Noted 4-23-02 CAT

Operational Safety Procedure (OSP)

EXPIRED

Cover Sheet

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Issue Date: 4-22-02	
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Title: ODH in Hall C Beam Entrance Tunnel	
Location: Hall C	
Risk classification (See *EH&S Manual* Chapter 3210 *Hazard Identification and Characterization.*)	Without mitigation measures (4, 3, or 2): 2 With specified measures implemented (1 or 0): 0
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Hazard reviewed:	Reviewer signature:
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OSP considering ODH in the Hall C Beam Entrance Tunnel

April 22, 2002 4-22-02

Reference: TOSP ODH status of Hall C entrance tunnel PHY-02—002

Summary: This OSP establishes the Hall C Beam Entrance Tunnel Aisle as ODH 0 and ODH 1 between the Beam Line Centerline and beam Left wall.

Introduction

The Hall C beam entrance tunnel has a small super conducting magnet for the Moller polarimeter that is fed by a closed loop transfer line from the ESR. This transfer line supplies 3 Atm. Helium gas at 4.5 K and N2 at ~3 Atm. and ~85 K and returns helium gas at 4.5 K and 1.2 Atm. The transfer line and magnet have several relief valves for system protection. Originally all of these valves were vented into the tunnel. The Moller magnet was changed in July 2001 to a magnet with a higher operating pressure cryostat. One of the system reliefs was too low for the new operating conditions and could open during non- routine fill operations under certain conditions. These conditions were satisfied during October 2001 and the "off spec." N2 relief opened during system maintenance when the N2 fill valve was allowed to be 100 % open for 15minutes. This resulted in an ODH alarm in the entrance tunnel. Subsequently the "off spec." Relief valve was replaced with a higher rating consistent with the new operating pressure range, all but three relief valves were vented to Hall C proper via a new 2 inch vent line and an additional "low mounted" ODH sensor was added to give better sensitivity for N2 spills. A TOSP was prepared and a Temporary ODH 1 rating assigned to permit operations. The TOSP contained an analysis of event probabilities that established that ODH 0 could be a credible assignment. The Temporary ODH 1 rating was acceptable during the interim period prior to the replacement and venting of the remaining three relief valves. Hall C is now in a protracted shutdown and the opportunity to perform the final upgrade is at hand. Therefore it is desirable to finalize the ODH status of the beam entrance tunnel and to clarify the ODH status under a variety of Moller system conditions. This OSP will define three Moller system states and the requirements for ODH 0 status.

ODH areas in Hall C Beam Entrance Tunnel

The Hall C Beam Entrance tunnel will be posted as an ODH 0 area in the aisle up to the Beam Line centerline and as an ODH 1 area between the Beam Line centerline and the Beam Left tunnel wall.

Moller system stages

The Moller system is capable of being in three distinct system stages. These stages are stage one system disconnected, stage two system connected and locked out and stage three system operational. ODH 0 status is highly desirable during all three stages. The system stages described below represent the minimum required conditions for ODH 0 for the various stages . Other posted requirements and work restrictions may apply from time to time. The three system stages are defined below:

Stage one – system disconnected

The Moller system is in stage one when all three u-tubes feeding the system are removed. In this stage there are no cold or high pressure sources of cryogens. The system is still connected to the 1.1 Atm. warm Helium return system and the 1.0 Atm. N2 atmospheric discharge line. These systems cannot pressurize the Moller system to any relief valve setting and in the event of a low probability violent removal of a relief valve cannot result in a large flow rate into the tunnel due to the small differential pressure and warm gas present. Ordinary leaks which are more common would produce even less flow. The Moller system is presently in this state as of April 17, 2002. Satisfying the conditions of stage one results in an assignment for ODH 0 for the **Hall C beam entrance tunnel aisle.**

Stage two- system connected and locked out

Stage two requires that the Moller system is completely connected and that the three cold valves are physically locked out using approved LOTO devices for power connectors. This prohibits the three cold valves from being opened and introducing cryogens into the Moller system. The warm connections are the same as stage one above. This system stage shall be used for mechanical maintenance and was last used in October during the relief valve replacement and venting described in the introduction. This stage is valuable for system mechanical maintenance and will be used in the future. Satisfaction of the requirements for stage two result in an assignment of ODH 0 for the **Hall C beam entrance tunnel aisle**.

Stage three – system operational

Stage three requires that the Moller is completely connected and all valves enabled for operation. The system is usually operated remotely by computer control. All relief valves in the entrance tunnel must be vented into Hall C proper. During stage three the **Hall C beam entrance tunnel aisle** is rated as an ODH 0 area. Periods of electrical , electronic and software maintenance or testing shall be considered to be stage three and shall meet all requirements of stage three including special equipment requirements.

Hall C beam entrance tunnel special equipment requirement.

The area in the **Hall C Beam Entrance Tunnel beam left of the centerline of the beam line** shall be an ODH 1 area and shall be considered a special equipment area at all times due to the restricted access. During any activity that requires staff to work bean left of the centerline of the beam line the following special equipment requirements shall be enforced.

1) All workers shall have personal oxygen monitors.

2) No person may work beam left of the centerline of the beam line if they are unable to exit the area quickly due to a disability or any equipment encumbrance. This shall include vision, hearing and speech disabilities including a lack of fluency with English that may inhibit the proper and safe use of the two man rule.

Posting requirements

The Hall C beam entrance tunnel shall be clearly posted for ODH status and special equipment requirements. The ODH status and special equipment requirements shall be posted at both entrances to the Hall C beam entrance tunnel and at a convenient midpoint in the tunnel.

Non standard conditions

The Hall C beam entrance tunnel aisle shall be considered as an ODH 1 area in its entirety if the conditions for the three stages described above cannot be met. The special equipment requirements shall apply at all times. The Hall C engineer shall determine if the beam entrance tunnel aisle cannot be in one of the three stages above and recommend to Physics EH&S a revision to the beam entrance tunnel posting and appropriate site notification of the status. This temporary status reversion to ODH 1 may require a TOSP for the duration of the non-standard condition if warranted.

Examples of non standard conditions that **do not** warrant a reassignment are routine removal or insertion of the three Moller system u-tubes inside Hall C near the tunnel entrance, installing or removing cryogenic valve lock outs prior to and after routine mechanical maintenance and routine system startup, shutdown and testing. These are examples of routine transitions between the three stages listed above.

TextOF PHY-02-002

REF. TOSP PHY-02-002

TOSP – ODH status Hall C beam tunnel

Nov. 1, 2001

Section 1

Introduction

An ODH alarm occurred in the Hall C beam entrance tunnel.
The post alarm system inspection revealed the following:

1) The Hall C beam tunnel ODH monitoring had a ceiling mounted "He" sensitive ODH sensor but NOT a floor mounted N2 ODH sensor.

2) A relief valve was found with a too low setting for the present installation.
The too low setting allowed some venting of N2 to occur during fill operations that produced an over fill condition. The too low relief valve had a setting of 15 psi compared to the magnet N2 relief pressure of 50 PSI.

3) Several low pressure relief valves on the Moller system vented to the Hall C beam entrance tunnel.

The combination of reduced N2 ODH sensitivity , a too low relief setting and the relief venting to the Hall C tunnel created the potential for an ODH situation.

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Immediate action taken

The Moller cryogenic system was locked out using "administrative group locks and do not operate tags". The three electric supply valves were disabled by installing a boot around the motor power supply plug and applying a lock and tag. The valve controller was placed in manual/local. The Hall C Log and Gen run coordinator were notified of the lock out status of the Moller pending approval of this TOSP.

Corrective actions

1) A Floor mounted ODH sensor sensitive to N2 dilution of the atmosphere was installed.

2) The relief valve with the inappropriate setting was replaced.
(The present valve is a 35 PSI relief , the replaced valve was 15 PSI.)

3) The seven low pressure Helium and N2 relief valve exhaust ports have been manifolded and piped out of the tunnel to an exhaust port in Hall C.

Final corrective action

Replacement relief valves for the three mechanical relief valves mounted on the Moller magnet were unavailable for immediate replacement and had to be ordered. Thus three original 50 psi valves remain vented to the Hall C tunnel.
The remaining three mechanical relief valves on the Moller will be replaced with relief valves having exhaust port fittings. These will be manifolded and piped to a vent located in the greater volume of Hall C. This vent size will be confirmed for all situations including a Loss of Vacuum in the Moller.
It is expected that this work will be completed during the next significant shut down in Hall C now scheduled for Dec 21st 2001 through Jan 20th 2002.

MOLLER N2 relief valve.

The Oxford Instruments installed 50 PSI relief valve on the N2 system of the Moller magnet is a non-porting type and cannot be piped to the relief header. The N2 system has a 35 psi mechanical relief valve and a 45 PSI Rupture disc that will open below the setting of the 50 psi relief valve and prevent the venting of N2 into the tunnel.

MOLLER He relief valves

The Oxford Instruments installed pair of helium relief valves on the Moller magnet are non-porting type relief valves that cannot be piped to the relief header. These are set at 50 psi. The He system has a 40 psi mechanical relief valve that is always connected to the magnet and is vented out of the tunnel. There are also a 25 PSI mechanical relief valve and a 45 PSI rupture disc that are connected to the magnet when the magnet is in warm return(cool down mode).All of these relief valves open at a pressure below the magnet relief valve's setting and prevent the magnet relief from venting into the tunnel

Duration of TOSP

Porting type relief valves have been ordered and will be installed at the next shutdown when a MOLLER warm up can be achieved. These new valves will be ported to the relief header. This TOSP will expire when these relief valves are installed. This replacement is expected to be complete no later than Jan 20, 2002.

Conditional ODH status of the Hall C beam entrance tunnel and recommendations.

The combination of N2 and He ODH monitoring mounted in a Hi/Low configuration and the porting of all low pressure relief valves out of the beam entrance tunnel restores the ODH zero condition for all situations considered (see below).
ODH status 0 is thus indicated now and could be even more justifiable after the final relief valve porting. However we are recommending that the tunnel be rated as an ODH 1 area requiring the two man rule for occupancy. A further recommendation is made that the Hall C beam entrance tunnel be posted to require personal ODH monitors for workers in the tunnel who work under or behind the beam line. This "special equipment" requirement is motivated by the fact that the area behind the beam line is congested and an individual could not exit in a few seconds as is the case for the aisle.

The author and reviewer believe that the analysis of the ODH condition of the Hall C beam tunnel is correct In identifying a mechanism for O2 replacement during a release. We are also in agreement that the description offered is incomplete in that it does not describe the spatial dependence of the Oxygen deficiency and it assumes thermal equilibrium exists on the average. The engineering analysis presented is a description of the average equilibrium O2 deficiency in the tunnel under a wide variety of release conditions. The predicted O2 deficiency for a release similar to the ODH event of Oct. 19th is a source of confidence in the analysis.

Section 2

ODH Evaluation for the Hall C Beam Entrance Tunnel

The Hall C Beam entrance tunnel contains a small SC magnet and a transfer line that delivers Helium and Nitrogen and returns cold helium gas back to the ESR. The He supply and He return have JLAB standard EV control valves with a Cv =3.0. The LN2 supply has a JLAB valve with Cv=0.3. There are warm gas headers for Helium (2inch sch. 10) and Nitrogen(1/2 inch sch. 10) and a separate 2 inch copper pipe header for porting relief valves. The system has numerous relief valves most of which are ported out of the tunnel. The system has motorized ball valves for cool down and transfer line pre-cooling. The table summarizes the control valves, relief valves and the systems.

EV control valves	Cv	Pin.	Nom rate Ft3/sec	Max rate Ft3/sec	
He supply	3.0	2.5 atm	0.6	2.7	(corresponds to 13.5 gm/sec flow limit)
He return	3.0	1.2 atm	NA	NA	(ignorable due to very low pressure)
N2 supply	0.3	3.0 atm	1.9	3.15	(corresponds to max flow at 45 psi , cv=0.3)

Helium system

	Qty	size	set	Cv	vent
Primary magnet	2	1 inch	50	2.8	tunnel
WR Mech	1	½ in.	35	0.74	Hall
WR RD	1	1 in.	45	2.8	Hall
Secondary magnet	1	½ in.	40	0.74	Hall
He supply xferline	1	½ in.	100	0.74	Hall

Nitrogen system

Primary magnet	1	¼ in.	50	0.3	tunnel
Magnet mech.	1	½ in.	35	0.7	Hall
Magnet RD	1	1 in.	45	2.8	Hall
N2 supply xferline	1	¼ in.	350	0.3	Hall

The following relief valves are also in the system and are not ported to the Hall as they are very high set pressure to protect trapped lines in the event that the Helium and N2 half u-tubes are pulled and the magnet isolated. These relief valves are very small , have very high set points and vent through a very restricted opening when the u-tube stinger is in place. It is customary at JLAB to ignore these.

Transfer line bayonet relief valves

He supply bayonet	2	¼ in.	350	0.3	tunnel
He return bayonet	1	¼ in.	350	0.3	tunnel
N2 supply bayonet	2	¼ in.	350	0.3	tunnel

Air replenishment in the Hall C beam tunnel

There are two mechanisms that replace air in the Hall C tunnel that has an oxygen deficiency, diffusion and natural convection. Diffusion can be shown to be a minor contributor so this will primarily focus on natural convection driven by the density difference between normal air and air with an O2 deficiency. The tunnel dimensions are 72 ft long and 8x8 ft2 cross section.

Natural convection replacement

The Hall C tunnel is wide open and is open to the Hall. Even the relatively small density differences that arise from a partially O2 deficient atmosphere can lead to substantial air replenishment in an open dead ended tunnel . The driving pressure is just computed from the head developed by a density difference considering only the tunnel height (8 ft.). The convection cell considered is the length of the tunnel plus the rise and fall at the ends (L= 72 +72 +8 +8 = 160 ft). A conservative flow area equal to 25 % of the total available tunnel cross section is assumed. This allows for the stagnant boundary layer at the floor and ceiling, the inter-flow zone at mid height and some allowance for equipment in the tunnel. The flow area is thus 2x8 ft2 or 16 ft2. The hydraulic diameter of a 2 x8 flow area is 3.2 ft or 38 inches. The tunnel volume is (72 x 8 x 8) = 4608 ft3.

The driving pressure is $dP = (rho2-rho1)*g*H$ >> $(ro2-ro1)*H$ using weight units for density
Where rho2 and ro2 are the deficient densities and rho1 and ro1 are the normal densities of air.
Considering N2 as the cause of the deficiency we get

$$DP = [\{(.79+.21*d)*28+(.21)*(1-d)*32\}-\{.79*28+.21*32\}] / 22.4 *(28.32/454) * 8 \text{ ft.} * (1 / 144) \quad \text{psi.}$$

$$= d*.21* (32-28) * (1.54 \times 10^{-4}) \quad \text{psi.}$$

$$= d * 1.29 \times 10^{-4} \quad \text{psi} \quad \text{here } d \text{ is the deficiency } (0.0 < d < 1.0)$$

If the air is displaced by Helium then the resulting $dP = d* 3.8 \times 10^{-3}$.
The driving pressure is greater because helium is much lighter than air.

Please note that I have assumed that a ft3 of either N2 or He introduced into the tunnel displaces a ft3 of air. This means that at the nominal max volume flow (3 Ft3/sec) thru the supply valves that it would take a time

$$T = V/Ql = 4600 / 3 = 1462 \text{ seconds}$$

for either He or N2 to displace the tunnel air without replacement. The replacement rate depends on the existence of an ODH deficiency as a source of driving pressure. A more accurate estimate could be made if an efficiency of displacement were used. This efficiency would be close to one for N2 in air and much smaller for He in air. The assumption of complete displacement is reasonable for N2 but is likely to result in a too large actual deficiency for Helium.

The replacement flow rate in Ft3 per sec is (ref. Crane , Flow of Fluids)

$$Qr = (dp * Dh / 43.5 / f / L / ro2)^{(1/2)} * Dh * Dh \quad \text{Ft3 /sec} \quad \text{Turb flow}$$

dP	driving pressure	psi
Dh	Hydraulic diameter	38 in.
Mu	Viscosity of air	0.02 centipoise
F	friction factor	0.01
L	length	160 ft.
r02	weight density of air	0.0803 #/ft3

The following is the replacement air when N2 is the dilutant gas

$$Qr(N2) = 47{,}627x(dP/L)^{(1/2)} = 47{,}627 * (d*1.29 \times 10^{-4} / 160)^{(1/2)} = 42.76\, \mathbf{(d)^{(1/2)}} \text{ ft3/sec}$$

And when He is the dilutant gas we get

Qr (He) = 47,627 * (dP/L)**(1/2) = 47,627 * (d * 3.8x10**(-3) /160)**(1/2) = 230.64 (d) **(1/2)

The following table lists some typical values of the replacement rate for various deficiencies.

O2 %	d	Qr (ft3/sec) (N2)	Qr (ft3/sec) (He)
21.0	0.0	0.00	0.00
18.9	0.1	13.52	72.93
16.8	0.2	19.12	103.14
10.5	0.5	30.23	163.08
00.0	1.0	42.76	230.64

The equation that governs the growth , decay or steady state deficiency of Oxygen follows. This equation considers that the mechanism for removal of Oxygen is a simple volume displacement due to the leakage Ql and that the method of replacement is a dilution process. The replacement rate is dependent on the deficiency so the equation is non-linear.

V * (d)' = - Qr * d + Ql

d' time derivative of deficiency
V Volume Ft3
d deficiency
Qr replacement rate Ft3/sec
Ql displacement rate Ft3/sec

This equation has a non-linearity as the Qr depends on the square root of d.
The right side can be solved easily for the equilibrium deficiency however and this is most useful.
Approximate solutions can be solved for easily if a constant replacement rate is inserted , then the solutions are familiar exponential functions that are accurate stepwise to study the time dependence.

Equilibrium solutions

V * (d)' = 0 = - Qr *d + Ql = - 42.76 * d **(3/2) + Ql

d = (Ql / 42.76) **(2/3)

The equilibrium deficiency for the max flow rate thru the Cv=0.3 LN2 supply valve is

d = (3.15/ 42.76) **(2/3) = 0.175

The equilibrium O2 concentration is therefore O2 % = 21 (1-d) = 21 (1-0.175) = 17.3 %
According to JLAB EH&S 6500-T3 this corresponds to a F = 3.5 x 10 **(-7) .

Diffusion air replacement

The equation for Equimolar counter diffusion (ref. Fund.of Heat and Mass Transfer , Incropera and DeWitt , 4th ed. Section 14.4.3 , eqn 14.4)

Na = Dab*A*(P-Po)/R/T/L = 5 x 10**(-8) kmole/sec >> 3.4x10(-4) Ft3/sec

Na	Kmole/sec
Dab	diffusion coefficient 0.21 x 10**(-4) for O2in air ~ N2 in air ~ O2 in N2
A	area 5.7 meters**2
L	length 21meters
R	Gas constant 8.2 x 10**(-2)atm/kmole/kelvin
T	Absolute temp 298 kelvin
P	partial pressure of O2 deficient atmosphere 0.00 Atm
Po	normal partial pressure 0.21 atm

The rather small air replacement rate means that diffusion is not a significant factor for a large volume such as the Hall C entrance tunnel.

ODH Risk assessment

The following are a set of events and the associated probability and fatality factor.
The nominal volume of He or N2 in the magnet is ~ 20 Liters and is 480 Ft3 or ~ 10 % of the tunnel volume. If either are lost "instantly" then the resulting O2 content of the entire tunnel is reduced 10 % or O2 = 19 % , if both vent simultaneously then the result is 17 %. A more reasonable situation would be for the He and N2 to inert a region 2 feet deep on the ceiling and floor for a distance of 30 feet , then mix resulting in a O2 % of 10.5 % for a 30 foot length of tunnel. This ignores the fact that an instant vent is impossible but it yields a useful estimate for F for these events. The table summarizes

event	spill(ft3)	dispersal volume	% O2	F
LOI He	480	4608 Ft3	18.8 %	0.0
LOI HeN2	960	4608 Ft3	16.62 %	1 x 10 **(-6)
LOI He	480	1920 Ft3	15.75 %	5 x 10 **(-6)
LOI HeN2	960	1920 Ft3	10.5 %	5 x 10 **(-2)

The following is a table of continuous spill situations at various rates and the resulting equilibrium O2 concentration calculated by the natural convection replacement developed above for the whole tunnel. These have validity for predicting the % O2 for a long duration spill that goes unnoticed.
I have used the much more conservative N2 generated replacement rates for both He and N2 spills.

	Spill rate Ft3/sec	Time w/o replacement sec	%O2 equilibrium	F
Nom He flow	0.6	7680	19.8 %	0.0
Max He flow	2.7	1707	17.7 %	2 x 10 **(-7)
Nom N2 flow	1.0	4608	19.3 %	0.0
Max N2 flow	3.15	1462	17.3 %	4 x 10 **(-7) sustainable for ~30min.
Max He&N2	5.85	788	15.4 %	9 x 10 **(-6)
Flow = 5 x max	15.0	307	10.55 %	5 x 10 **(-2) requires ESR control failure
Flow 10 x max	30.0	153	4.4 %	1.0 exceeds ESR He capacity

ESR He Flow limit 3.15 Ft3/sec (13.5 Gm/sec) maximum sustainable He flow w/o control failure
ESR LN2 flow limit 0.6 Ft3/sec (21 Gm/sec) maximum sustainable N2 flow w/o control failure

Note 1: The recent ODH incident in the Hall C tunnel involved the LN2 supply valve being 50 % open for 10 minutes and 100 % open for ~ 30 minutes or ~1800 seconds. The time from the alarm until the MCC team arrived is about 15 minutes and the valve was 100% open for at ~ 10 minutes before the alarm went off.

The valve was closed 5 minutes after the MCC team investigated. The reported ODH as measured by the MCC team was ~ 17 % at a point about 1/3 into the tunnel. The lowest measured ODH at the head near the magnet was 15.8 %. The assignment of an F=3.5 x 10 **(-7) for that event seems reasonable. If there was no validity to the natural convection replacement theory presented above then the tunnel should have been nearly inert at ~ 1800 seconds.

Note 2 : The Hall C transfer lines have an inventory of 200,000 gms of LN2.This is 5,640 Ft3 at STP. The ODH event on Oct 19 must have spilled this inventory into the Hall C tunnel. This is based on a calculation of the transfer line volume ,the flow out the valve into the Moller system and the total make up flow from the ESR. These three quantities are ~200,000 grams each.

Some abbreviations used in the following summary

SV = supply valve   p = primary probability   f= fatality factor
RV = relief valve   P2 = secondary probability

The probability times the fatality factor or for compound events the product of the probabilities times the fatality factor yields the fatality for the event. The sum over all events yields the overall fatality for ODH evaluation. That sum must be less than 10**(-7) to permit ODH 0 status.

SUMMARY of EVENTS **PHI(I) = P x P2 x f**

1) Failure of transfer line p= 10**(-10) (see note)

1a) both He & N2 max flow rate & line failure	f= 9 x 10 **(-6)	**9 x 10**(-16)**
1b) transfer line failure & rate = 5x max	f= 5 x 10**(-2)	**5 x 10**(-12)**
1c) transfer line failure & rate = 10 x max	f= 1.0	**1 x 10 **(-10)**

Note 1: A catastrophic failure of the Moller transfer line would require another simultaneous failure. Due to the impossibility of bringing mechanized equipment into the Hall C tunnel the NRC probability for a gas line greater than 3 inch (high quality) is used.

2) Failure of Gas return line p= 10**(-9) or failure of 10 Fittings P= 3x10**(-6)

2a) nom flow rate	f= 0.0	
2b) max flow rate	f= 4 x 10 **(-7)	**1.3 x 10**(-12)**
2c) both fail	f= 9 x 10 **(-6)	**2.7 x 10**(-11)**
2d) 5 x max flow P2= 3x10**(-5)	f= 5 x 10 **(-2)	**4.5 x 10**(-12)**

Note: 2C should probably have a second probability multiplier

3) Rupture of relief valve p= 10**(-8)

3a) rupture of He relief	f= 2 x 10 **(-7)	**2 x 10 **(-15)**
3b) rupture of N2 relief	f= 4 x 10 **(-7)	**4 x 10 **(-15)**
3c) rupture of both	f= 9 x 10**(-6)	**9 x 10 **(-14)**

3d) simultaneous ESR control failure flow 5 x max p2= 3 x 10 **(-5) , f=5 x 10**(-2) **1.5 x 10 **(-15)**

4) control failures p=3 x 10**(-5)

4a) Both He return valve close , SV open f=0.0 system deadheaded 0.0
4b) All He valves close , 40 psi RV vents f=0.0 system vents into Hall 0.0
4c) All He valves close , 40 psi RV fails shut P2 = 10**(-5) f= 0.0 0.0
4d) N2 SV full open & vent plugged P2= 10**(-4) f= 4 x 10 **(-7) 4 x 10 **(-15)

5) Human error – He system p= 10 **(-2)/D (D=1)
5a) all valves close & 40 psi RV fails shut
or main relief premature open P2 = 10**(-5) f= 5x 10**(-2) 5x10**(-9)
5b) SV open full & 40 psi RV fails shut
or premature open main relief P2 = 10**(-5) f= 2 x 10 **(-7) 2 x 10 **(-14)
5c) SV full open & 50 psi RV rupture P2=10**(-8) f= 2 x 10 **(-7) 2 x 10 **(-17)

6) Human error N2 system p= 10**(-2)/D (D=1)
5a) SV full open & RV rupture p2= 10**(-8) f= 4 x10**(-7) 4 x 10 **(-17)
5b) SV shut , vent plugged p2= 10**(-4) f= 0.0 0.0
5c) SV full open , vent plugged p2=10**(-4) f=4 x10**(-7) 4 x 10 **(-13)

7) magnet failure He or N2 into insulating vacuum p= 10**(-6)

7a) Magnet fails nom flow f= 0.0 0.0
7b) Magnet fails , control fails SV max open f= 4 x 10 **(-7) 4 x 10 **(-13)
7c) Magnet fails , ESR control fails flow 5x max p2= 3 x10**(-5) f= 5 x 10**(-2) 1.5 x 10 **(-12)

8) Magnet relief premature open p = 10**(-5)
8a) nom flow rate f=0 0.0
8b) max flow rate f= 4 x 10 **(-7) 4 x 10**(-12)
8c) both max flow rate p2=10** (-5) f= 9 x 10 **(-6) 1 x 10 **(-15)

ODH summary

None of the above comes close to 10**(-7) and the sum is far from 10**(-7)!
The smallest incident is item 5a {5 x 10 **(-9)}.