air-operated valve); the rate for a normally closed damper to fail to close is not considered significant. The failure rate for the normally closed RA damper to close is then 1x10e-3 per demand. The rate for the normally closed EA and OA dampers to open, which are energized by the same relay and solenoid valve, is estimated to be 1.6x10e-3 per demand. The rate for the four parallel, normally closed inlet dampers energized by one relay/solenoid is 2.2x10e-3 per demand. Since failure of any one of the dampers prevents purging, the probability of damper failure is the sum of these three failure rates, or 4.8x10e-3 per demand. Two ventilation units serve the A.R., so the probability of damper failure is twice that of a single unit, or 9.6x10e-3/d. The 'availability' of the compressed air system for the dampers is considered to be very high. The system configuration consists of two compressors, a primary and a backup, and a storage reservoir. Since there have been no known failures of this system during the life of the TVDG, the affect of the air system on the damper reliability is insignificant. Power failure is already considered in A.2.1-2 above.

Factoring damper failure rates into the failure modes discussed previously is shown below:

Auto Mode:

Gas Leak → 3x10e-7/hr	ODH Monitor Operates	+ Auto Run Circuit Fails on ODH 1x10e-3/d	→	3x10e-10/hr
Gas Leak	+	ODH Monitor Fails 1x10e-3/hr	→	3x10e-10/hr
Gas Leak	+	Damper Failure 9.6x10e-3/d	→	2.9x10e-9/hr
			TOTAL	3.5x10e-9/hr

Manually Operated Fan Mode:

	→ Fan On by Operator .7/d	→ Fan fails, 7x10e-4/d	→ 1.5x10e-10/hr
Gas Leak → 3x10e-7/hr		→ Fan Runs, Damper Fails 9.6x10e-3/d	→ 2.0x10-9/hr
	→ Fan Not Turned On by Operator .3/d		→ 9x10e-8/hr
		TOTAL	9.2X10e-8/hr

The failure rates for the above are then:

Operation/failure mode	Failure Rate
Automatic, F.M. 1	3.0x10e-7/hr
Automatic, F.M. 2 (fail)	3.5x10e-9/hr
Manual, F.M. 1	2.1x10e-7/hr
Manual, F.M. 2 (fail)	9.2x10e-8/hr

A.3 ODH Classification

The ODH hazard is mitigated when the purge fan can effectively exhaust any accumulation of insulation gas out of the building. If mixing of insulation gas at an estimated 11,000-scfm with air does not occur, or if air is less than 50% of the final mixture (average), then the capacity of the fan is equal to or greater than the volume of gas produced by the leak. Insulation gas from a broken window can accumulate in the lower level only if substantial mixing with air occurs in the process of settling to the lower level. If the air is more than 50% of the resulting gas-air mixture from a leak, then the volume of the mixture exceeds the fan capacity and gas will temporarily accumulate in the lower level at average oxygen concentrations of 10.5% or higher. However, at this oxygen concentration the ODH classification is '0', as shown in the table below.

Case	% Air	Air-Gas Leakage Rate,cfm	S.G. into fan	%O2 in Mix	'F' Factor	Failure Rate	'F' Rate	ODH Class
1	60	27,500	1.74	12.6	8.4e-4	3.0e-7	2.5e-10	U
2	55	24,400	1.83	11.6	5.2e-3	same	1.6e-9	0
3	50	22,000	1.93	10.5	.033	same	1.0e-8	0
4	45	20,000	1.97	9.45	.208	same	6.2e-8	0

The following table gives the resulting classification when the fan comes on, either by automatic or manual actuation:

Operating Condition	Failure Rate	'F' Factor	'F' * Rate	ODH
Window Fails, Purge Fan runs Air >50%	3.0x10e-7/hr	. 033	9.9x10e-9/hr	0
Window Fails, Purge Fan runs Air <50%	3.0x10e-7/hr	1.0 at 0% air	3.0x10e-7/hr, but no accumulation	unclassified

The following table gives the ODH classification when the fan does not come on or the ventilation dampers fail. Without the purge fan the lower level can fill up in less than 3 minutes. The 'F' factor depends on the extent that air mixes with the gas leak with 1.0 being the worst case.

Operating Condition	Failure Rate	'F' Factor	'F' * Rate	ODH
Window Fails, Purge Fan or Damper Fails In Automatic	3.5x10e-9/hr	1.0	3.5x10e-9/hr	0
Window Fails, Purge Fan or Damper Fail In Manual	9.2x10e-8/hr	1.0	9.2x10e-8/hr	0

If the purge fan is disconnected for repair or not functional, the 'F' rate is 3.0x10e-7/hr, the product of the failure rate $3.0x10e\text{-}7^2$ and the 'F' factor of 1.0. This is an ODH classification of '1'.

It should be noted that the above classifications are developed from 'average' oxygen concentrations in accordance with the SBMS procedure. Hazardous oxygen levels will always be found in the region surrounding the leak. This would be true in any type facility.

A.4 Upgrade of Emergency Purge Fan

An actual flow rate of the existing purge fan was measured while flowing to the target rooms. The fan produced a flow of about 24-25,000 scfm at 3.0 inches static pressure. The motor current was measured at a different time to be 23 amps. The existence of the smaller ¾ hp axial fan in parallel with the purge fan did not affect the performance of the purge fan. This smaller fan rated for 2100 scfm did not seem to be operational at all during the test. A maximum flow through the axial fan was measured to be 300 scfm when the purge fan was running, possibly due to reverse flow through the back draft damper (direction of flow could not be measured).

Purge Fan Design Specifications:

The facility specifications for the Emergency Purge Fan differ from the existing operating conditions of the fan, as measured by R. Diaz on 11 April 2001. A summary of the operating parameters is as follows:

	Facility Specification	Actual Measured	Actual Corrected*
Flow, scfm	20,930	25,000	21,300
Static Press, "w.c.	3.0	3.0	2.2
Fan Speed, RPM	685	805	685

*Formulas shown on this page are used for correcting actual measurements from measured speed of 805 rpm to the design speed of 685 rpm. These formula were supplied by Greg Brill of Howden Fan (716-847-5256):

$$Scfm_1=Scfm_2*(RPM_1/RPM_2)$$

$$SP_1=SP_2*(RPM_1/RPM_2)^2$$

The corrected flow rate shows good correlation to the design flow, 21,300 versus 20,930 scfm. The static pressure measurement of 2.2" is considerably lower than the design. Howden attributes this difference to age of the fan and to the ideal condition under which the fan is factory tested (e.g., long straight inlet and outlet ducting lengths).

Purge Fan Sizing for SF6/N2 Gas Mixture:

In order to pump the heavier gas that may result from the release of insulation gas into the A.R. the Purge Fan speed will be reduced from 25,000 scfm to 20,250 scfm. The lower volumetric flow will preclude significant accumulation of air-gas mixture in the lower level and the existing fan motor will have sufficient horsepower to handle the denser gas at this flow rate.

An optional upgrade to the purge fan may be implemented to meet the original facility specification of 21,000 scfm while pumping the heavier gas. The following changes would be necessary:

a. Increase the motor size from the existing 20-hp to 25-hp. The existing motor mounting base is suitable for the larger 25-hp motor, and the existing motor starter is rated for a 25-hp motor.
b. Change belt sheaves and belts to reduce the fan speed to design specification of 685 RPM from 805 RPM.

Calculation of the new static pressure (SP) and motor hp (or amperage), using a specific gravity (SG) ratio of gas to air equal to 2, is as follows:

$$SP_1=SP_2*(RPM_1/RPM_2)^2*(SG_1/SG_2)$$

$$A_1=A_2*(RPM_1/RPM_2)^3*(SG_1/SG_2)$$

The static pressure of the fan at a flow of 21,000 scfm and with a SG of 2 increases to 4.4 inches water column from 3.0 inches. The motor current required will be about 27.3 amps, or 25 hp. According to Howden Buffalo, the higher static pressure is expected to be acceptable for this type of fan.

Appendix B: ODH Analysis of MP Beam Line Failure

B.1 Gas Leakage Rate and Oxygen Depletion

The vacuum beam line inside the MP pressure vessel may fail if exposed to the external pressure of the insulation gas at 195 psia. Failure in this mode could potentially occur at the acceleration tubes, bellows, or flange gaskets. In this case insulation gas would flow out of the pressure vessel at both ends through the beam line, and enter the Accelerator Room through a ruptured, low pressure rated beam line component outside the MP (e.g., bellows). 'Fast Shut' valves are installed at both ends of the accelerator. These valves fail closed on loss of power or loss of utility air pressure. A control system de-energizes these valves to close if a loss of vacuum condition is sensed. The port diameter of the 'fast shut' valve is 2.5 inches. If one of the 'fast shut' valves fails to close, the flow through the valve disregarding flow friction is conservatively estimated to be 7,800 scfm. This is less than the flow rate occurring from a window failure.

B.2 Failure Rates

The probability of beam line failure is based upon the past running history of the Tandem. With no failure in a 30-year period and a future Tandem usage rate equal to past usage, the probability of failure is estimated to be one failure in 30 years, or 3.8x10e-6/hr. The failure rate including the University of Minnesota experience[4] is 3x10e-7/hr.

The failure rate of the 'fast shut' valve is the sum of the failure rates of the air-operated ball valve (3x10e-4/d), the solenoid pilot valve (1x10e-3/d), and the pressure switch (1x10e-4/d), equal to 1.4x10e-3 per demand. The rate for either of the two valves at each end of the MP to fail to close is twice that for one, or 2.8x10e-3 per demand. The probability of both valves failing to close at the same time is extremely low at 2.0x10e-6 per demand. The product of the beam line failure rate and the failure rate for one valve is 8.4x10e-10 per hour.

B.3 ODH Classification

There is no classification of the acceleration room due to the low MP beam line failure rate. Reliance on the operation of the purge fan is not necessary for this classification.

Appendix C: ODH Analysis of A.R. Gas Dryer Relief Valves

C.1 Failure Mode

The relief valves on the dryer have a set pressure of 250 psig. The relief valves will open and insulation gas will exhaust into the lower level of the Accelerator Room if the pressure-regulating valve PCV-1 upstream of the relief valves fails or is set improperly.

The latter failure mode may occur if the pressure-regulating valve is set improperly during pressure check of the gaskets on the gas dryer at 200 psig. This pressure check is done routinely prior to pressurization of the accelerator to avoid lost time if a leak is found, since pressurization of the accelerator takes 2-2.5 hours. It is estimated that the procedure is performed about 10 times per year[1]. Two operators perform this check: one pressurizes the dryer from the ME Equipment room and one checks for leaks at the dryer in the Accelerator Room lower level. The accelerator is isolated and not pressurized during the check.

C.2 Gas Leakage Rates and Oxygen Depletion:

The maximum possible flow rate out of the two dryer relief valves will be restricted by the 1.5", 600-class pressure regulating valve PCV-1 upstream of the relief valves to about 750-scfm if the gas supply is at 400 psig (Cv flow factor equal to 5.86). Since the MP pressure vessel is not pressurized, the MP volume will not contribute to the flow rate. If the purge fan comes on, there will be no accumulation of insulation gas in the lower level. If the purge fan does not come on, the insulation gas will fill the 10 foot deep lower level at the rates shown below:

Case	%Tank Gas	% Air	S.G.	%O2 in Mix	'F' Factor	Flow Rate, scfm	Fill Rate, ft/min*
1	100	0	2.85	0	1.0	750	.12
2	40	60	1.74	12.6	8.43-4	1,875	.3
3	30	70	1.56	15	1.3e-5	2,500	.4
4	20	80	1.37	17	3.8e-7	3,750	.6

* Fill rate assumes flow of gas to adjoining lower level through 5' wide passageway.

C.3 Failure Rates:

Oversetting of the pressure-regulating valve will cause the dryer relief valves to lift. Based on past experience the rate at which the relief valve has lifted is estimated to be one time every 5 years[3]. If the pressure check is done about 10 times (i.e., demands) per year this corresponds to 2x10e-2 per pressure test (i.e., demand). This compares well to the SBMS human error rate estimate of 3x10e-2 per demand for general human error of omission (e.g., failure to return manually operated test valve to proper configuration after maintenance). In order to increase the safety margin, a failure rate of one time every 2.5 years is used, equal to 4.0x10e-2 failures per test (demand) or 2.0x10e-2 failures per hour if the test takes 2 hours.

C.4 ODH Classification:

The ODH classification is determined from the ‘F’ rate, which is the product of the ‘F’ factor and the failure rate of 2.0x10e-2/hr. A low mixing percentage of insulation gas with air in the lower level is expected. The volumetric flow of the mixture could range from 750 scfm (100% gas) to probably less than 1,875 scfm (mixture is 40% gas and 60% air). At 750 scfm the gas accumulation rate is only .12 fpm or .6 feet in 5 minutes, and the ‘F’ rate is 2.0x10e-2. At this rate it would take over 30 minutes for the gas to reach breathing level. At 1,875 scfm the gas accumulation rate is .3 feet per minute or 1.5 feet in 5 minutes (about 10 minutes to reach breathing level), and the ‘F’ rate is 8.0x10e-6 per hour. The ODH classification without reliance on the purge fan is then ‘1’ based on an escape time of 5 minutes.

The purge fan will pump out all of the gas resulting from the relief valve opening. If the purge fan is functional in manual or automatic mode, therefore, the ODH classification of the A.R. will not be affected by incidents of the dryer relief valves opening.

The following factors also improve the scenario of the gas dryer relief valves opening:

The maximum insulation gas flow rate of 750 scfm occurs only when the pressure-regulating valve is adjusted to open fully or if it fails full open (not likely for a modulating valve that ‘fails closed’). Relief valve opening is detected immediately due to the noise. One or both operators will respond to stop pressurization within minutes, closing the valve to avoid a harmful situation.

As in any facility there are hazards in addition to ODH that are present when personnel are in close proximity to lifting relief valves (e.g., hearing, loss of equilibrium, etc.). It is recommended that the area around the relief valves is kept clear and pressurization conducted in steps. Leak checking then would start only when pressurization is stopped and the system stable.

Appendix D: ODH Analysis for ME Room

D.1 Failure Modes, Gas Leakage Rates, and Oxygen Depletion

D.1.1 Relief Valves.

The ME room includes the following overpressure devices:

Item	Location	Qty	Set Pressure	Size
1	Compressor Suction	2	250 psig	4”
2	Compressor Discharge	2	585	1.5”
3	Compressor 1st Stage	2	500	1.5”
4	Compressor 2nd Stage	2	590	1”
5	Compressor 3rd Stage	2	635	. 75”
6	PCV1 Downstream	1	250	2”
7	Scavenge Pump	1	300	1”
8	Kinney Vacuum Pump Discharge**	2	5-6	4”
9	Kinney Vacuum Pump Discharge	1	4	3/8”

**These are not conventional relief valves, but special overprotection devices that replaced the original bursting disks.

The opening of relief devices located in the ME Room has occurred during gas transfer operations. It is estimated that gas transfer takes 2-2.5 hours for either filling or emptying a MP pressure vessel. A gas transfer operation is conducted about 10 times per year, a total of 40 to 50 hours per year. During these procedures system operators are present.

Items 1-6 do not discharge into the ME Room, and are not considered in ODH analysis. High vacuum pump discharge pressure opening items 8 and 9 is a known failure mode that will cause gas to enter the ME Room. The vacuum pump is used to transfer gas from the MP to the Gas Storage Area when the MP vacuum is 10 inches Hg vacuum or higher. The compressor(s) are needed in series with the vacuum pump to pump to the high-pressure storage cylinders. The compressor flow is matched to the vacuum pump flow by bypassing the compressor discharge back to the compressor suction. Item 9 relief valve is very small, but it provides a warning to the operator to correct the overpressure before item 8 opens. Excessive vacuum discharge pressure may results from any of the following conditions:

a. Oversetting of pressure controller of the inlet regulator PCV33 to the vacuum pump;
b. Failure to set or readjust the compressor bypass valve properly;
c. Incorrect position of other valves in the system;
d. Securing the compressor or power failure while in bypass.

The estimated flow rate through the overpressure devices, item 8, for the first three conditions at 10 inches Hg (10 psia) into the vacuum pump is 560 scfm based on the pump rating of 850 scfm at 1 atm inlet. For the last condition gas can be fed backwards to the vacuum pump discharge from the Gas Storage Area through the throttled bypass valve. In this case the flow is estimated to be equal to the compressor capacity or 2 x 146 scfm, which would be approximately equal to the flow setting of the bypass valve. The overpressure devices, item 8, are not conventional relief valves and an operator must manually reset them after opening.

D.1.2 Compressors

The maximum compressor leakage rate due to seal failure is assumed to be equal to the capacity of two compressors, or 292 scfm. The flange gaskets used in the compressor discharge line are the metal reinforced 0-ring type. Only very low leakage rates have been experienced using this type of gasket.

D1.3 Oxygen Depletion

The leakage of the insulation gas having a specific gravity of 2.85 into the ME Room will gravitate to the lowest level. The 'F' factor for the ME Room is considered to be 1.0 for specific locations in the room where the gas discharges high and an operator may be susceptible to an ODH condition, such as near item 8. The heavy insulation gas gravitates to the ME Room floor and overflows into the open pit in the NE corner of the room or enters the ventilation duct in the SW location. An open area of about 3-sq. ft. at the bottom of the pit will allow gas to flow without restriction into the Accelerator Room lower level.

Turning on the emergency purge fan substantially alleviates the ODH condition. The purge flow rate is about 10,000 scfm, which equals a rate of 4 minutes to turn over the volume of air in the room. This influx of fresh air significantly exceeds the maximum leak rate of 560 scfm.

D.2 Failure Rates

The overpressure devices, item 8, are estimated to open one time every 10 years, or once every 500 hours of gas transfer, 2.0x10e-3/hr[1].

The failure modes in the compressor system are seal failure and compressor discharge piping flange leakage. The failure rate for compressor leakage from the SBMS is estimated to be 2 units x 5.0x10e-6/hr = 1.0x10e-5/hr. The failure rate for piping flange leakage is not considered due to the very low leakage rates that have been experienced in this type gasket.

A summary of the individual component failure rates is provided in the table below.

Event	Failure Mode	Leak Rate, Scfm	Failure Rate
1	RD 8, RV 9	560	2.0x10e-3/hr
2	Compressor	292	1.0x10e-5/hr

Events 1 and 2 could result in a hazardous gas discharge at an elevation above the operator. The sum of the failure rates for these events is 2.0x10e-3/hr.

These failures will trigger corrective actions by the operator. Once an operator notices leakage, the leakage will be stopped and/or the purge fan turned on. The failure rate for an operator to detect and stop flow is estimated to be 2-3 times out of 10 for general human error at very high stress levels (SBMS), or 3.0x10e-1/demand. The following diagrams show the failure rates for a manually operated purge fan (existing) and for an automatically operated fan, discussed in greater detail in Appendix A.

Manual Action by Operator:

		→ Fan Runs, Dampers Fail 9.6x10e-3/d		→ 1.4x10e-5/hr
Gas Leak → 2.0x10e-3/hr	→ Leak Stopped, Fan→ on by Operator .7/d	| → Fan Fails 7x10e-4/d (from App. A)		→ 9.8x10e-7/hr
	→ Operator Fails to Correct .3/d	→		→6.0x10e-4/hr
			TOTAL	6.1X10e-4/hr

Automatic Purge Fan, Leak Continues:

Gas Leak → 2.0x10e-3/hr	ODH monitor → operates	Auto Circuit fails on ODH 1x10e-3/d	→		→2.0x10e-6/hr
	OR				
Gas Leak 2.0x10e-3/hr	+	ODH Monitor fails 1x10e-3/hr	→		→2.0x10e-6/hr
	OR				
Gas Leak 2.0x10e-3/hr	+	Damper Failure 9.6x10e-3/d	→		→1.9x10e-6/hr
				TOTAL	5.9x10e-6/hr

\+ concurrent event
→ sequential event

In summary the calculated failure rate for a gas leak occurring and the condition not being corrected by the operator either by using the purge fan or by stopping the leak is 6.1x10e-4 events per hour. For a purge fan that comes on automatically the failure rate for a gas leak and the purge fan not coming on is 5.9x10e-6/hr.

D.3 ODH Classification

The ODH classification of the ME Room is based on leakage events that may cause high gas discharge. The classification is determined from the ‘F’ rate, which is the product of the ‘F’ factor of 1.0 and the failure rate of 6.1x10e-4/hr. This equates to an ODH Class ‘2’ rating during gas transfer operations. If an automatic purge fan were operational, the ‘F’ rate would drop to 5.9x10e-6/hr, ODH Class ‘1’. The room should be ODH Class ‘0’ during all times that gas transfers are not in process. If the purge fan is disabled, the ‘F’ rate is 2.0x10e-3/hr, Class ‘3’.

D.4 ME Room Modifications

The venting of RD8 relief devices to the outside will reduce the probability of a gas leak from 2.0x10e-3/hr to 2.1x10e-5/hr. If the purge fan is manually operated, the failure rate becomes 6.4x10e-6/hr. If the purge fan is automatically operated, the failure rate is now 6.2x10e-8/hr. For a 'F' rate of 1.0 the ODH classification for manual mode is '1', for the auto mode is '0'. If the purge fan is disabled, the ODH class is '2'.

It is recommended that the gas supply valves on the gas panel in the ME Room be distinctly marked to enable the operator to close valves quickly and isolate the ME Room from the gas supply if leakage occurs. These shutoff valves must provide isolation from both the Gas Storage Area and the MP pressure vessels.

Appendix E – Calculation of MP Leak & A.R. Accumulation Rate

L. Snydstrup

I. Calculation of Mass of MP Gas at Pressure P:

(from Properties of Gses & Liquids, Virial Equation - Reid, et al
TP242.R4 1987)

$i := 1..3 \quad j := 1..3 \qquad n := 1..40$

		Mole or Vol. Fraction:	Molecular Weight:
Given:	1.Sulfur Hexaflouride:	$y_1 := .46$	$M_1 := 146.054 \cdot \frac{gm}{mole}$
	2. Nitrogen:	$y_2 := .44$	$M_2 := 28.013 \cdot \frac{gm}{mole}$
	3. Carbon Dioxide:	$y_3 := .10$	$M_3 := 44.010 \cdot \frac{gm}{mole}$

Univ. Gas Constant: $R \equiv 83.144 \cdot 10^5 \cdot \frac{Pa \cdot cm^3}{mole \cdot K}$

Gas Temperature: $T_o := 293 \cdot K$

Pressure: $P_o := 195 \cdot psi$

$P_o = 1.344 \times 10^6 Pa$

Volume of MP Accelerator: $Vol := 11250 \cdot ft^3$

Molecular Weight of Gas Mixture (use mole fraction, not mass fraction):

$$MW := \sum_{i=1}^{3} y_i \cdot M_i$$

$MW = 0.084 kg\, mol^{-1}$

Calculate Initial Gas Mixture Mass in MP using Partial Pressure Approach and Ideal Gases:

(p. 408, Van Wylen & Sonntag)

$$P_{p_i} := y_i \cdot P_o$$

$$m_{p_i} := \frac{P_{p_i} \cdot Vol \cdot M_i}{R \cdot T_o}$$

$m_{p_i} =$

$1.181 \cdot 10^4$	kg
$2.167 \cdot 10^3$	
773.756	

$$m_{go} := m_{p_1} + m_{p_2} + m_{p_3}$$

$$m_{go} = 1.475 \times 10^4 \, kg$$

Density at Standard Conditions $P_a := 14.69 \cdot psi$ $T_a := 293 \cdot K$

$$p_i := y_i \cdot P_a$$

$$\rho_i := \frac{p_i \cdot M_i}{R \cdot T_a}$$

$$\rho_{sc} := \sum_{i=1}^{3} \rho_i$$

$$\rho_{sc} = 0.218 \frac{lb}{ft^3}$$

II. Calculation of Mass Flow Rate thru Window:

$P_o = 195\,psi$

Assume Orifice Diameter of 3" .

Calculation of Mass Flow Rate during Choked Flow
(Gas Dynamics, Zucrow, Hoffman)

γ=specific heat ratio=cp/cv
Γ=specific heat ratio function
P=stagnation pressure, Pa (N/m2)
A=throat area,m2
R=gas constant,J/kg-K
T=stagnation temperature, K
k=coefficient of discharge
d=diameter of flow opening, cm

$$R_g := \frac{R}{MW}$$

$$R_g = 0.099\,\frac{joule}{gm\cdot K}$$

$$d := 7.6\cdot cm$$

$$A := \frac{\pi\cdot d^2}{4}$$

$$A = 45.365\,cm^2$$

$$\gamma := 1.156$$

$$\Gamma := \gamma\cdot\left(\frac{2}{\gamma+1}\right)^{\frac{(\gamma+1)}{2\cdot(\gamma-1)}}$$

$$\Gamma = 0.688$$

$$k := .8$$

$R_g := .099\cdot\frac{joule}{gm\cdot K}$ (See specificheat.mcd)

$$m_m := \frac{A\cdot\Gamma\cdot P_o\cdot k}{(\gamma\cdot R_g\cdot T_o)^{.5}}$$

$$m_m = 2.425\times 10^3\,\frac{lb}{min}$$

$$m_m = 18.331\,kg\,s^{-1}$$

a_s is sonic speed:

$$a_s := (\gamma\cdot R_g\cdot T_o)^{.5}$$

$$a_s = 600.78\,\frac{ft}{sec}$$

$$\rho_{sc} = 0.218\,\frac{lb}{ft^3}$$

$$Q := \frac{m_m}{\rho_{sc}}$$

$$Q = 5.254\,m^3\,s^{-1}$$

$$Q = 1.113\times 10^4\,\frac{ft^3}{min}$$

III. Exponential Decay of MP Gas - Isothermal:

Exponential decay occurs whenever a quantity changes at a rate which is proportional to the value of itself. mg is the mass of the pressurized gas in the MP volume. mg decreases at a rate that is proportional to the amount of mass (i.e., pressure) in the MP.

$Z := 1.0$ (Assume Constant Initial Compressibility Factor, Z)

$$\kappa_1 := \frac{A \cdot \Gamma \cdot k}{(\gamma \cdot R_g \cdot T_o)^{.5}} \qquad \kappa_2 := \frac{Z \cdot R_g \cdot T_o}{Vol}$$

$$\kappa_1 = 1.363 \times 10^{-5}\, m\, s \qquad \kappa_2 = 91.055\, m^{-1}\, s^{-2}$$

$$\tau := \frac{1}{\kappa_1 \cdot \kappa_2}$$ Time constant

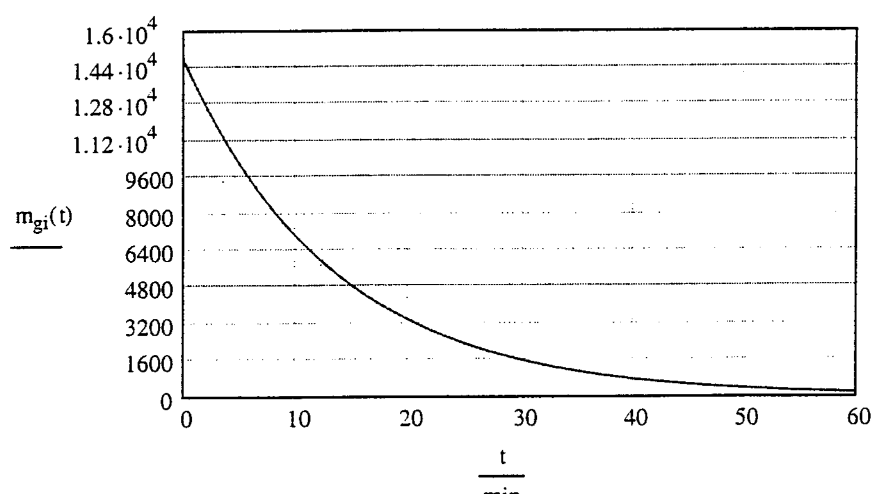
$\tau = 805.497\, s$

$t := 0, 60s .. 3600 \cdot s$

$$m_{gi}(t) := m_{go} \cdot e^{\frac{-t}{\tau}}$$ Definition of exponential decay for conditions defined by the next two equations - isothermal case.

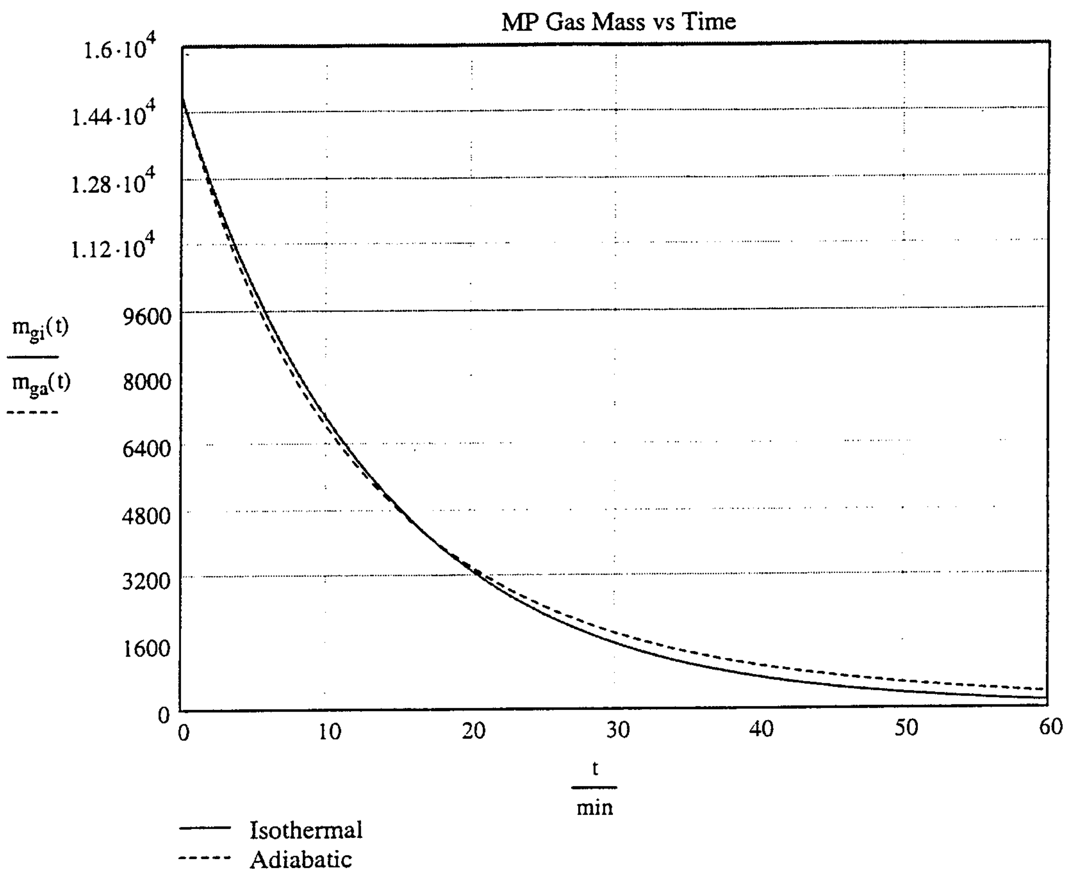
$$P_{mi}(t) := \kappa_2 \cdot m_{gi}(t)$$ Equation of state

$$\frac{d}{dt} m_g(t) = \kappa_1 \cdot P_m(t)$$ Differential equation for mass flow rate at sonically choked condition.



$$P_{mi}(0 \cdot sec) = 194.832\, \frac{lbf}{in^2}$$

(Check Z above)


MP Gas Mass vs Time
1.6·10^4
1.44·10^4
1.28·10^4
1.12·10^4
9600
8000
6400
4800
3200
1600
0
m_gi(t)
m_ga(t)
0
10
20
30
40
50
60
t
min
Isothermal
Adiabatic

IV. Decay of MP Gas - Adiabatic:
(Gas Temp is not constant)

Assume sonic velocity is constant and that specific heat ratio is constant for adiabatic case. Compressibility factor is constant.

$$\frac{T(t)}{T_a} = \left(\frac{P_{ma}(t)}{P_m(0\cdot sec)}\right)^{\frac{\gamma-1}{\gamma}}$$

$$P_{mi}(0\cdot sec) = 194.832\,\frac{lbf}{in^2}$$

$$T_o = 293\,K$$

Temperature of gas decreases with pressure decay. Pma(t) is pressure of gas mixture for adiabatic condition, and is a function of time.

$$T(t) = T_a\cdot\left(\frac{P_{ma}(t)}{P_o}\right)^{\frac{\gamma-1}{\gamma}} \qquad (1)$$

(Isentropic P-T relationship)

$$P_{ma}(t) = \frac{Z\cdot R_g}{Vol}\cdot T(t)\cdot m_{ga}(t) \qquad (2)$$

(This is the equation of state)

Combining (1) and (2):

$$P_{ma}(t) = \left(\frac{m_{ga}(t)}{m_{go}}\right)^{\gamma}\cdot P_o{}^{\gamma-1} \qquad (3)$$

$$\frac{d}{dt}m_{ga}(t) = \kappa_1\cdot P_{ma}(t) \qquad (4)$$

(This is the differential equation for mass flow rate at sonically choked condition.)

Combining (3) and (4):

$$\frac{d}{dt}m_{ga}(t) = \kappa_1\cdot P_o\cdot\left(\frac{m_{ga}(t)}{m_{go}}\right)^{\gamma} \qquad (5)$$

Aver Temp for Adia Condition:

$$T_{av} := 240\cdot K$$

$$\kappa'_1 := \frac{A\cdot\Gamma\cdot k}{(\gamma\cdot R_g\cdot T_{av})^{.5}}$$

Solution to (5): $m_{ga}(t) = \left[m_{go}{}^{1-\gamma} - (1-\gamma)\cdot\kappa_1\cdot\kappa'_2{}^{\gamma}\cdot P_o{}^{1-\gamma}\cdot t\right]^{\frac{1}{1-\gamma}}$

(5) in dimensionless form:

$$m_{ga}(t) := kg\cdot\left[\left(\frac{m_{go}}{kg}\right)^{1-\gamma} - (1-\gamma)\cdot\left(\frac{\kappa'_1}{m\cdot s}\right)\left(\kappa_2\cdot m\cdot s^2\right)^{\gamma}\cdot\left(\frac{P_o}{Pa}\right)^{1-\gamma}\cdot\frac{t}{s}\right]^{\frac{1}{1-\gamma}}$$

V. Calculate Mass of gas accumulated in Room:

Calculate Totalized Mass of Gas Mixture exiting MP (isothermal):

$$m_e(t) := m_{go} - m_{gi}(t)$$

Calculate Total Mass Flow pumped by Emer. Exhaust Fan:

$$Q_{fan} := 21000 \cdot \frac{ft^3}{min}$$

$$m_{fan} := Q_{fan} \cdot \rho_{sc}$$

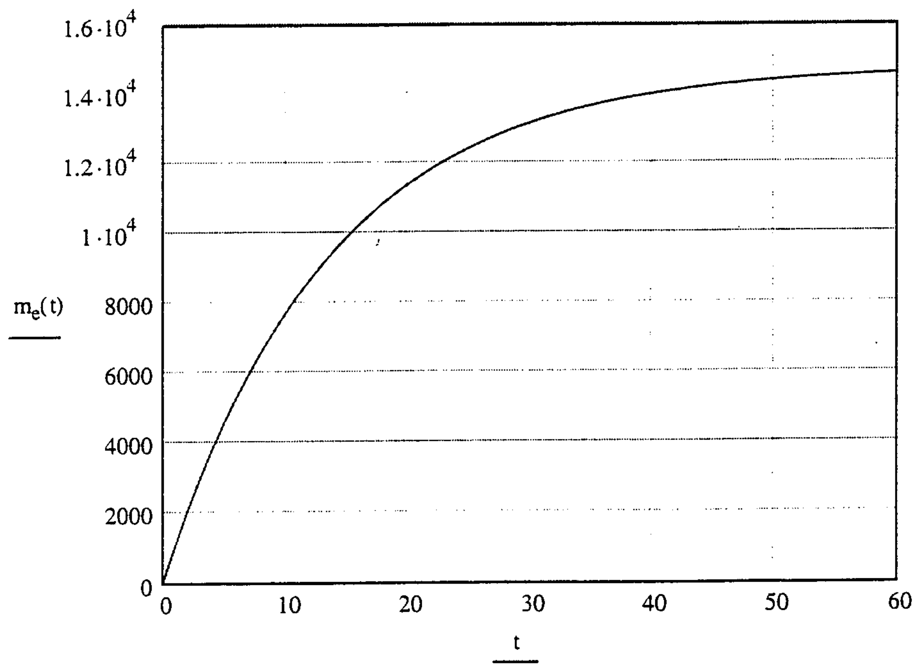
$$m_{fan} = 4.574 \times 10^3 \frac{lb}{min}$$

$\eta := .5$ Percentage of gas entering fan with air

$$m_{tfan}(t) := \eta \cdot Q_{fan} \cdot \rho_{sc} \cdot t$$

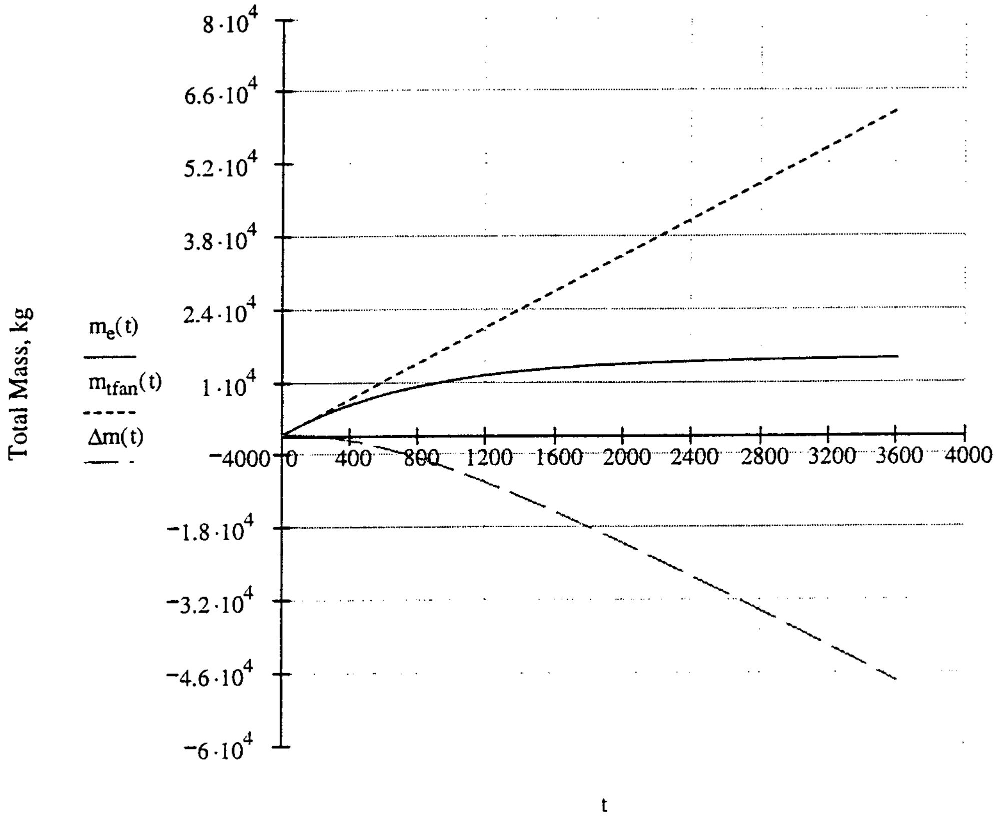
Calculate Mass of gas entering in Room:

$$\Delta m(t) := m_e(t) - m_{tfan}(t)$$



nnn

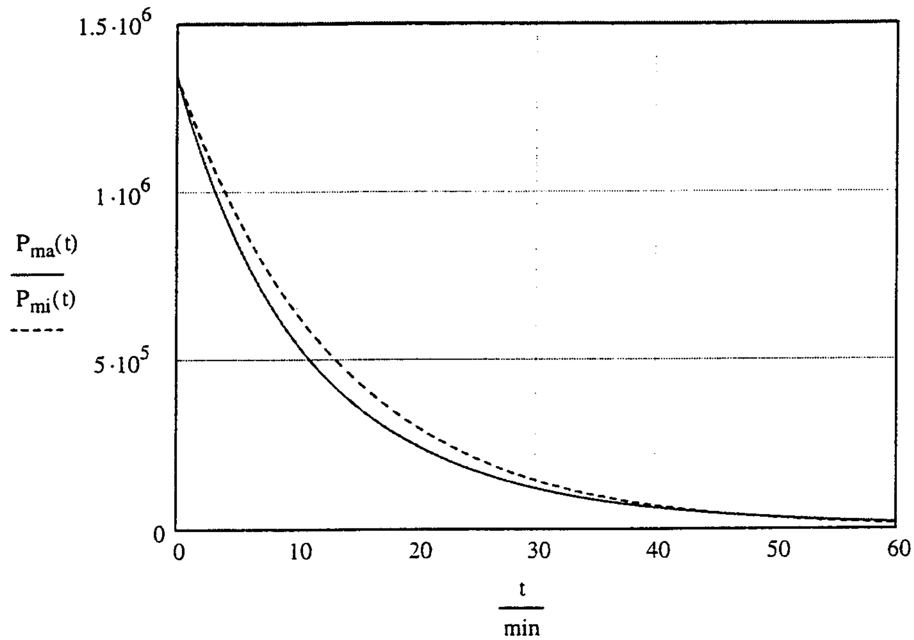
$\dot{q} := 250 \quad \Delta m(q \cdot s) = -385.646\,kg \quad V := \frac{\Delta m(q \cdot s)}{\rho_{sc}} \quad V = -3.904 \times 10^3\,f$

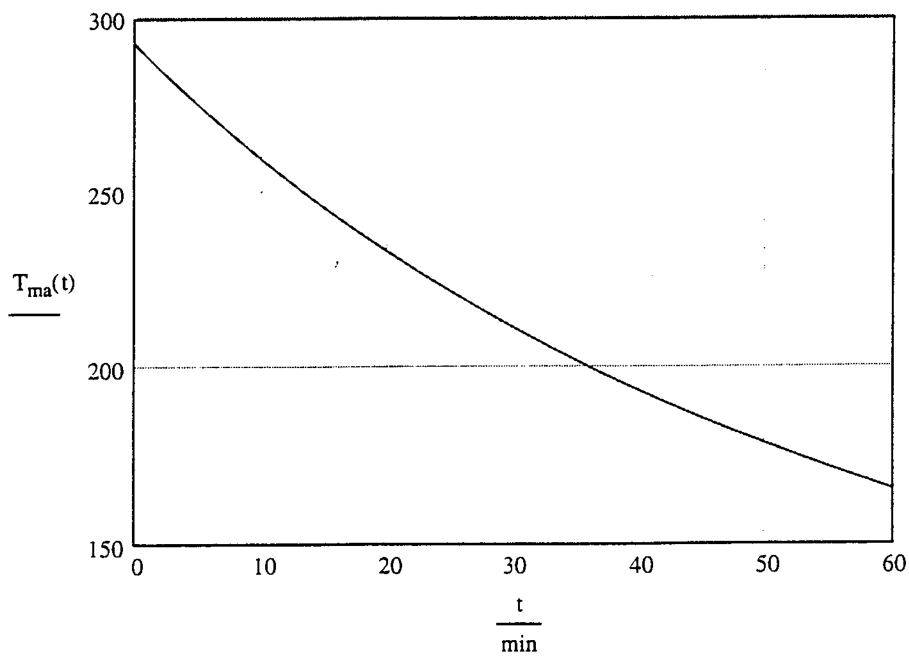


VI. P-T Profiles:

$$P_{ma}(t) := \left[\left(\frac{m_{ga}(t)}{kg}\right)^{\gamma}\cdot\left(\kappa_2\cdot m\cdot s^2\right)^{\gamma}\cdot\left(\frac{P_o}{Pa}\right)^{1-\gamma}\right]\cdot Pa$$

$$T_{ma}(t) := T_o\cdot\left(\frac{P_{ma}(t)}{P_o}\right)^{\frac{\gamma-1}{\gamma}}$$





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C-A Accelerator Systems Safety Review Committee

Memo

date: *October 10, 2001*

to: *ASSRC Members and Guests*

from: *J.W. Glenn, R. Karol*

subject: *Minutes of* ***Meeting on TVDG ODH Calculation***

Members: JW. Glenn*, J. Alessi*, J. Cullen*, A. Etkin*, P.K. Feng, P. Ingrassia*, R. Karol*, P. Lang, E. Lessard*, P. Cirnigliaro*, J. Levesque, G. McIntyre, J. Peters*, T. Monahan*, D. Phillips*, J. Sandberg, J. Scott*, C. Schaefer, J. Tuozzolo*, K.C. Wu*
* present

Presenters: L. Snydstrup, C.Carlson

L. Snydstrup presented his preliminary "Calculation of Oxygen Deficiency Hazards for TVDG", dated 10/8/01 to the Committee. He reviewed the configuration of the TVDG building by using a plan view of both floor levels. The primary rooms that have potential sources of the MP insulating gas (45% SF_6, 45% N_2 and 10% CO_2) are the accelerator room (AR), mechanical equipment (ME) room and the gas storage building located on the hill above the TVDG building, south of building 704. TVDG rooms that can have insulating gas leak into them from these primary rooms are: the electrical equipment (EE) room under the control room via a cableway from the AR; the basement, via the EE room and target room trenches; and the TTB via the AR. There are four target rooms that have no credible paths to accumulate insulating gas from the AR.

On the east end of the basement is an emergency purge fan that can exhaust the AR, ME room, and target rooms. When this fan is on, ventilation duct dampers automatically reposition from their normal recirculating position to their purge position. It is calculated that the 20 hp motor for the blower may not pump the heaviest possible mix of air and insulating gas possible. It is planned to reduce the pumping speed by 10% and/or increase the motor power to 25 hp.

Snydstrup reviewed the details of his calculation and the resulting ODH classification of each room. A mixture of actual TVDG failure rate data (based on the C-A TVDG and a similar tandem Van De Graaff) and failure rate data listed in the SBMS ODH Subject Area was used. Because of the high density of the MP insulating gas (S.G. of 2.85) compared with air, he correctly did not assume homogeneous mixing of the gas following a gas release into a room. The Committee agreed with this approach, which is different than the SBMS model. The SBMS model is more applicable to the common air displacing gasses such as helium or nitrogen.

The summary table in the calculation, TVDG Building ODH Classifications and Recommendations, was reviewed and discussions were held on the details of this table. Several concerns were voiced during this discussion, which are listed at the end of the minutes. In answer to a question by Etkin, it was noted that the purge fan suctions are located low in the rooms that are connected to the emergency purge fan. This is the correct location because of the high density of the insulating gas.

Carlson explained that the MP beam shutoff valves are rated to withstand the full MP pressure. These valves automatically close if there is a loss of vacuum in the beam pipe. The loss of vacuum could be caused if the beam line within the MP tank failed, allowing insulating gas to flow into the beam pipe. This failure has not occurred during the known history of Emperor Tandems.

Carlson noted that there are about 18 windows in each MP tank. Snydstrup stated that his window failure rate was based on any of these windows failing. Monahan asked about relief valve testing. Snydstrup replied that the reliefs are tested every 5 years by a vendor. Carlson noted that the relief valve flanges are leak checked under pressure following reinstallation. He noted that the MP vessels, including access doors and windows were designed and tested to code. Documentation of the design and applicable codes are available. The MP vessels were originally tested to 350 psig and currently operate at about 180 psig.

Snydstrup explained that there are two ODH sensors on both the upper and lower levels of the AR. The ODH instruments are fail-safe (i.e. trip on loss of power). The trip points are 19.5% oxygen (decreasing).

Etkin was concerned about the response of the TVDG ODH sensors to a mixture of air and insulating gas. This concern is based on a recent similar issue with the Jefferson Lab ODH oxygen monitor response to mixtures of air and helium or nitrogen. Glenn asked that either a document search be made or a test be conducted to verify that the TVDG ODH monitors would accurately respond to an insulating gas release.

Cirnigliaro asked if failure of the exhaust purge duct and purge fan dampers was considered in the calculation that determined the exhaust purge system failure rate. Snydstrup stated that it wasn't. The dampers are air operated. Glenn asked that the calculation be revised to include this additional failure mode.

As there are redundant ODH monitors at critical locations in the Accelerator room, the Committee approved the option of continuing to operate with one of the pair off-line for maintenance or repair.

The ME room has only one ODH instrument, which alarms and starts the emergency purge system upon sensing a low oxygen level in the room. This monitor is only required to be operable when gas transfer operations are in progress because that is the only time that significant quantities of pressurized insulating gas are present in that room.

Questions focusing on the audible alarms, determined the need to provide an additional ODH alarm in the EE room, basemen area.

In answer to a question by Wu, Snydstrup noted that the recent purge flow test by R. Diaz was conducted by measuring the airflow velocity profile at the purge fan with the purge system duct dampers in the purge positions. Thus the measurement applied to the actual emergency condition configuration. The airflow measurement results were adjusted to account for the heavier insulating gas/air mixture present during a gas release (Appendix A5). Carlson noted that during the normal recirculation mode of ventilation, there is about 30% fresh air intake into the building. During the emergency purge mode, 100% fresh air enters the building. The fresh air supplies are high in the room.

Referencing the summary table in the calculation, Snydstrup noted that the ME room Kinney vacuum pump overpressure protection devices (Item #8 in Appendix D) have not yet been vented outside the building; the Committee heartily encourages the timely completion of this upgrade as this brings the ME Room to a hazard level comparable to the rest of the facility. The emergency purge fan sheaves and/or motor have not yet been changed. Glenn asked that the need to increase the purge fan motor from 20 hp to 25 hp, in light of reduced pumping speed be evaluated to determine if more motor power is needed for the upgraded ODH level. Snydstrup agreed to re-examine this issue. Alessi stated that required modifications are expected to be completed with a high priority.

Etkin suggested that, for reliability, the TVDG have spare purge fan belts on-hand because a recent experience at RHIC showed that BNL Plant Engineering might not have spares readily available.

Carlson stated that the emergency purge system is tested semi-annually and the testing includes verification of the proper position of the duct dampers.

Glenn suggested that the appropriate TVDG personnel be trained in ODH Class 1 in order to be prepared for situations when the emergency purge fan is out of service.

The Committee concluded that the calculation by L. Snydstrup was complete and well done. The concerns listed below need to be addressed in the final revision.

<u>Committee Concerns</u>:

1. The TVDG Building ODH Classifications and Recommendations table in the calculation needs a final update, based on the final TVDG ODH System configuration and revised calculation. The issues that need to be considered in the revised calculation are listed below.
2. Verify that the oxygen sensors will accurately respond to the actual oxygen concentration for an air/insulating gas mixture. This may be done by obtaining verifying documentation or by conducting a documented test.
3. The calculation needs to be revised to include the additional failure mode of the emergency purge system air operated dampers.
4. An additional audible alarm needs to be placed at a location that can be heard in the EE room and the basement to warn personnel when an ODH hazard exists.
5. The ME room Kinney vacuum pump overpressure protection devices (Item #8 in Appendix D of the calculation) should be vented outside the building in order to allow the ME room to be classified ODH 0.
6. The need to increase the purge fan motor from 20 hp to 25 hp should be evaluated.
7. The appropriate TVDG personnel should be trained in ODH Class 1 in order to be prepared for situations when the emergency purge fan is out of service.
8. TVDG procedures need to be revised to reflect the new ODH system configurations and requirements.

9. A copy of the final calculation needs to be sent to Lessard and Karol for TVDG ASE and ASSRC records.

Dist: ASSRC
Guests
D Lowenstein
D Passarello