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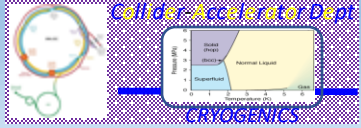
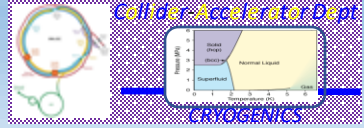


Brookhaven National Laboratory
Collider Accelerator Dept

RHIC Recovery review

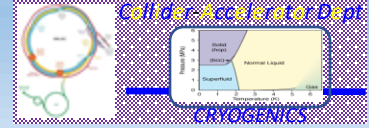
ODH Analysis for SERVICE BLDGS

Ashish Shukla, Chintan Sheth, Roberto Than



Outline

- Analysis methodology
- Calculation Inputs
  (Helium Inventory, Building info and components info)
- Normal operation/Unusual Events Initiator
- Components failure and release rate
- Results for different operating modes,
  with and without ventilation
- Conclusion



Operation

Equipment Failure Rate
Release/Leakage Rate

ODH Sensor

1x10^{-6}
Failed branch

ODH Not working

O2 Level to 0

Fatality Factor = 1

#1.Fatality Rate

Working branch
Compliment

1-1x10^{-6}

Both Fans Not Working

1x10^{-8}

O2 Level to 0

Fatality Factor = 1

At least 1 Fan Working

1-1x10^{-8}

O2 Level

Fatality Factor < 1

#2.Fatality Rate

#3.Fatality Rate

18.6 bar Event: 1E-5

•Equipment Failure Rate
•Release/Leakage Rate

4 bar Normal Operation: 1-1E-5

ODH Sensor

1x10^{-6}

ODH Not working

O2 Level to 0

Fatality Factor = 1

Working branch
Compliment

1-1x10^{-6}

Both Fans Not Working

O2 Level to 0

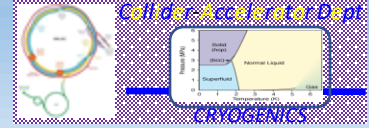
Fatality Factor = 1

At least 1 Fan Working

O2 Level

Fatality Factor < 1

#4.Fatality Rate



•Equipment Failure Rate
•Release/Leakage Rate

Normal 4.5K Operation Mode

1x10^{-4}

Same ODH/ Fans branch chain

Unusual Initiator Event: 5x10^{-6}

Event Branch

Normal Operation Events: 1-(5x10^{-6})

1x10^{-4}

1.1x10^{-6}

ODH Not working

O2 Level to 0

Fatality Factor = 1

#1.Fatality Rate

ODH Sensing System

•Equipment Failure Rate: **1x10^{-4}**
•Release/Leakage Rate

7x10^{-8}

Both Fans Not Working

O2 Level to 0

Fatality Factor = 1

Not Considered

Working branch Complement

1-(1.1x10^{-6})

At least 1 Fan Working

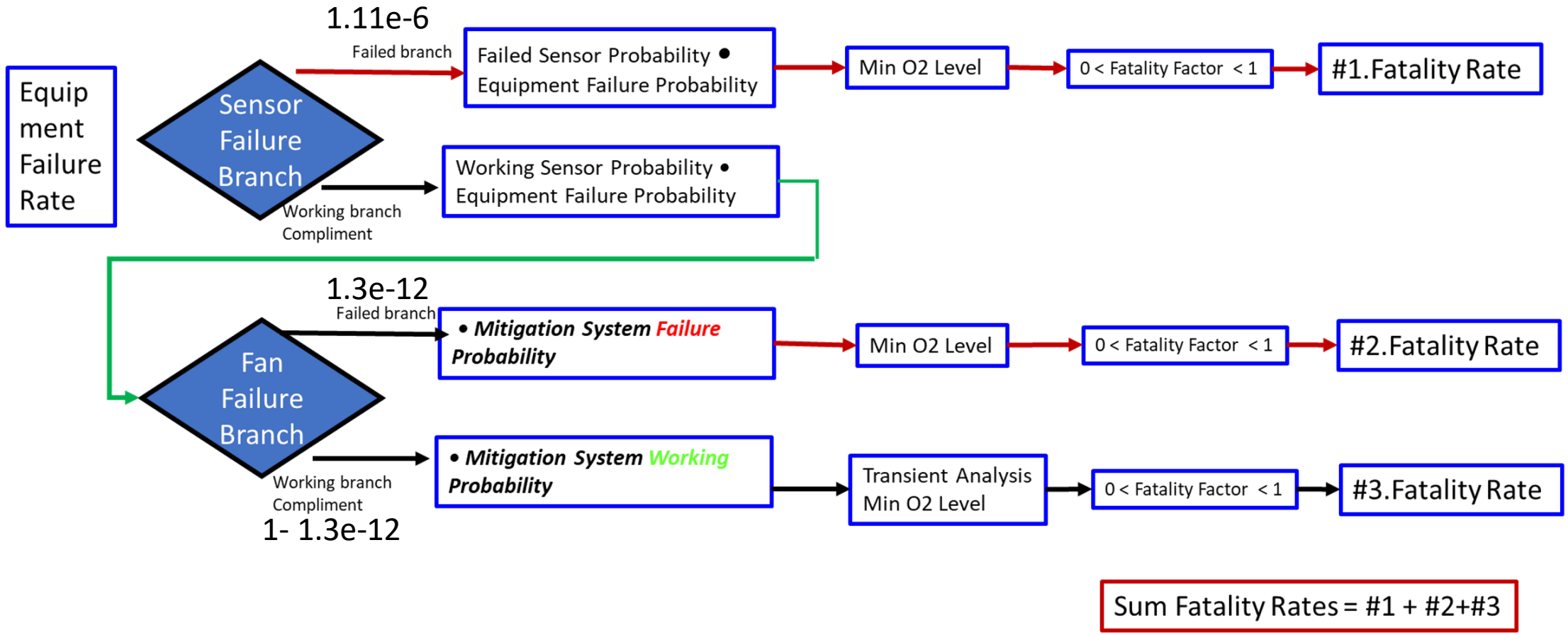
1-(7x10^{-8})

O2 Level

Fatality Factor < 1

#2.Fatality Rate

GENERAL FAILURE TREE DIAGRAM



Probability Tree

Components inside Insulating vacuum vessel failing and leading to releasing via components failing on the insulating vacuum boundaries

Components inside Insulating vacuum vessel

18.6 bar & CCB event: e.g. 1E-5 ·

∑ Equipment Failure Rate

4 bar operation: 1-(1E-5)·

∑Equipment Failure Rate

∑Equipment Failure Rate

Components On Insulating vacuum vessel boundary

Equipment Failure Rate
Man Cover:
Hivacuum ports:
[O-ring interfaces:]

Leakage/Release

∑Equipment Failure Rate

Fan/HVAC Branch

Failed branch

0.003

Fan/HVAC Non Availability

O2 Level to 0

Fatality Factor = 1

#1.Fatality Rate

Working branch
Compliment

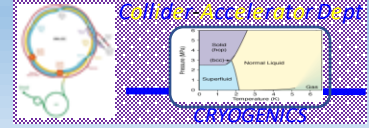
0.997

Fan/HVAC Availability

O2 Level

Fatality Factor < 1

#2.Fatality Rate

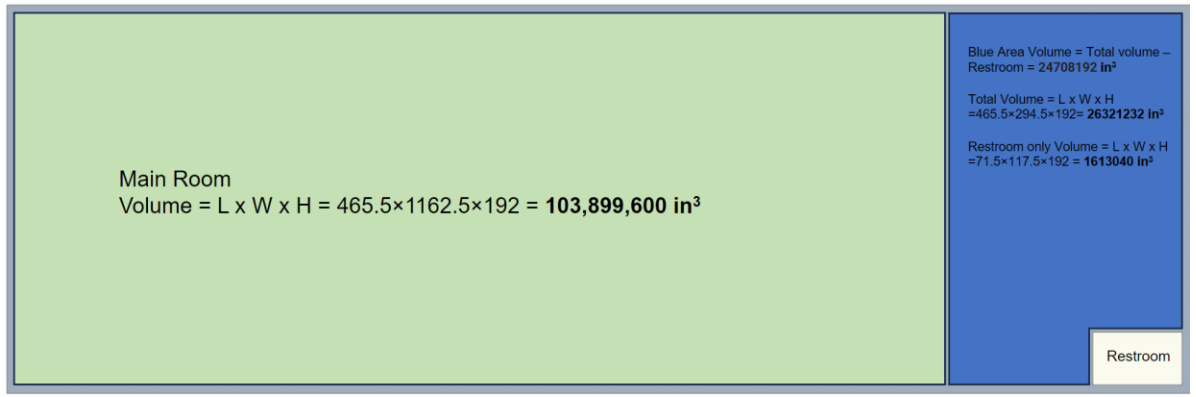


Helium Inventory in RHIC

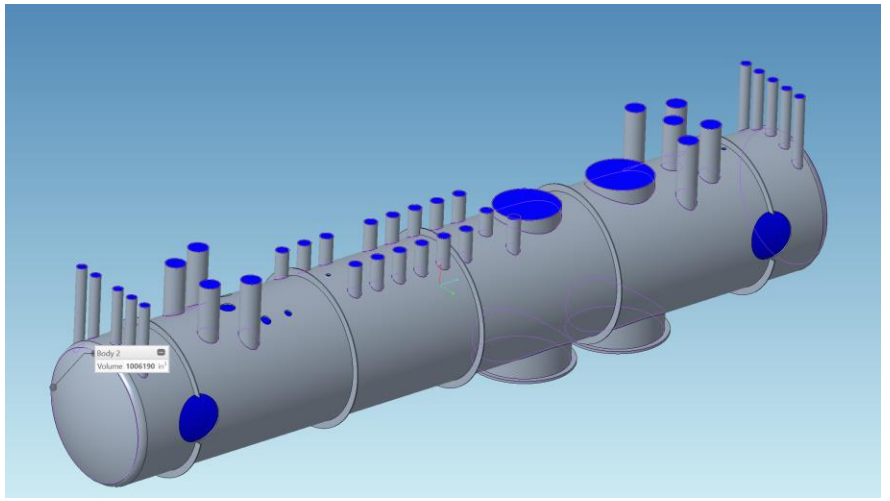
- Sextant M-Line inventory: ≈ 3000 Gal ≈ 300,000 SCF
- Building Volume: ≈60,000 CF to ≈ 90,000 CF
- Net Free Volume: ≈ 55,000 CF to ≈ 85,000 CF
- No fresh Air: O2 ➔ 0%
- HVAC Fresh Air: Make-up ➔ 1800 to 3000 CFM
- ODH Sensing & Fans: Fresh Air Make-up ➔ 14,000 to 26,000 CFM
- Insulating Vacuum Volume Relief piped out of building
- Reliefs piped out of building
- Ruptures inside Insulating vacuum volume: Reliefs outside building
- Ruptures outside insulating vacuum volume into building

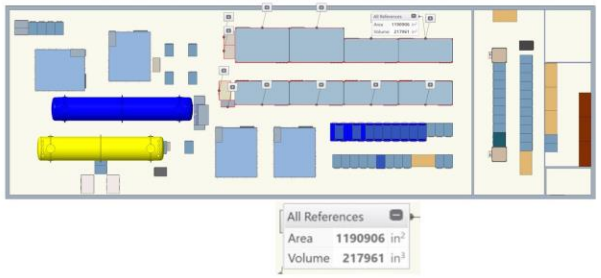
Valvebox Components:

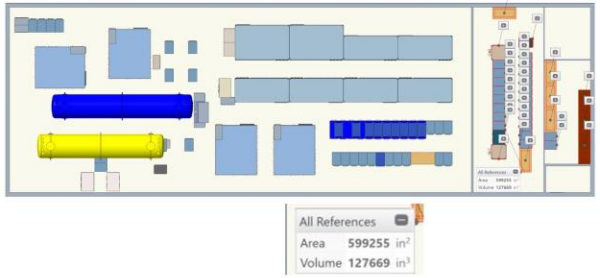
Failure and Leakage to inside of building:1004B



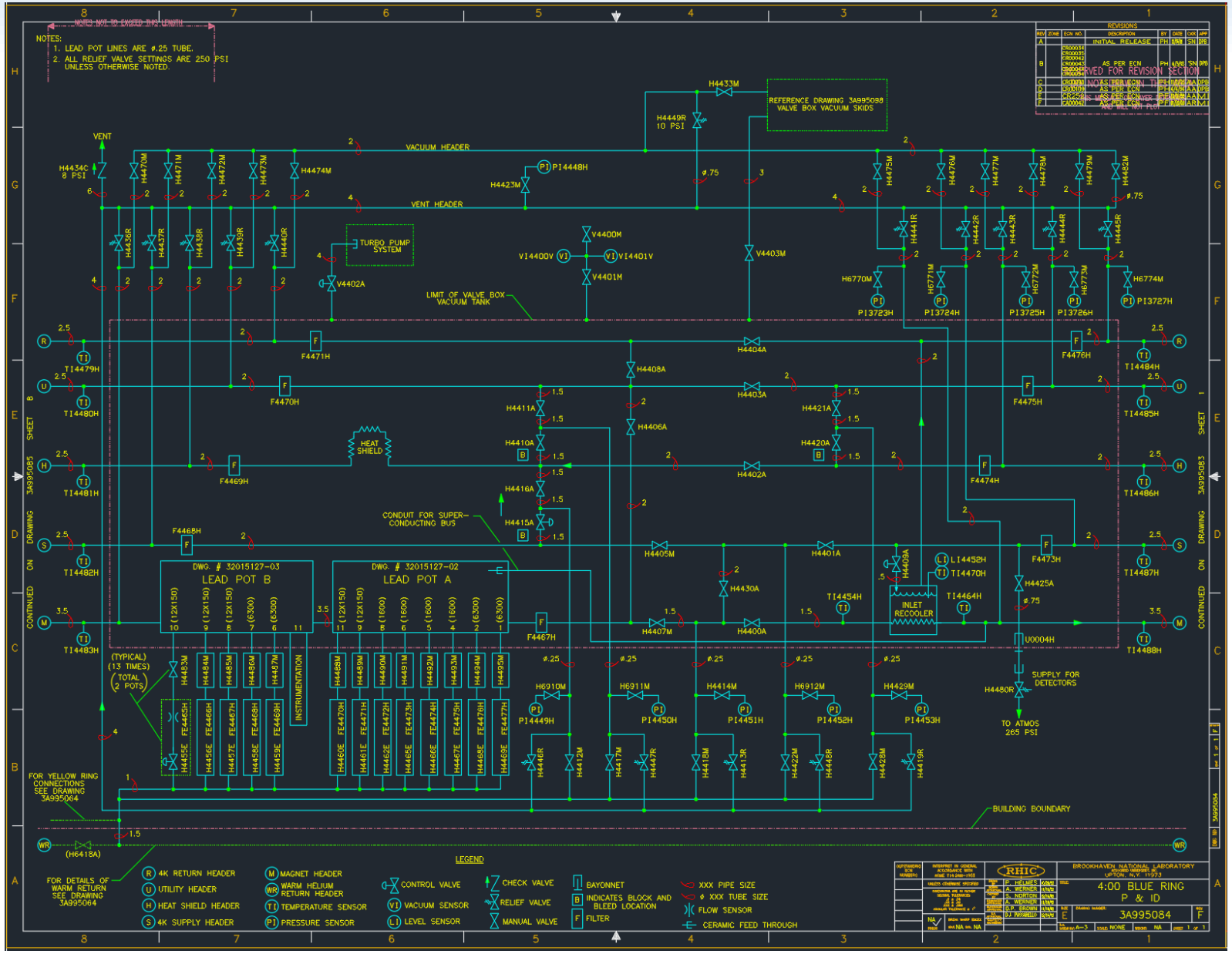
	in³	Ft³
1004B Gross Volume	149,355,675	86,433
1004B Equipment Volume	7,298,002	4,223
1004B Net Volume	142,057,673	82,209



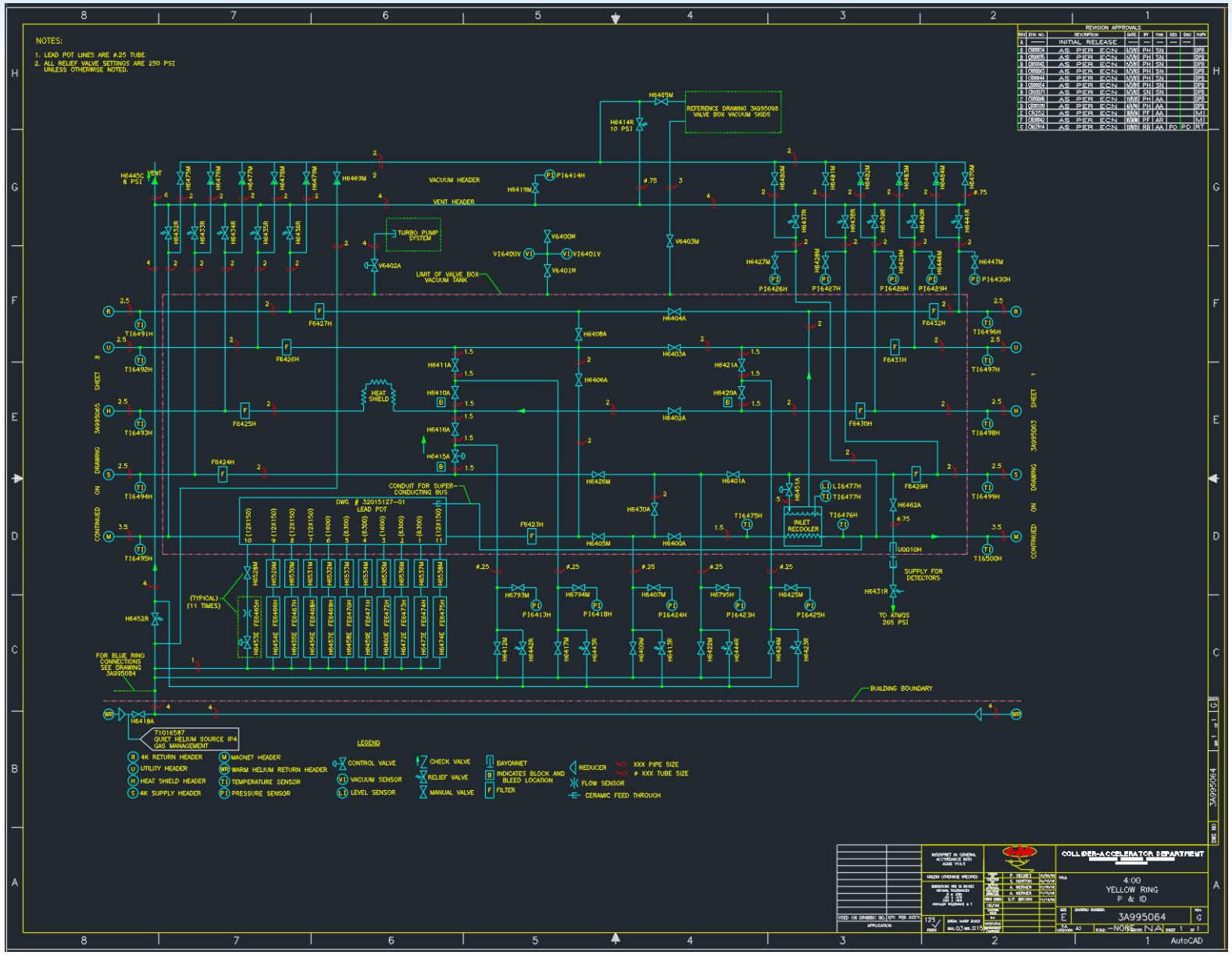




1004B – Blue Valve Box P&ID



1004B – Yellow Valve Box P&ID



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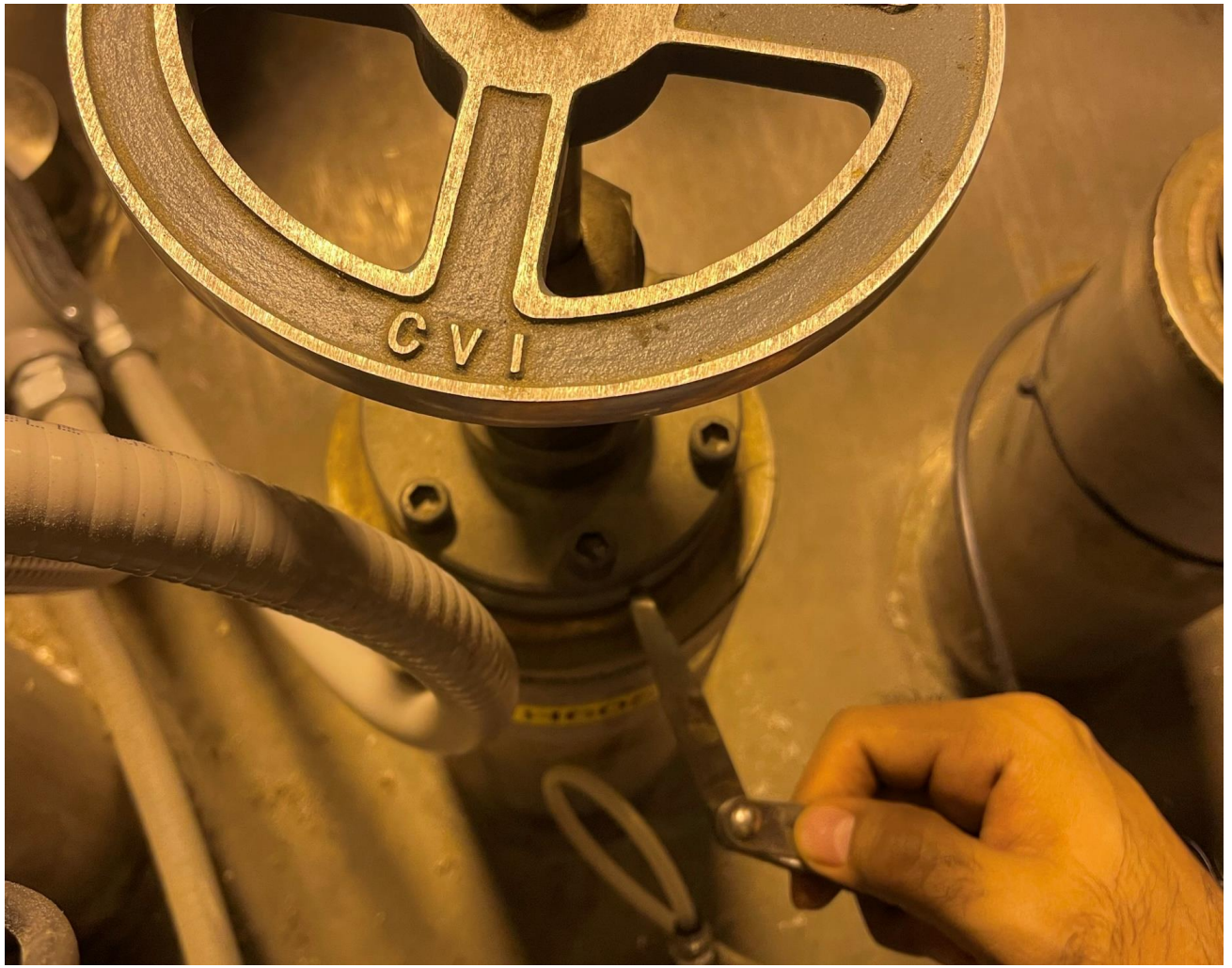
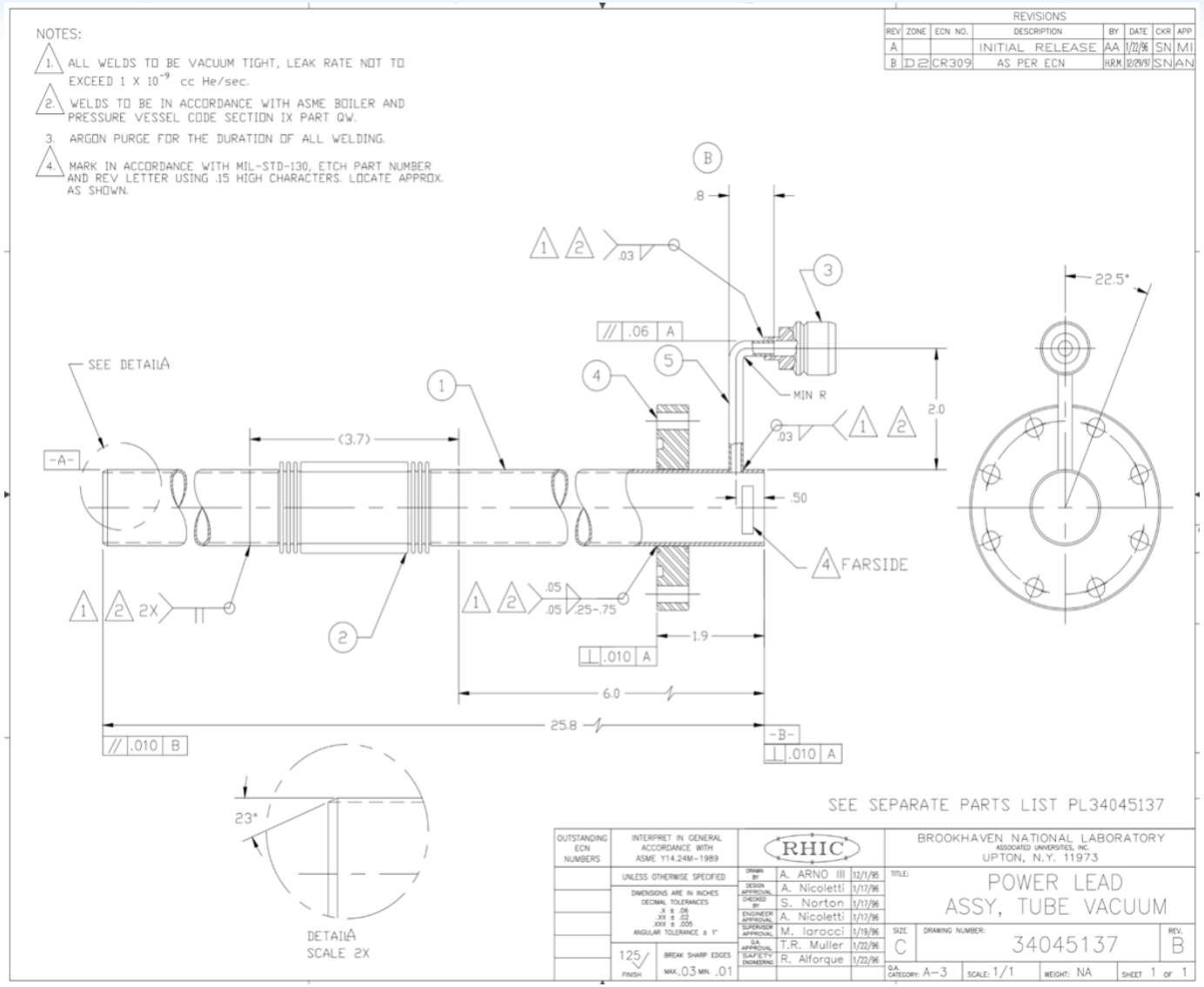
Valve box Components: Type & Quantities

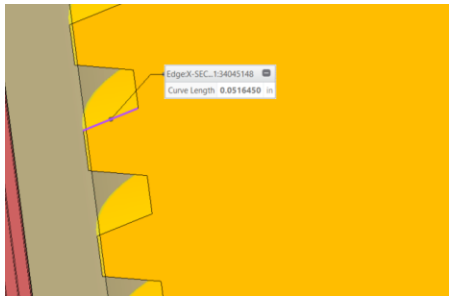
	6:00	6:00	4:00	4:00	2:00	2:00	12:00	12:00	10:00	10:00	8:00	8:00
	Blue	Yel	Blue	Yel	Blue	Yel	Blue	Yel	Blue	Yel	Blue	Yel
	VB	VB	VB	VB	VB	VB	VB	VB	VB	VB	VB	VB
Valves total	41	41	18	18	18	18	23	23	18	18	18	18
Valves M-Line	10	10	2	2	2	2	2	2	2	2	2	2
Valves S-Line	11	11	6	6	6	6	8	8	6	6	6	6
Valves H-Line	7	7	4	4	4	4	5	5	4	4	4	4
Valves R-Line	4	4	1	1	1	1	1	1	1	1	1	1
Valves U-Line	9	9	5	5	5	5	7	7	5	5	5	5
1/4" Instrument Line/ M-Line	3	3	2	2	2	2	2	2	2	2	2	2
1/4" Instrument Line/ S-Line	2	2	2	2	2	2	2	2	2	2	2	2
1/4" Instrument Line/ H-Line	2	2	2	2	2	2	2	2	2	2	2	2
1/4" Instrument Line/ R-Line	2	2	2	2	2	2	2	2	2	2	2	2
1/4" Instrument Line/ U-Line	2	2	2	2	2	2	2	2	2	2	2	2
2"NPS Flanges pairs	20	20	20	20	20	20	20	20	20	20	20	20
3/4"Bayonet cap	1	1	1	1	1	1	1	1	1	1	1	1
6300A Leads	0	0	4	4	0	0	0	0	4	4	0	0
1600A Leads	4	2	4	2	6	4	4	2	6	4	4	2
150AQ Leads	60	60	60	60	60	60	60	60	60	60	60	60
Ball Valves M-Line	2	2	2	2	2	2	2	2	2	2	2	2
Ball Valves S-Line	2	2	2	2	2	2	2	2	2	2	2	2
Ball Valves H-Line	2	2	2	2	2	2	2	2	2	2	2	2
Ball Valves R-Line	2	2	2	2	2	2	2	2	2	2	2	2
Ball Valves U-Line	2	2	2	2	2	2	2	2	2	2	2	2
Manhole Cover	1	1	2	2	1	1	1	1	2	2	1	1
Vacuum Ports	1	1	1	1	1	1	1	1	1	1	1	1

Valve Stem & Valve bonnet

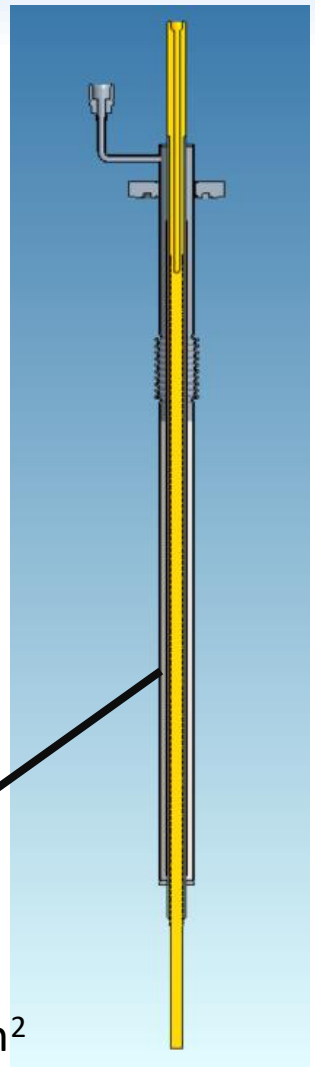


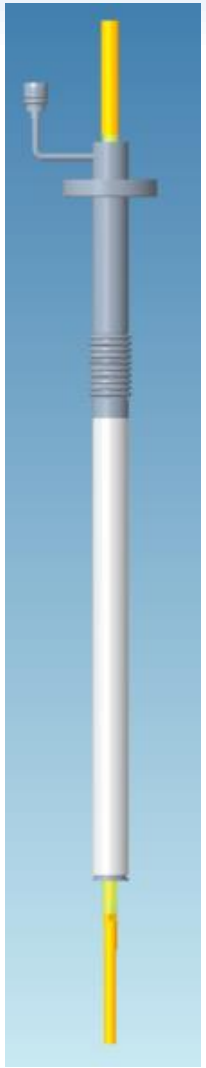
1600 Amp Current Lead



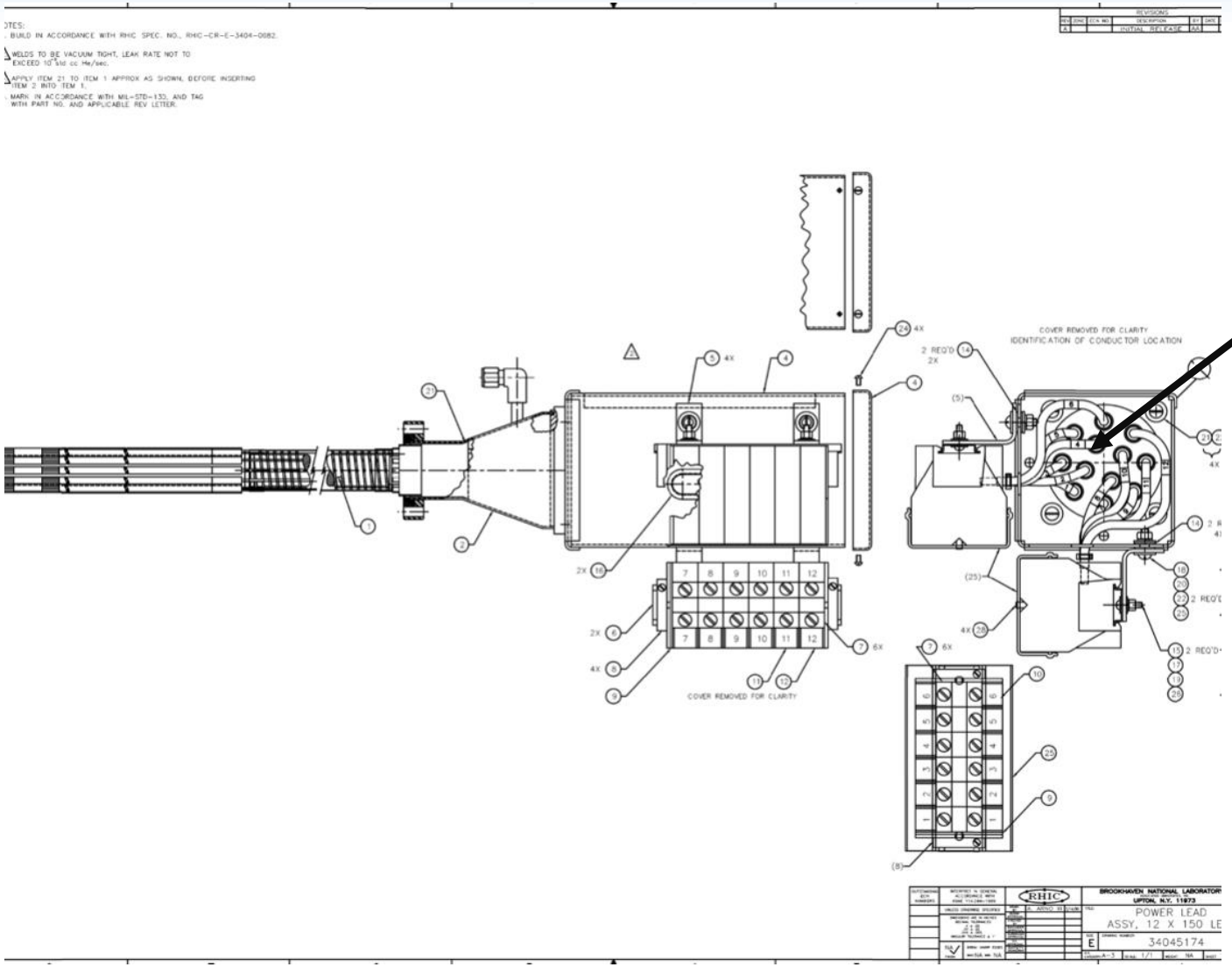


Spiral Leak
Cross Sectional Area:
0.036”x0.052” = 0.00187in^2

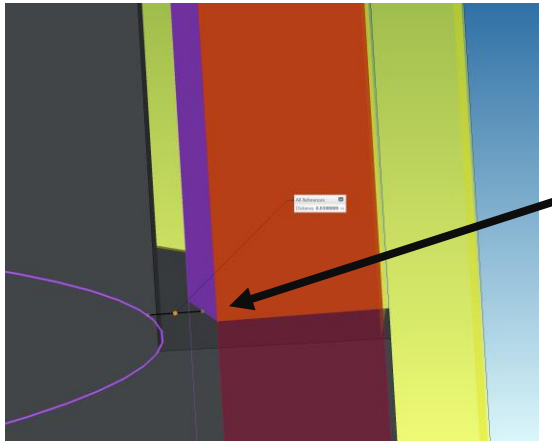


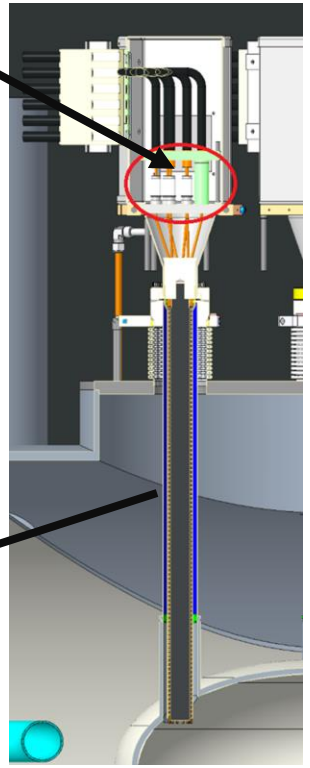


150 Amp Current Lead



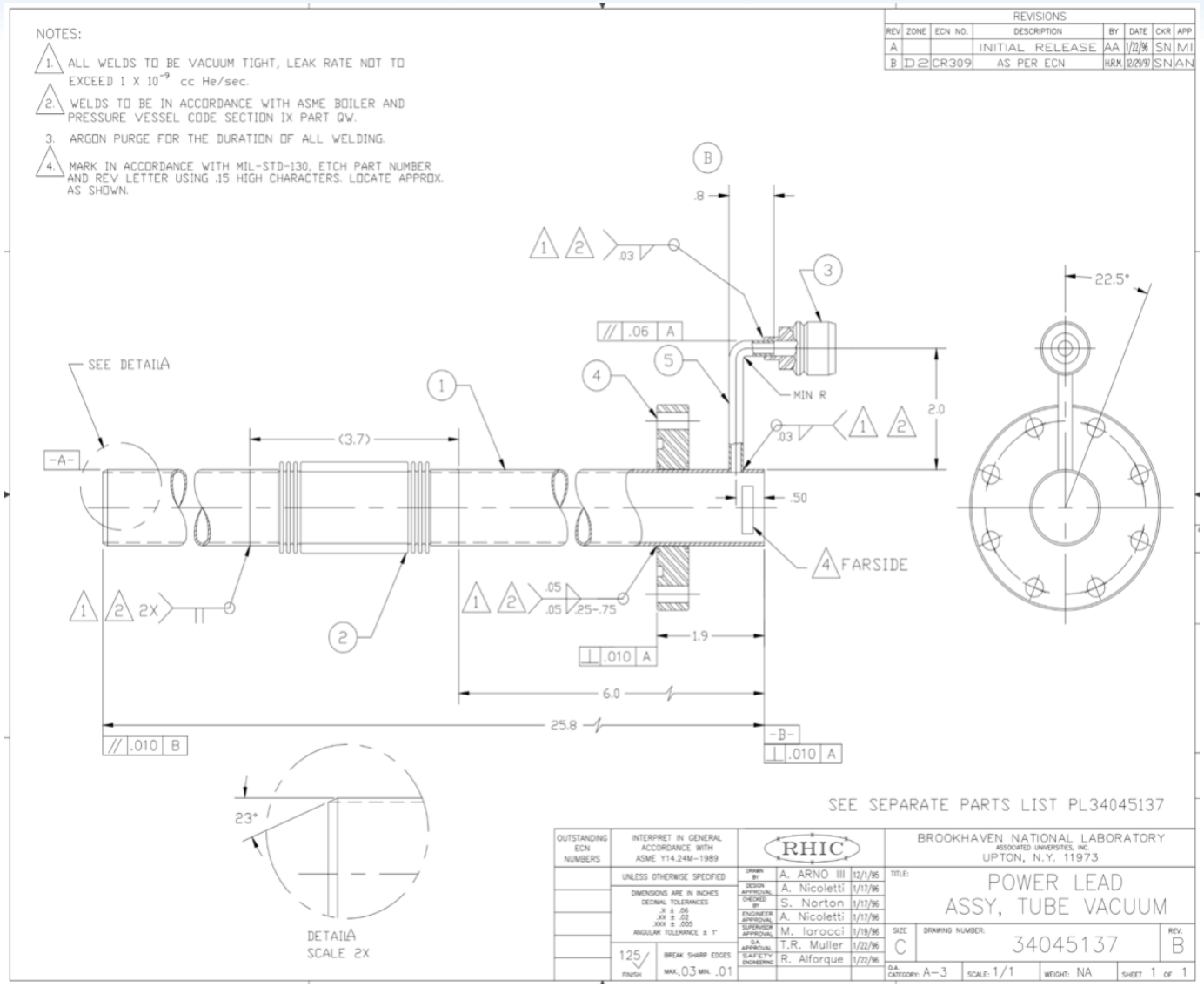
Leak through ceramic break will see same amount of He flow as the Spiral Leak since they share the same flow path.



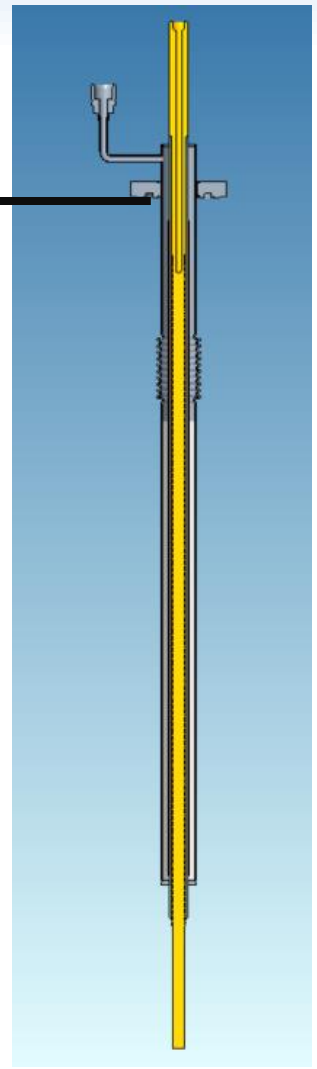


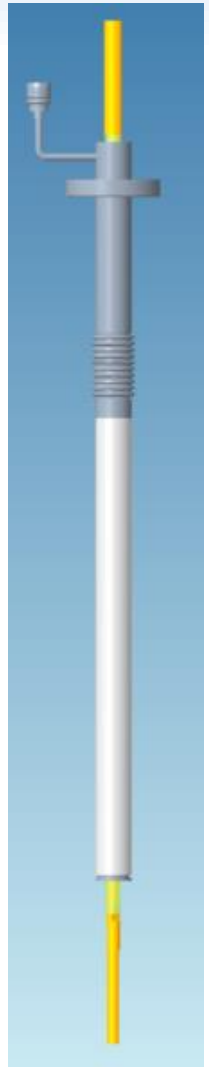
Spiral Leak
Cross Sectional Area:
$0.035" \times 0.19" = 0.00665 in^2$

1600 Amp Current Lead

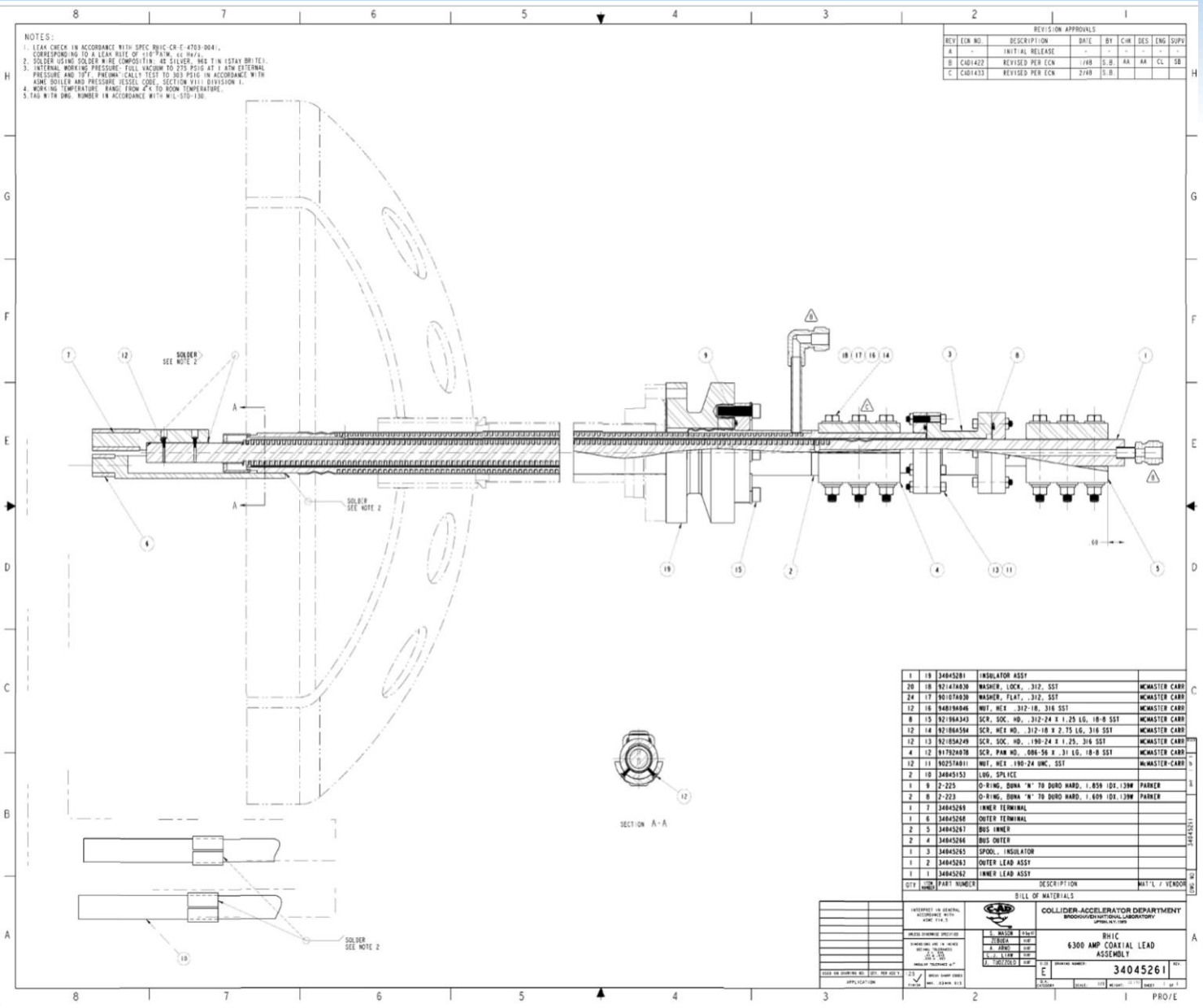


Flange Leak
Dia 1.786", Gap 0.002"
Leak Area 0.012 Inch^2





6300 Amp Current Lead



Dia at Flange O-ring 1.86", Gap 0.002"
Leak Area 0.012 Inch^2

Spiral leak area Inner: 0.125"X0.15
Leak Area 0.019 Inch^2

Spiral leak area Outer: 0.107"X0.12
Leak Area 0.013 Inch^2

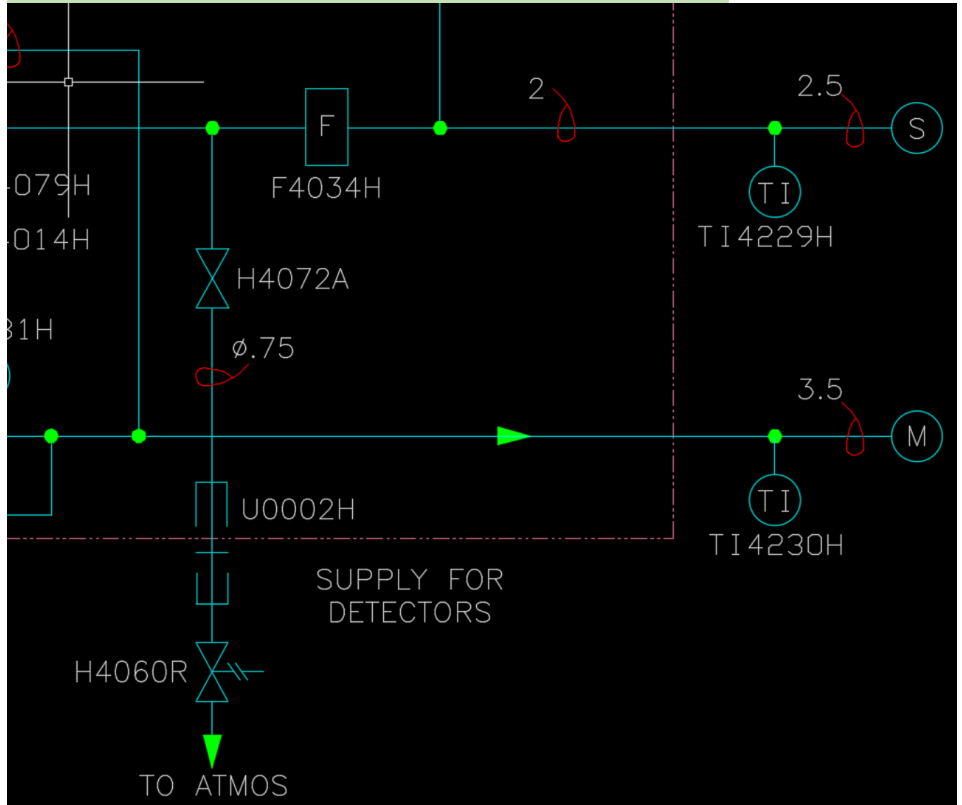
Bayonet, Capped {S-Line}

Limited by isolation valve: cryogenic valve seat failure.

Bayonet O-ring seal

Bayonet capped Trapped volume ¼” relief @250 psig

Series: Double failure to release



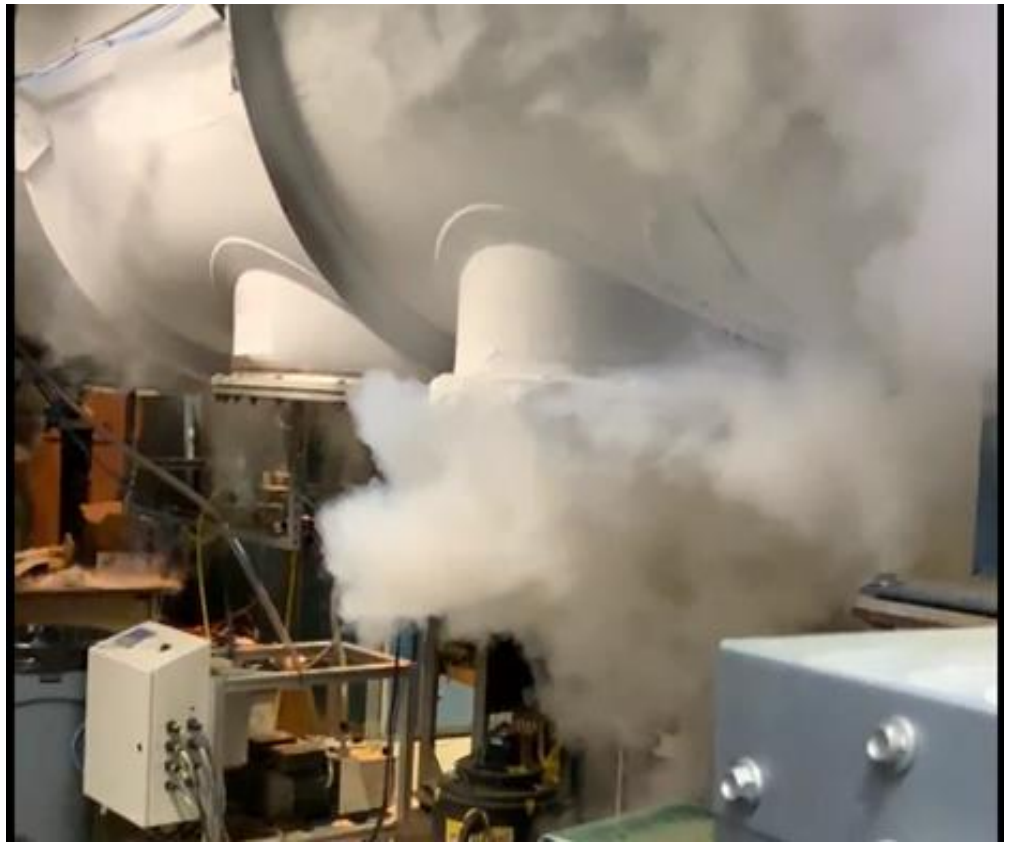
Flanges
{Relief pipe}

Dia 2.1" Gap 0.002"

Relef Area 0.0132 Inch^2

Manway port cover

- Man cover diameter 44.5"
- Assumed 16 Ruptures of 0.08" along the perimeter of the O-ring
- Total leak area 0.315 Inch^2



Bellow Rupture is result of sputtering.

Bello hole is measured and found to be 0.5X0.25 $Inch^2$

Normal event and unusual events process parameters

	Conditions during failure events under Normal Operational Mode branch		Conditions during failure events under Unusual Initiator Mode branch	
Process circuit	Normal Pressure (Bar)	Normal Temperature (K)	Event Pressure (Bar)	Event Temperature (K)
M Line	4	4.8	18.6	10
H Line	15	45	18.6	56
S Line	3.5	4.8	18.6	10
U Line	1.3	4.8	18.6	10
R Line	1.3	4.8	18.6	10

Normal event and unusual events leak rates

			Molar Flow Release Rate	
Line	**Components**	**Leak Area Inch^2**	**Normal operation event**	**Unusual initiator event**
			SCFM	SCFM
M Line	Valve stem seal Leak 0.5" dia and 0.002" gap	3.14E-03	135.3	210.1
	Valve Bonnet Flange leak, 2.5" dia with 0.002: gap	1.57E-02	676.4	1050.7
	150 Lead Ceramic/SS304Cap Rupture	6.65E-03	286.4	444.8
	12x150 Lead helium line rupture	6.65E-03	286.4	444.8
	1600A Lead Leak: Flange Interface Norel/G10 Insulator	1.80E-03	77.5	120.4
	1600A Lead Flange o-ring failure: Flange gap: 0.002" x 2.5 inch diameter (3.38"Flange), oring dia 1.786	1.12E-02	483.2	750.7
	1600A Lead: Helium lead cooling return tube rupture: 3/8"OD x 0.035"WT	1.80E-03	77.5	120.4
	6300A Lead Leak: Norel/G10 Insulator flange	1.88E-02	807.4	1254.2
	6300A Lead Flange o-ring failure: Flange gap: 0.002" x 2.5 inch diameter (3.38"Flange) oring dia 1.86	1.17E-02	503.2	781.8
	6300A Lead: Helium lead cooling return tube rupture: 3/8"OD x 0.035"WT	1.32E-02	568.4	883.0
	Relief valve flange connection	1.32E-02	568.2	882.6
	1/4" Tube Instrument Line	1.57E-03	67.6	105.1
	Ball Valve	3.14E-03	135.3	210.1
H Line	Valve stem seal	3.14E-03	59.8	66.3
	Valve Bonnet	1.57E-02	298.8	331.3
	Relief valve flange connection	1.32E-02	251.0	278.3
	1/4" Tube Instrument Line	1.57E-03	29.9	33.1
	Ball Valve	3.14E-03	59.8	66.3
S Line	Valve stem seal	3.14E-03	120.6	210.1
	Valve Bonnet	1.57E-02	602.8	1050.7
	Capped Bayonet (0.75"NPS) with small 250 psig relief	4.71E-03	180.9	315.2
	Relief valve flange connection	1.32E-02	506.4	882.6
	1/4" Tube Instrument Line	1.57E-03	60.3	105.1
	Ball Valve	3.14E-03	120.6	210.1
U Line	Valve stem seal	3.14E-03	15.4	210.1
	Valve Bonnet	1.57E-02	77.2	1050.7
	Relief valve flange connection	1.32E-02	64.8	882.6
	1/4" Tube Instrument Line	1.57E-03	7.7	105.1
	Ball Valve	3.14E-03	15.4	210.1
R Line	Valve stem seal	3.14E-03	15.4	210.1
	Valve Bonnet	1.57E-02	77.2	1050.7
	Relief valve flange connection	1.32E-02	64.8	882.6
	1/4" Tube Instrument Line	1.57E-03	7.7	105.1
	Ball Valve	3.14E-03	15.4	210.1
INSULATING VESSEL			SCFM	SCFM
	Mancover+Bellow	0.44	1769	1769
	HiVacuum Pumpout Port: Turbo and vacuum gages ports	0.057	227.4	227.4

Probability of failure of vacuum insulation

# of Components	200
Failure Probability	1.00E-09
SC bus short probability	5.00E-05
Event Probability	5.02E-05

ODH Classifications

- Fatality Rate less than < 10^{-7} /hr
- O2 Concentration ≥ 14%
- ODH 0: Posting & training

Based on the ODH Classification, the Department Chair /Division Manager or designee establishes and maintains the minimum controls required as follows:

ODH Classification	Controls
0	Postings Training
1	Postings Training (including practical demonstration of personal protective equipment [PPE]) PPE: • Personal Oxygen Monitor • Self-Rescue Respirator (Supplied Atmosphere)

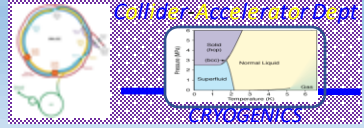
Step 1 Based on the minimum oxygen concentration, the Department Chair /Division Manager or designee establishes and maintains the minimum controls required as follows:

Oxygen Concentration	Controls
≥14%	Controls Required by ODH Classification (step 2).
≥10%<14%	Controls Required by ODH Classification (step 2) plus ODH Monitoring (either fixed area or POM) that alarms locally.
<10%	Controls Required by ODH Classification (step 2) plus ODH Monitoring that provides alarms/indication both locally and before entering the area.

Alarms must be perceptible in the environment used (e.g., visual or vibration in high noise areas).

Note: Ensure to incorporate the impact from added monitoring to the ODH Classification process.

Fatalities / Hr.	ODH Classification
10 -9 (i.e., Oxygen concentration not less than 18%)	No Classification Required
>0 but <10^{-7} (Note 1)	0
>=10^{-7} but <10^{-5}	1
>=10^{-5} but <10^{-3}	2
>=10^{-3} but <10^{-1}	3
>=10^{-1}	4



4.5K case, 1 ODH fan is working at 80% capacity

Building	Gross [Feet^3]	Equipment [Feet^3]	Net [Feet^3]	ODH capacity for 2 Fan 0.8 capacity	Leak rate SCFM	Min O2 level	Fatality rate	ODH class
1004B	86433	13309	73124	12264	1769.0	18.0%	7.75E-10	0
1006B	71176	2280	68896	13040	1769.0	18.2%	1.08E-09	0
1008B	57843	3345	54498	12960	1769.0	18.1%	7.02E-10	0
1010A	85877	4885	80991	8144	1769.0	16.4%	8.25E-10	0
1012A	86128	2614	83514	7608	1769.0	16.1%	8.09E-10	0
1002B	74362	3310	71052	10312	1769.0	17.4%	7.04E-10	0

1004B transient for 1 ODH fan

CASE: HELIUM MODE

FAN CAPACITY: 12264 CFM

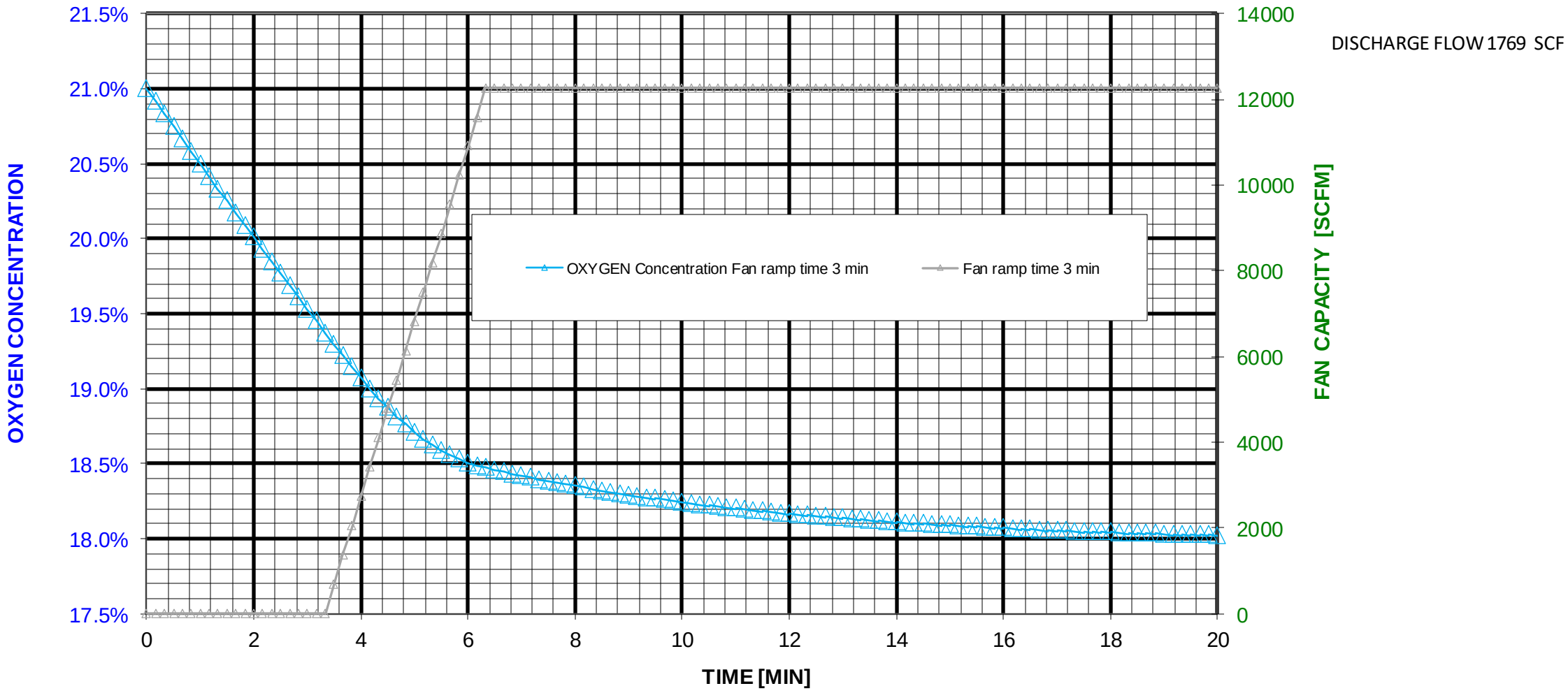
BUILDING VOLUME: 73123.8704537037 CF

4.5K case, Service buildings

Fan triggers at: 19.5" % Concentration 3 minute ramp duration

Minimum O2 concentration: 17.97 %

DISCHARGE FLOW 1769 SCF

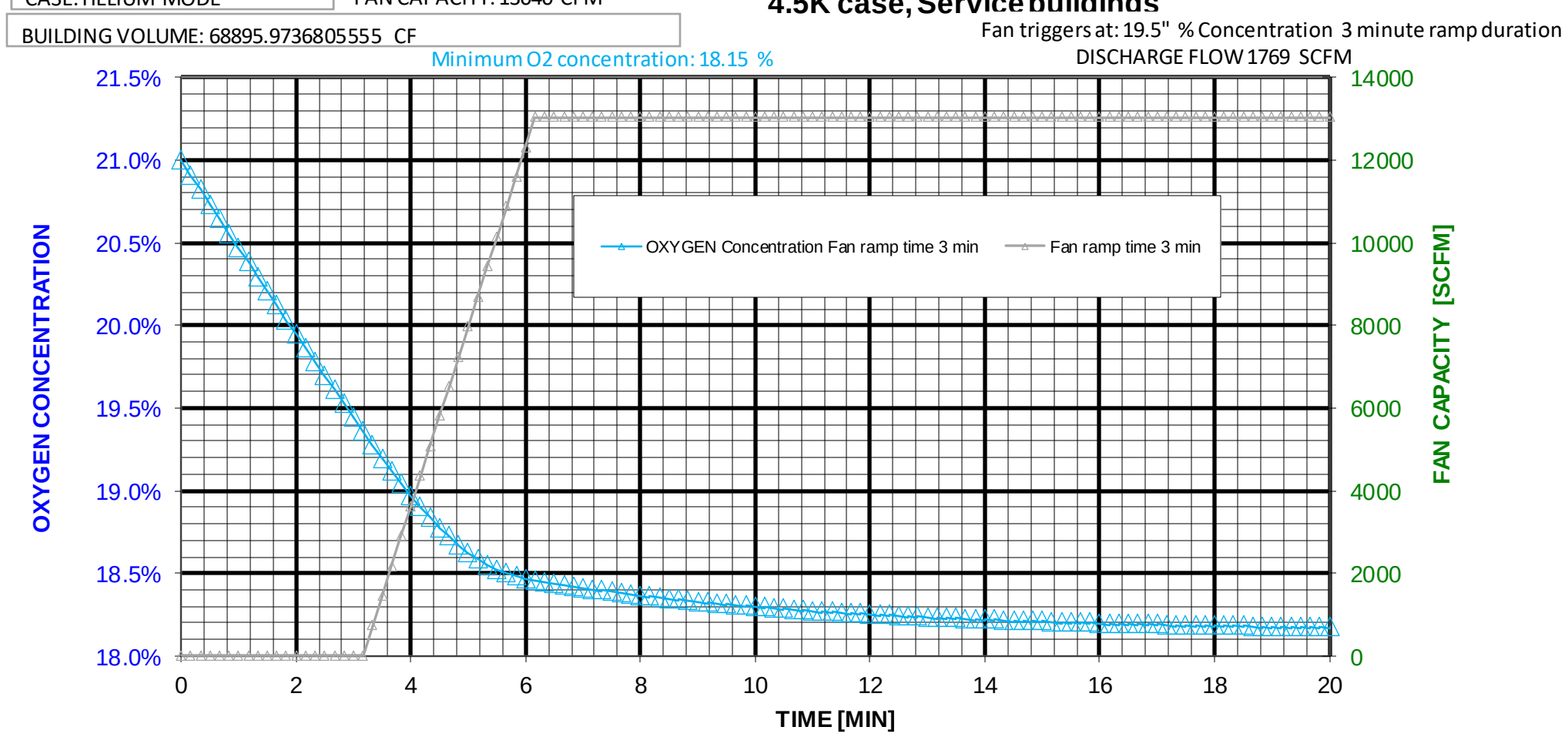


1006B transient for 1 ODH fan

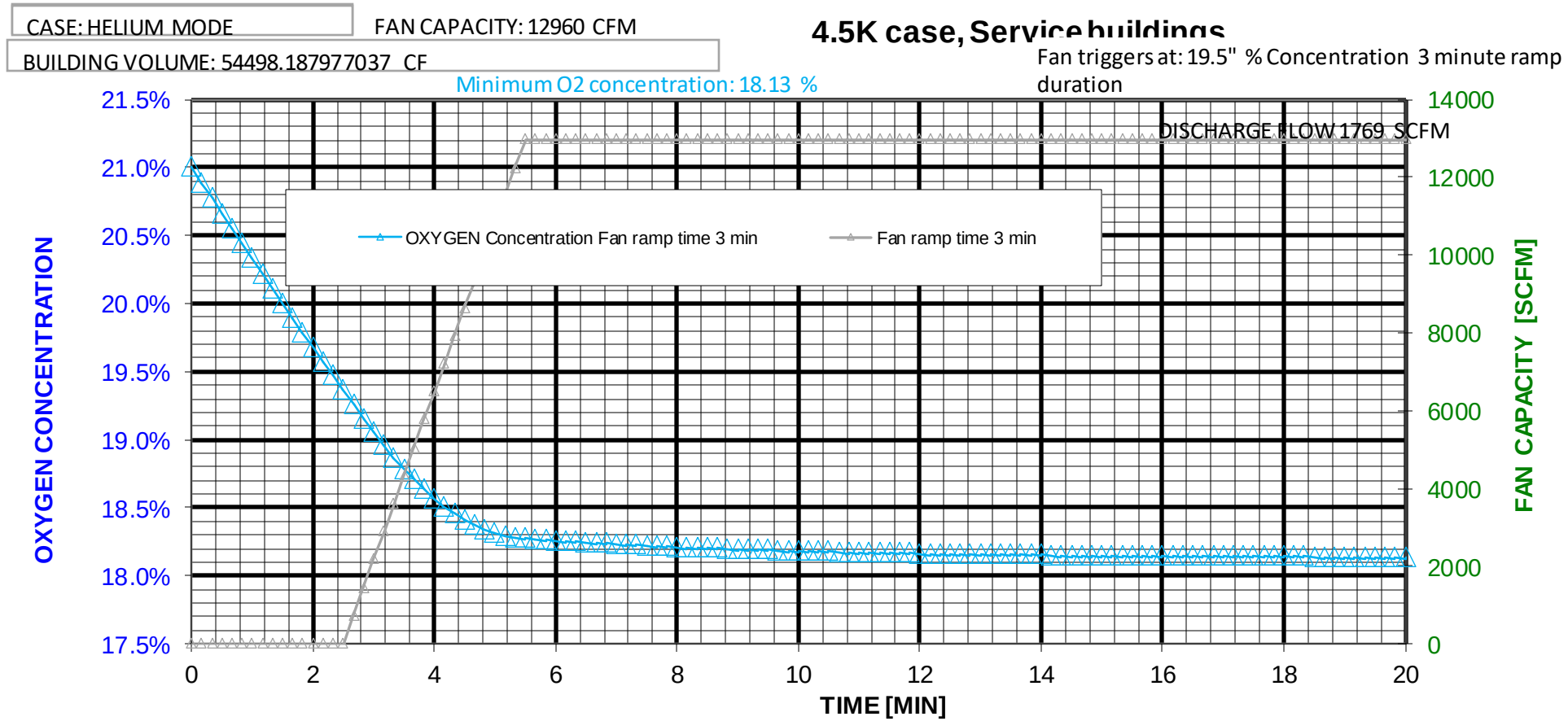
CASE: HELIUM MODE

FAN CAPACITY: 13040 CFM

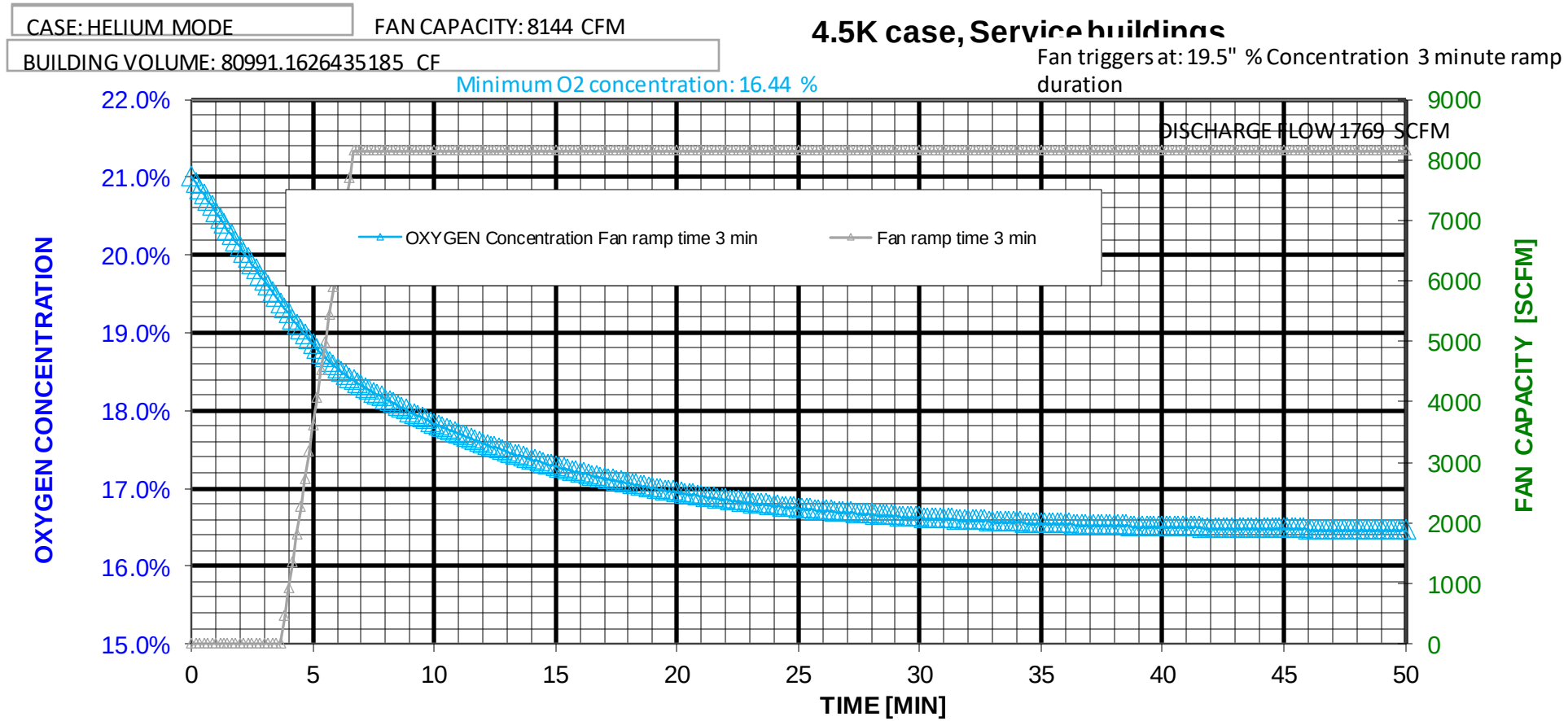
BUILDING VOLUME: 68895.9736805555 CF



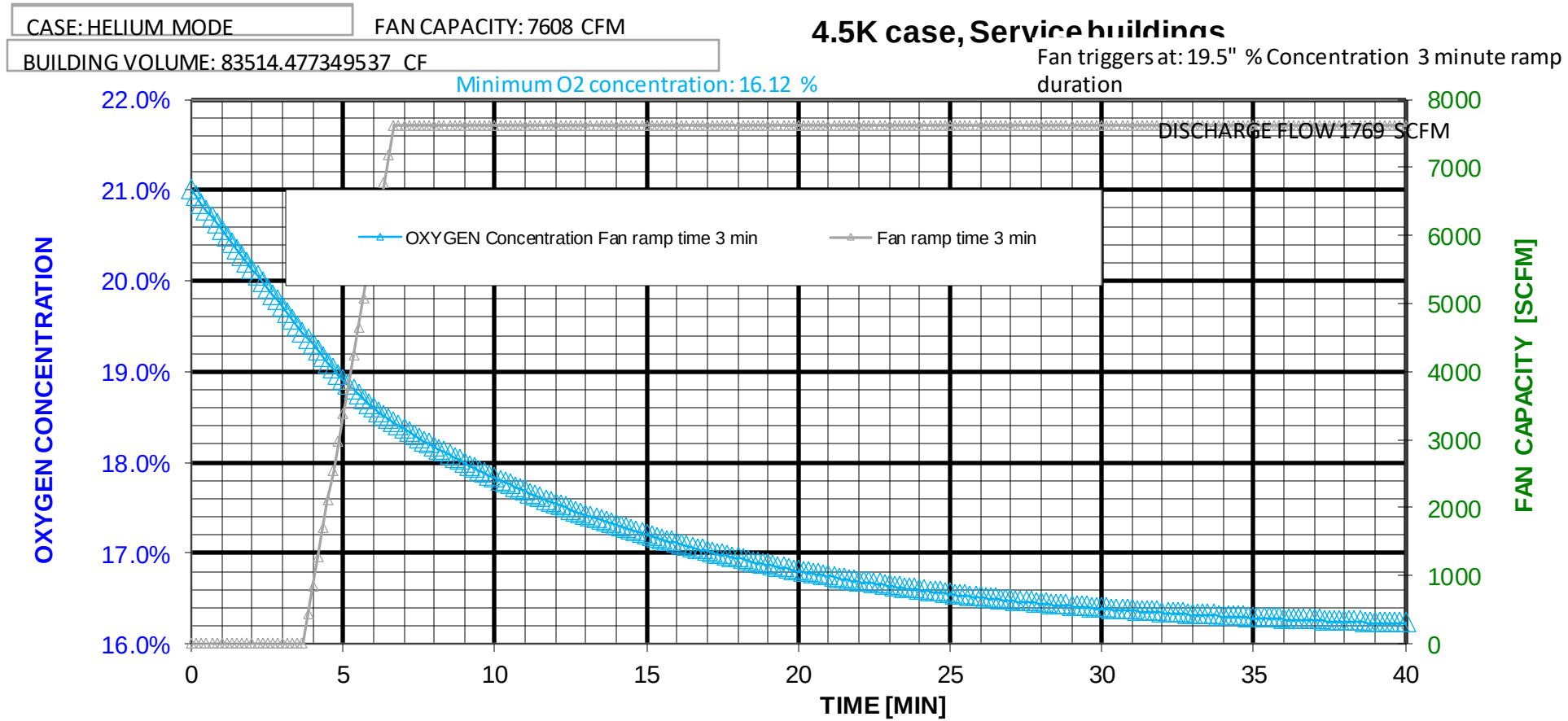
1008B transient for 1 ODH fan



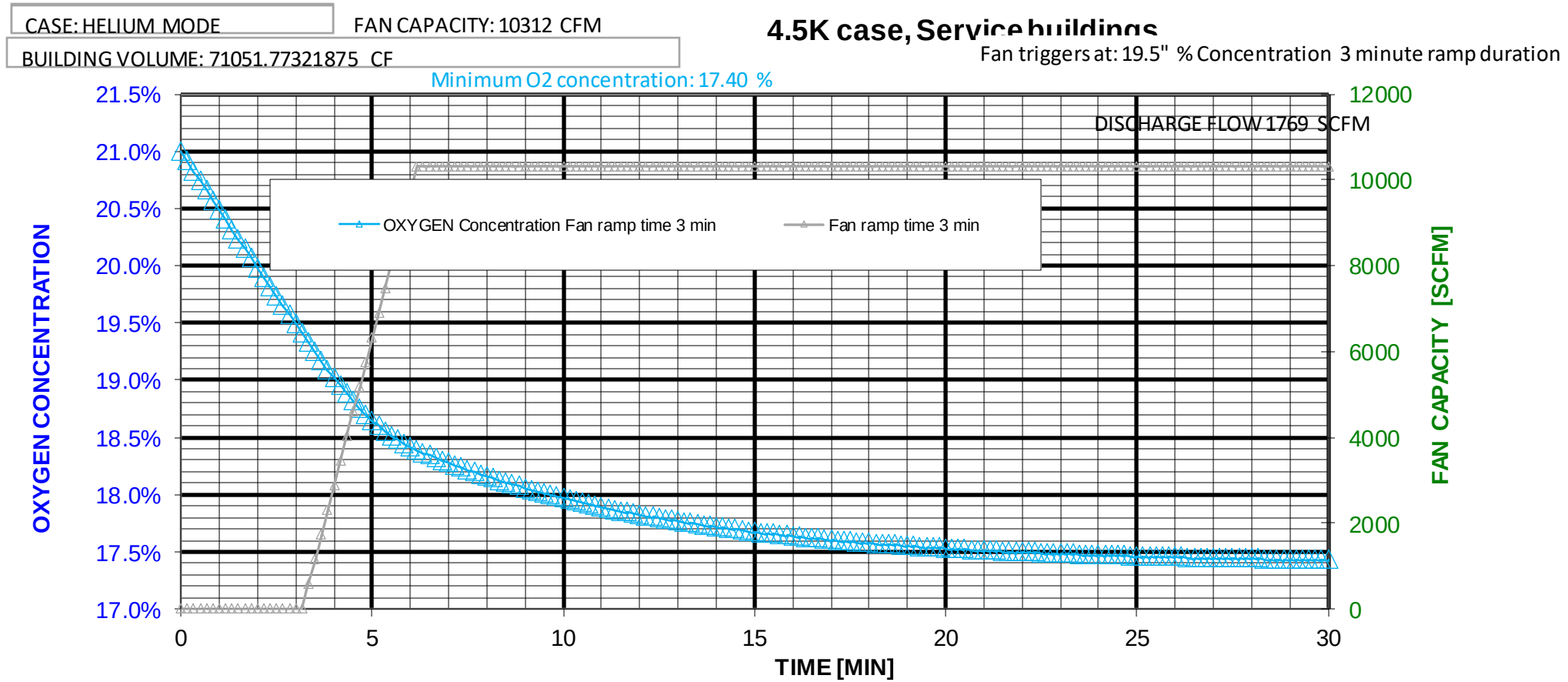
1010A transient for 1 ODH fan



1012A transient for 1 ODH fan



1002B transient for 1 ODH fan



4.5K case, 2 ODH fans are working at 80% capacity

Building	Gross [Feet^3]	Equipment [Feet^3]	Net [Feet^3]	ODH capacity for 2 Fan 0.8 capacity	Leak rate SCFM	Min O2 level	Fatality rate	ODH class
1004B	86433	13309	73124	24528	1769.0	18.9%	7.74E-10	0
1006B	71176	2280	68896	26080	1769.0	18.9%	1.08E-09	0
1008B	57843	3345	54498	25920	1769.0	18.7%	7.02E-10	0
1010A	85877	4885	80991	16288	1769.0	18.7%	8.03E-10	0
1012A	86128	2614	83514	15216	1769.0	18.6%	7.90E-10	0
1002B	74362	3310	71052	20624	1769.0	18.9%	7.02E-10	0
Auxiliary Buildings with 1 ODH fan								
1004E	3000	20	2980	3000	128	9.0%	1.0E-8	0
1010Mez	10500	1200	9300	--	128	0%	2.0E-8	0

1004B transient for 2 ODH fan

CASE: HELIUM MODE

FAN CAPACITY: 24528 CFM

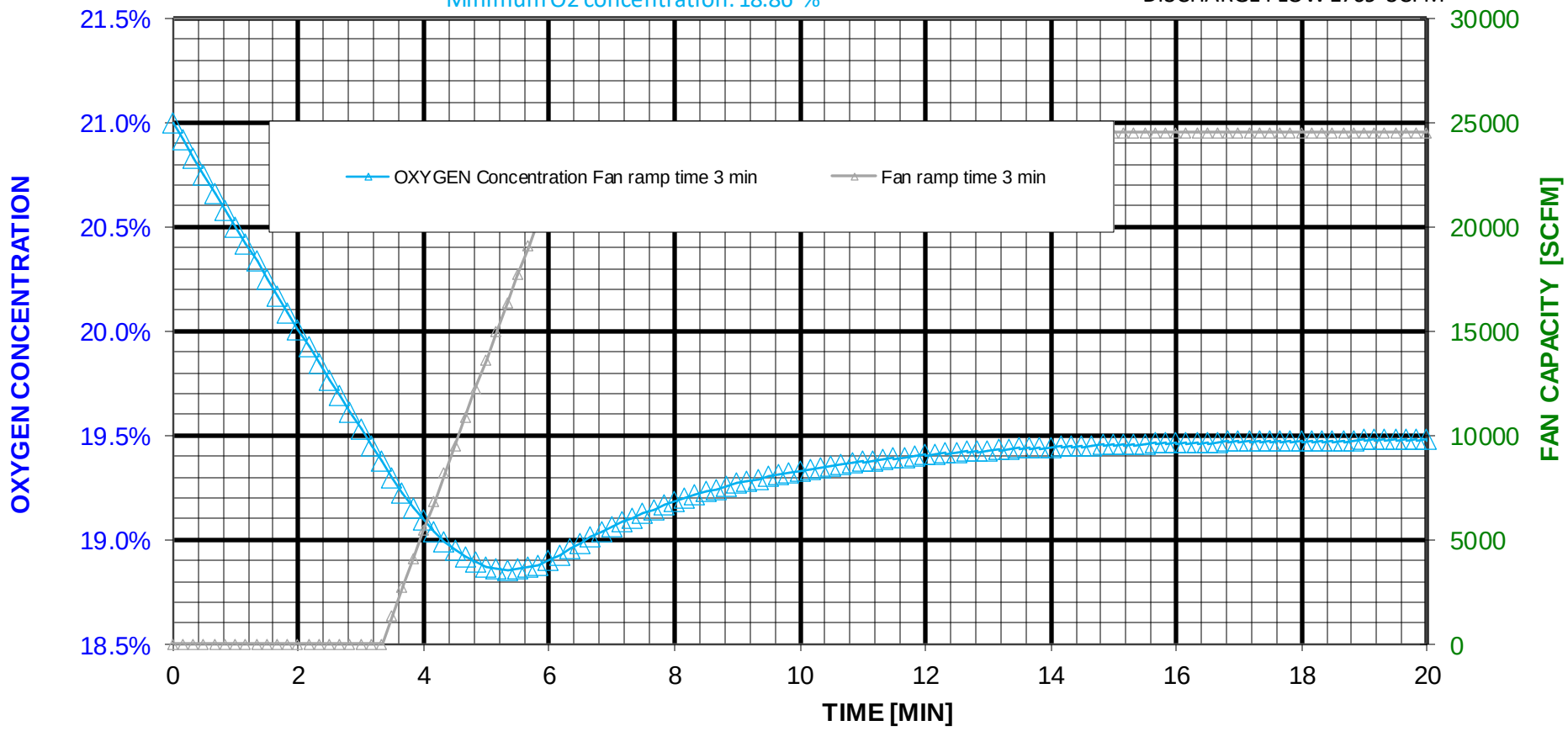
4.5K case, Service buildings

Fan triggers at: 19.5" % Concentration 3 minute ramp duration

BUILDING VOLUME: 73123.8704537037 CF

DISCHARGE FLOW 1769 SCFM

Minimum O2 concentration: 18.86 %



1006B transient for 2 ODH fan

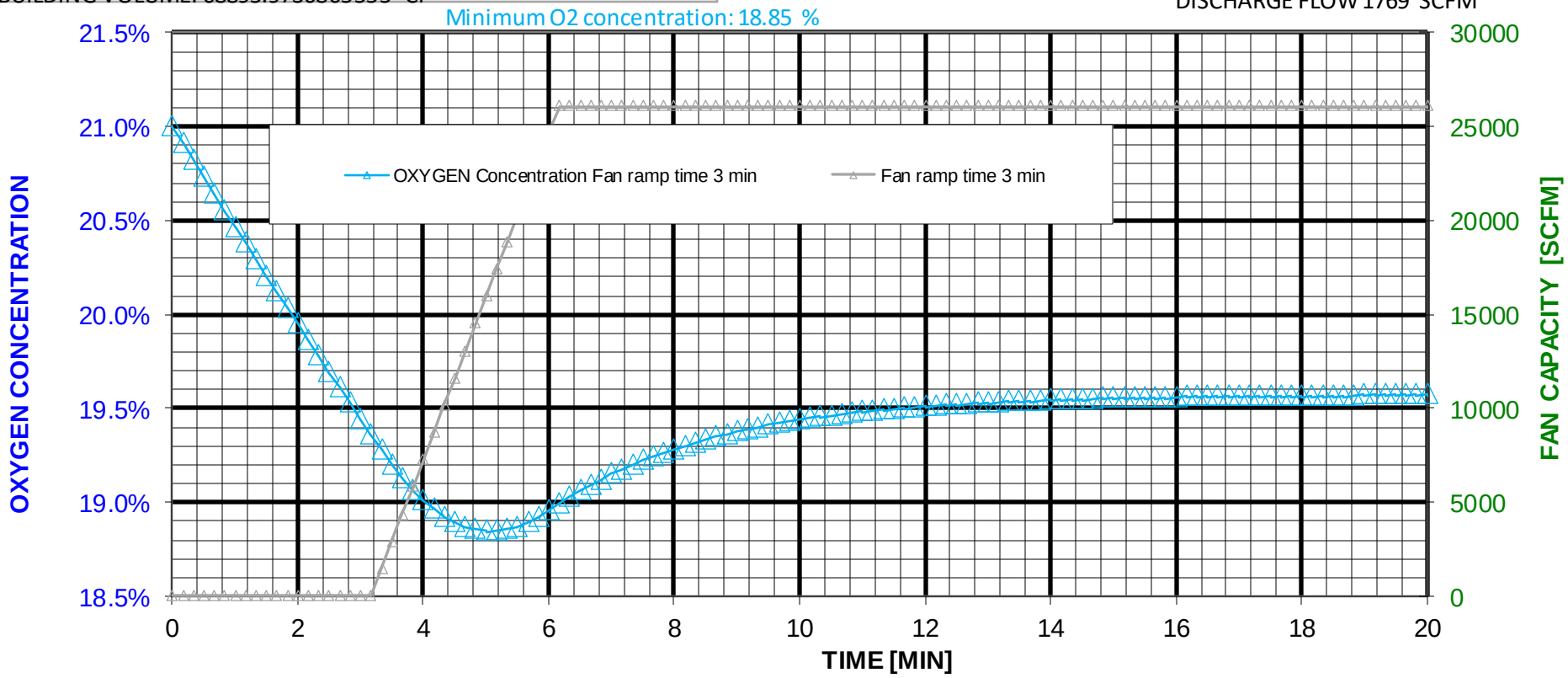
CASE: HELIUM MODE FAN CAPACITY: 26080 CFM

BUILDING VOLUME: 68895.9736805555 CF

4.5K case, Service buildings

Fan triggers at: 19.5" % Concentration 3 minute ramp duration

DISCHARGE FLOW 1769 SCFM



1008B transient for 2 ODH fan

CASE: HELIUM MODE

FAN CAPACITY: 25920 CFM

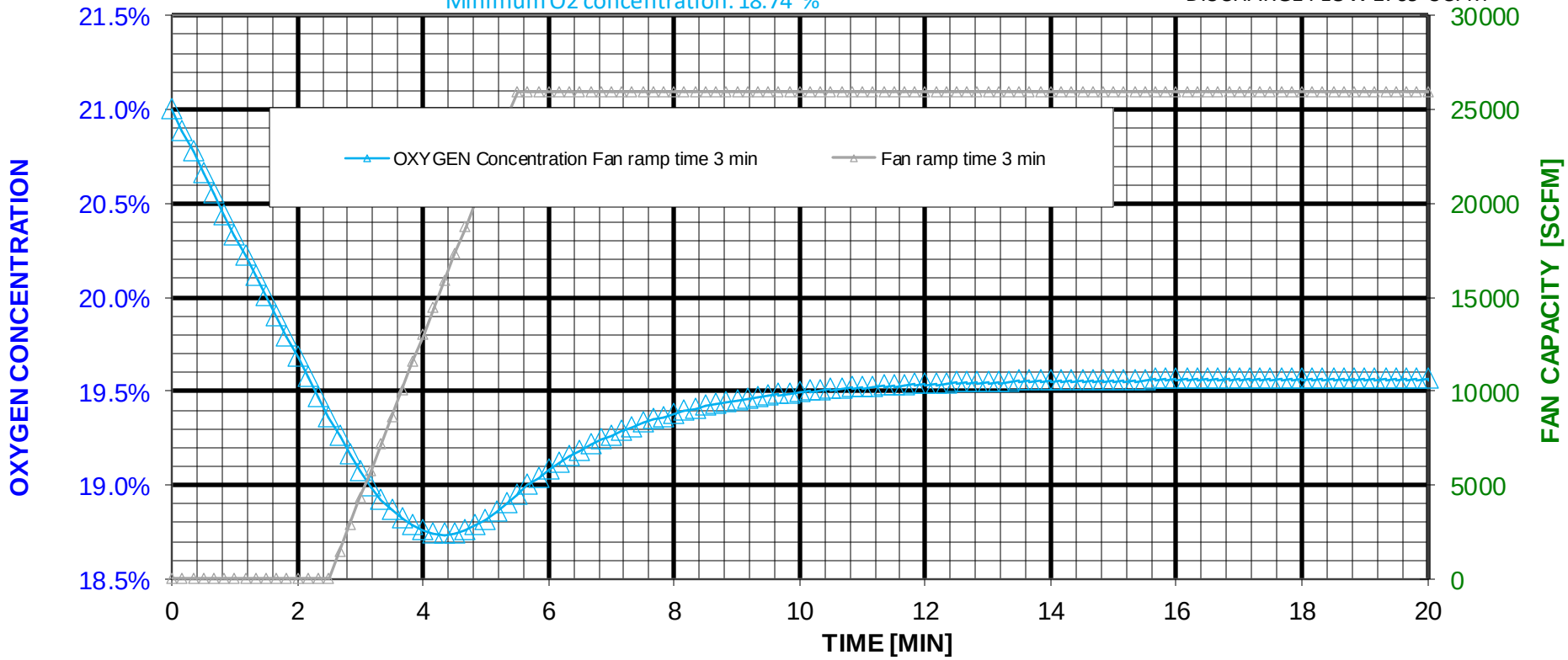
4.5K case, Service buildings

Fan triggers at: 19.5" % Concentration 3 minute ramp duration

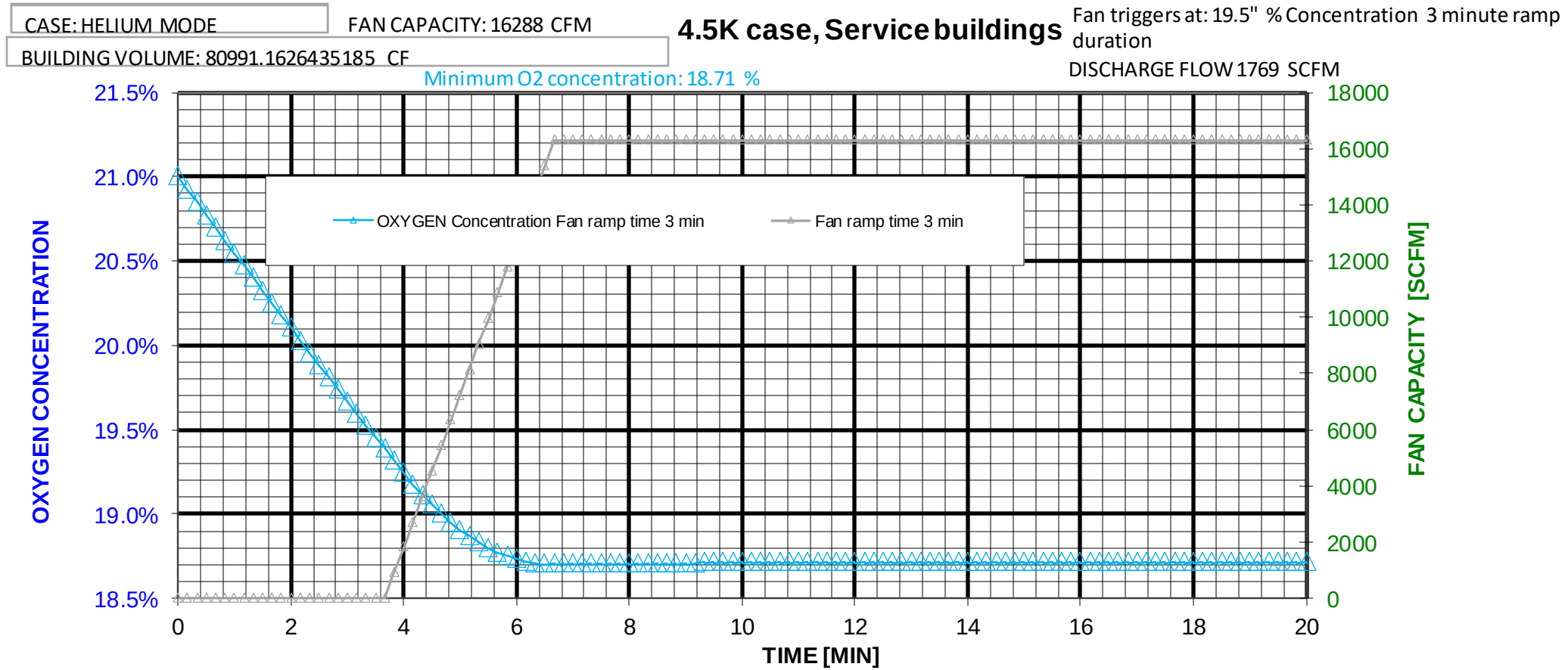
BUILDING VOLUME: 54498.187977037 CF

DISCHARGE FLOW 1769 SCFM

Minimum O2 concentration: 18.74 %



1010A transient for 2 ODH fan



1012A transient for 2 ODH fan

CASE: HELIUM MODE

FAN CAPACITY: 15216 CFM

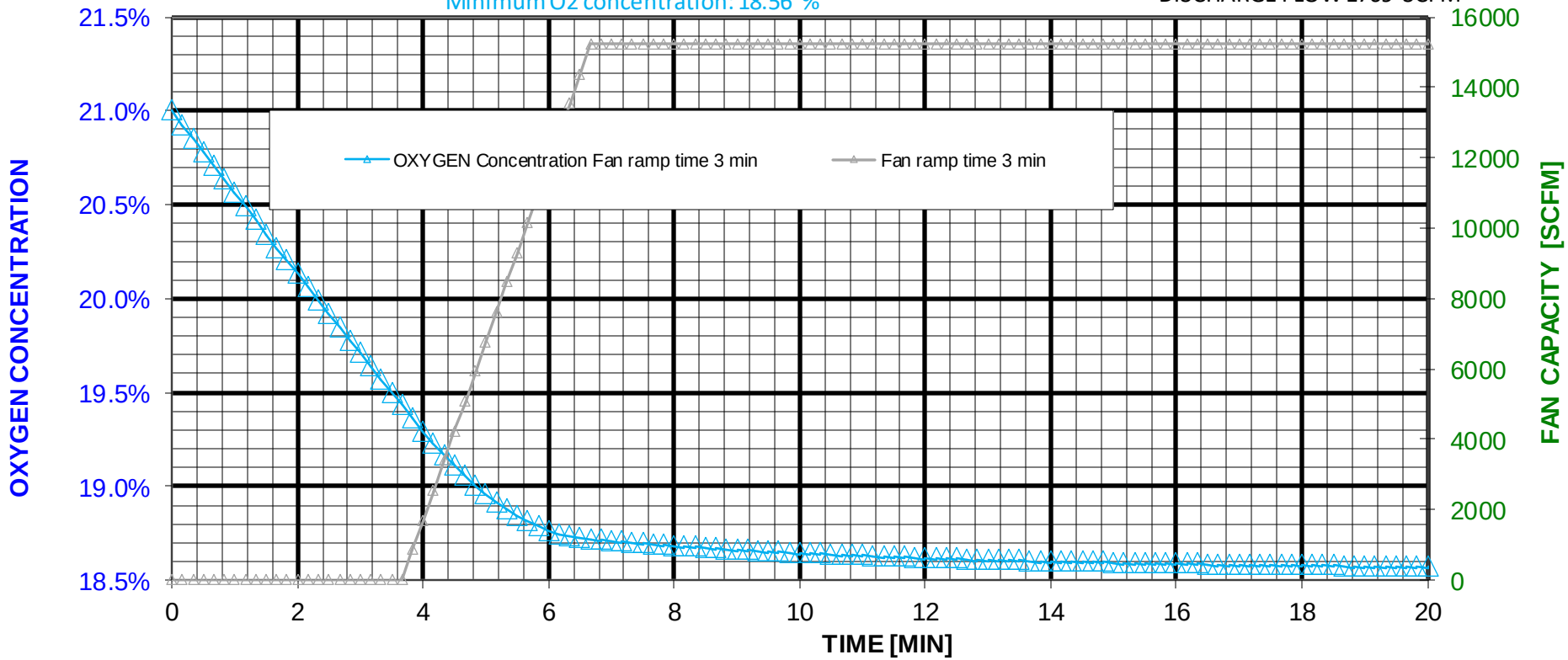
4.5K case, Service buildings

Fan triggers at: 19.5" % Concentration 3 minute ramp duration

BUILDING VOLUME: 83514.477349537 CF

DISCHARGE FLOW 1769 SCFM

Minimum O2 concentration: 18.56 %



1002B transient for 2 ODH fan

CASE: HELIUM MODE

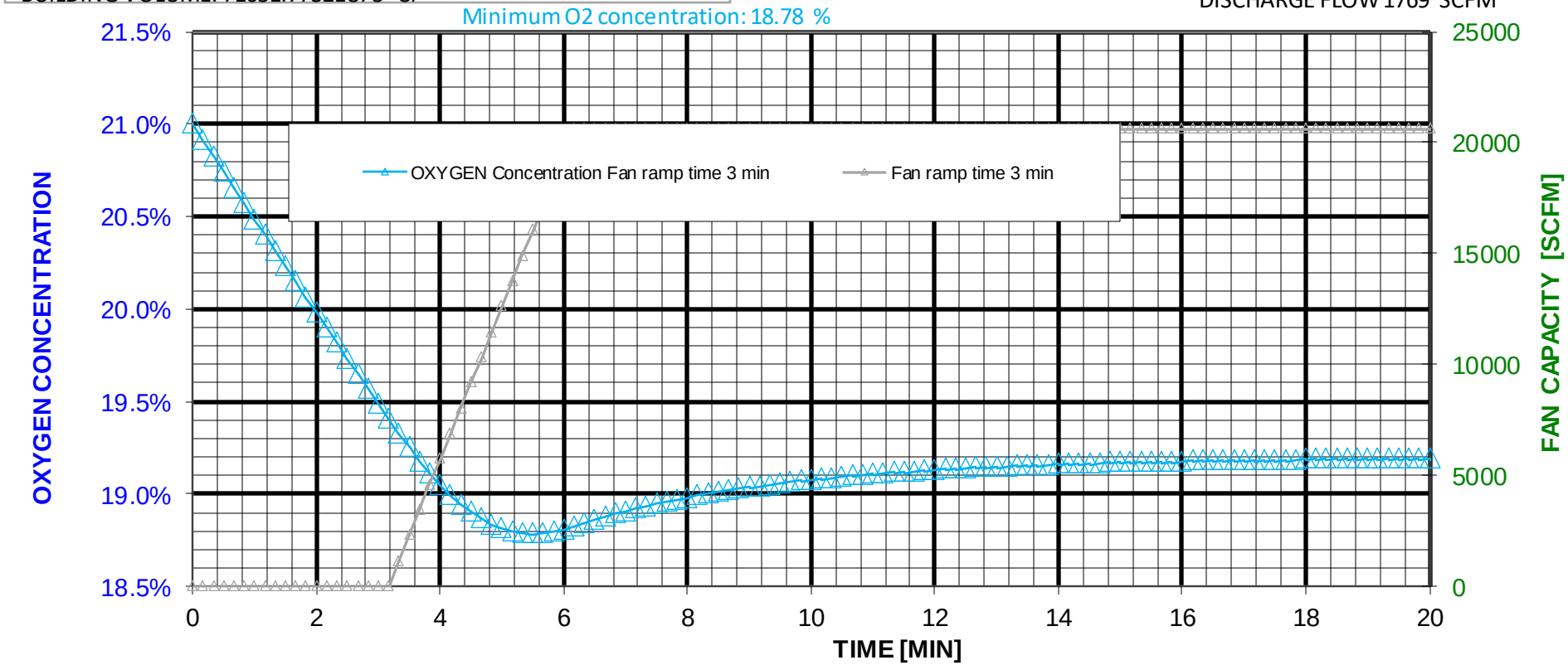
FAN CAPACITY: 20624 CFM

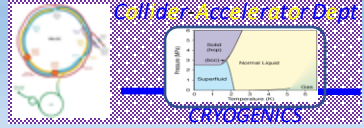
BUILDING VOLUME: 71051.77321875 CF

4.5K case, Service buildings

Fan triggers at: 19.5" % Concentration 3 minute ramp duration

DISCHARGE FLOW 1769 SCFM

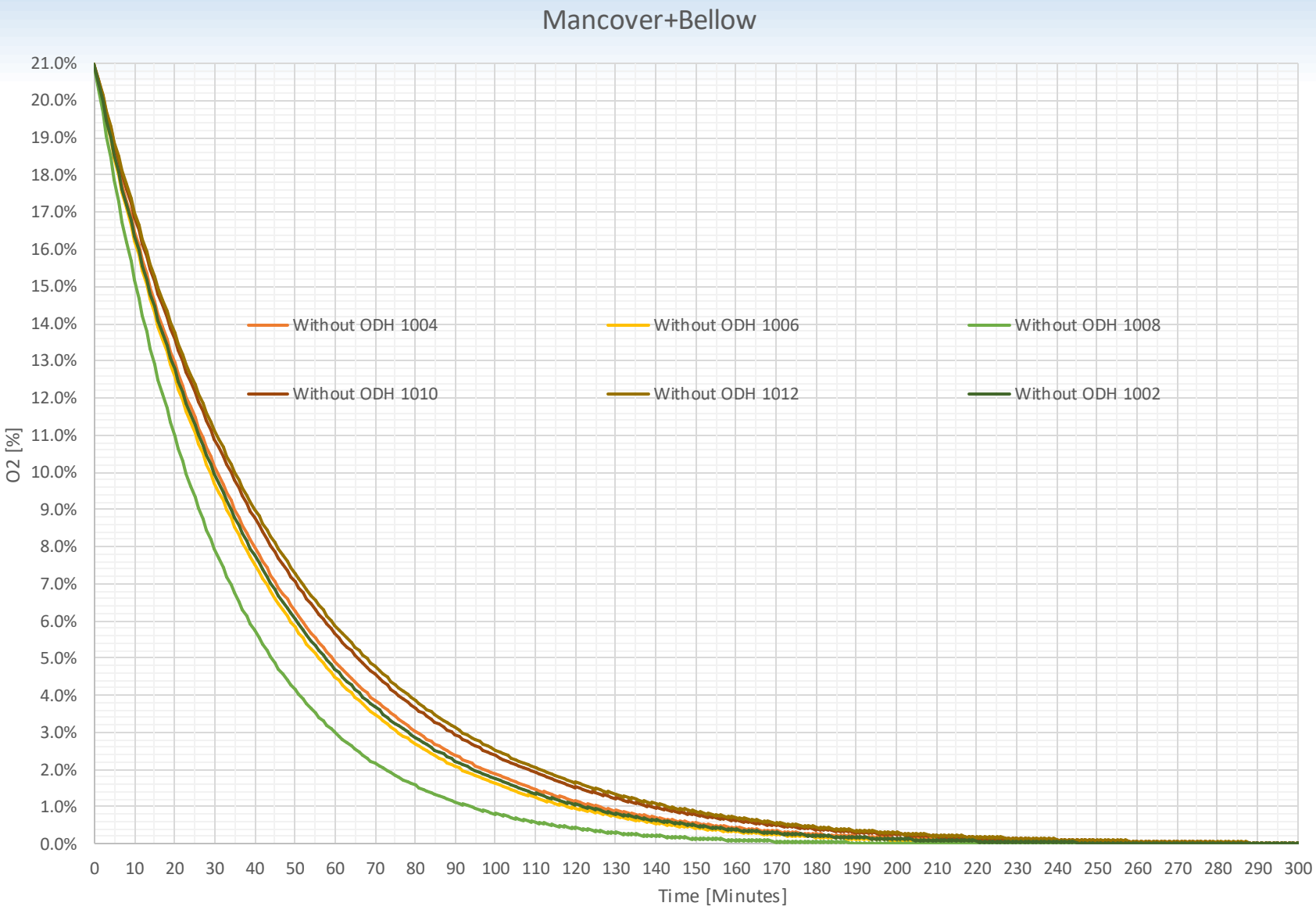




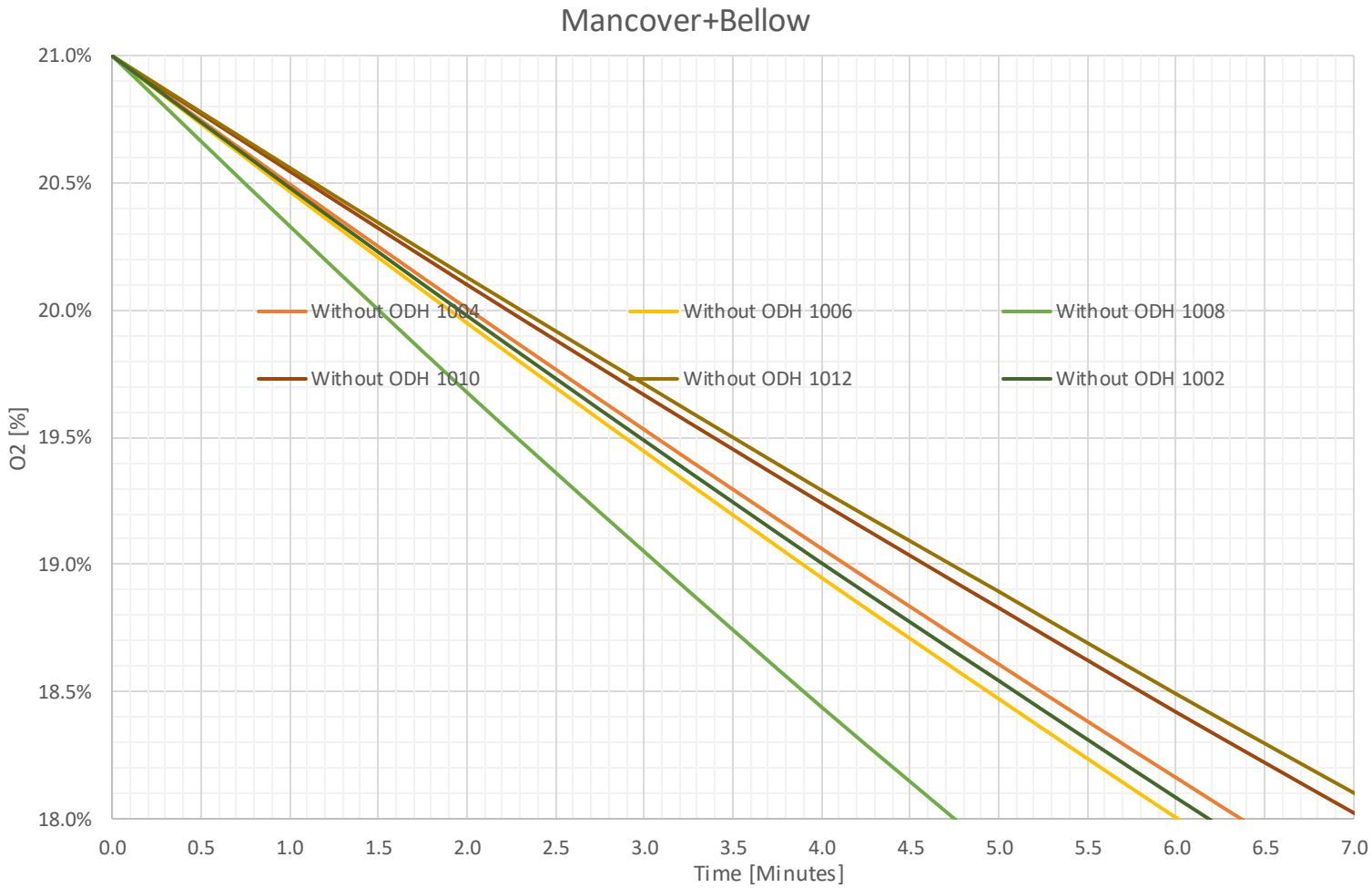
4.5K case, Fatality rate without HVAC and ODH

Building	Gross [Feet^3]	Equipment [Feet^3]	Net [Feet^3]	Min O2 level	Fatality rate	ODH class
1004B	86433	13309	73124	0	6.34E-04	2
1006B	71176	2280	68896	0	8.81E-04	2
1008B	57843	3345	54498	0	5.75E-04	2
1010A	85877	4885	80991	0	6.57E-04	2
1012A	86128	2614	83514	0	6.47E-04	2
1002B	74362	3310	71052	0	5.75E-04	2
Auxiliary Buildings for largest leak						
1004E	3000	20	2980	0	1.3E-8	0
1010Mez	10500	1200	9300	0	2E-8	0

O2 concentration without HVAC and ODH fan



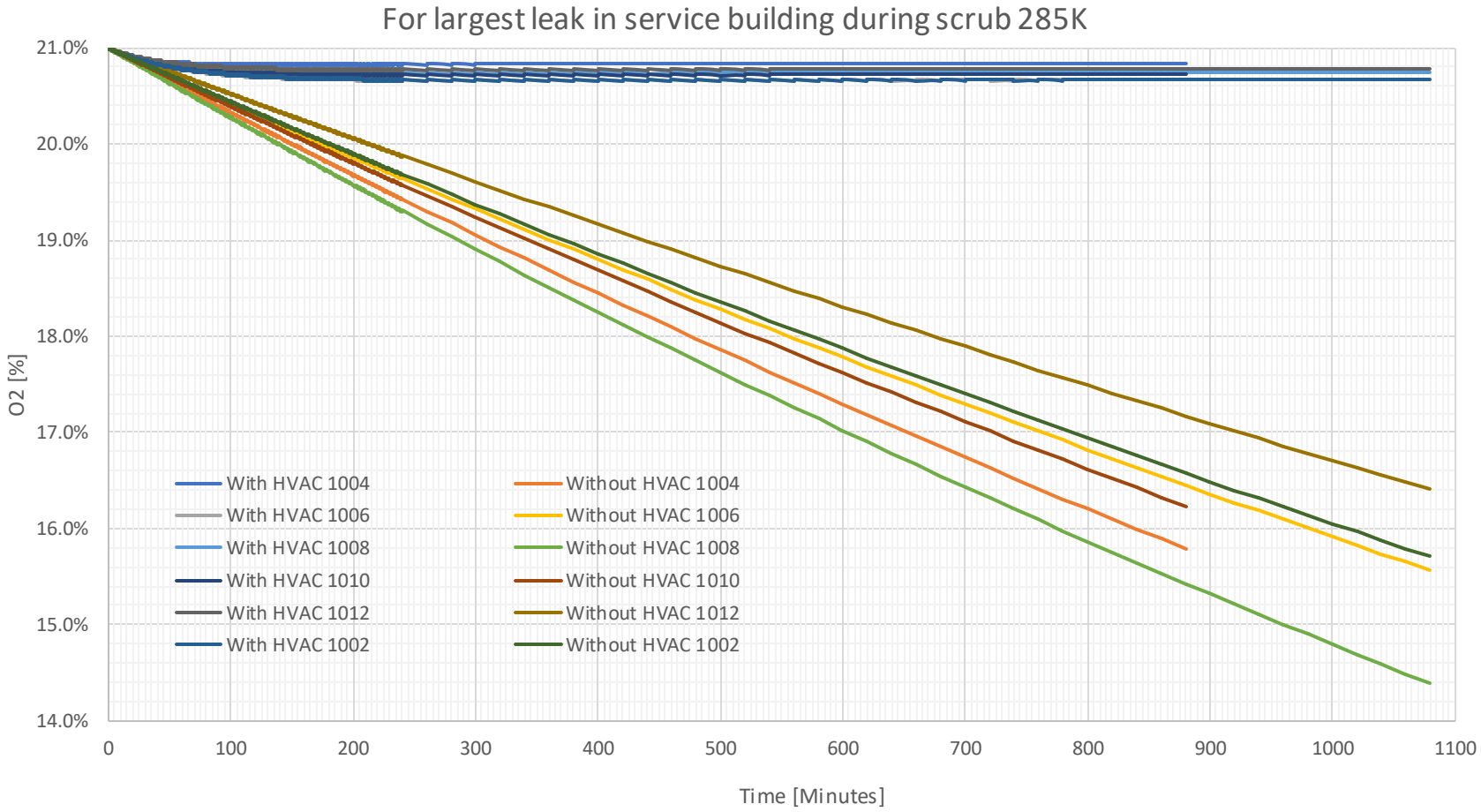
O2 concentration without HVAC and ODH fan



For 285K scrub mode

Building	Gross [Feet^3]	Equipment [Feet^3]	Net [Feet^3]	Min O2 level	Fatality rate	ODH class
1004B	86433	13309	73124	15.6%	1.7E-10	0
1006B	71176	2280	68896	15.3%	3.9E-10	0
1008B	57843	3345	54498	14.1%	2.1E-09	0
1010A	85877	4885	80991	16.1%	8.1E-11	0
1012A	86128	2614	83514	16.2%	6.5E-11	0
1002B	74362	3310	71052	15.5%	2.0E-10	0
Auxiliary Buildings for largest leak						
1004E	3000	20	2980	0.02%	1.3E-8	0
1010Mez	10500	1200	9300	1.86%	2E-8	0

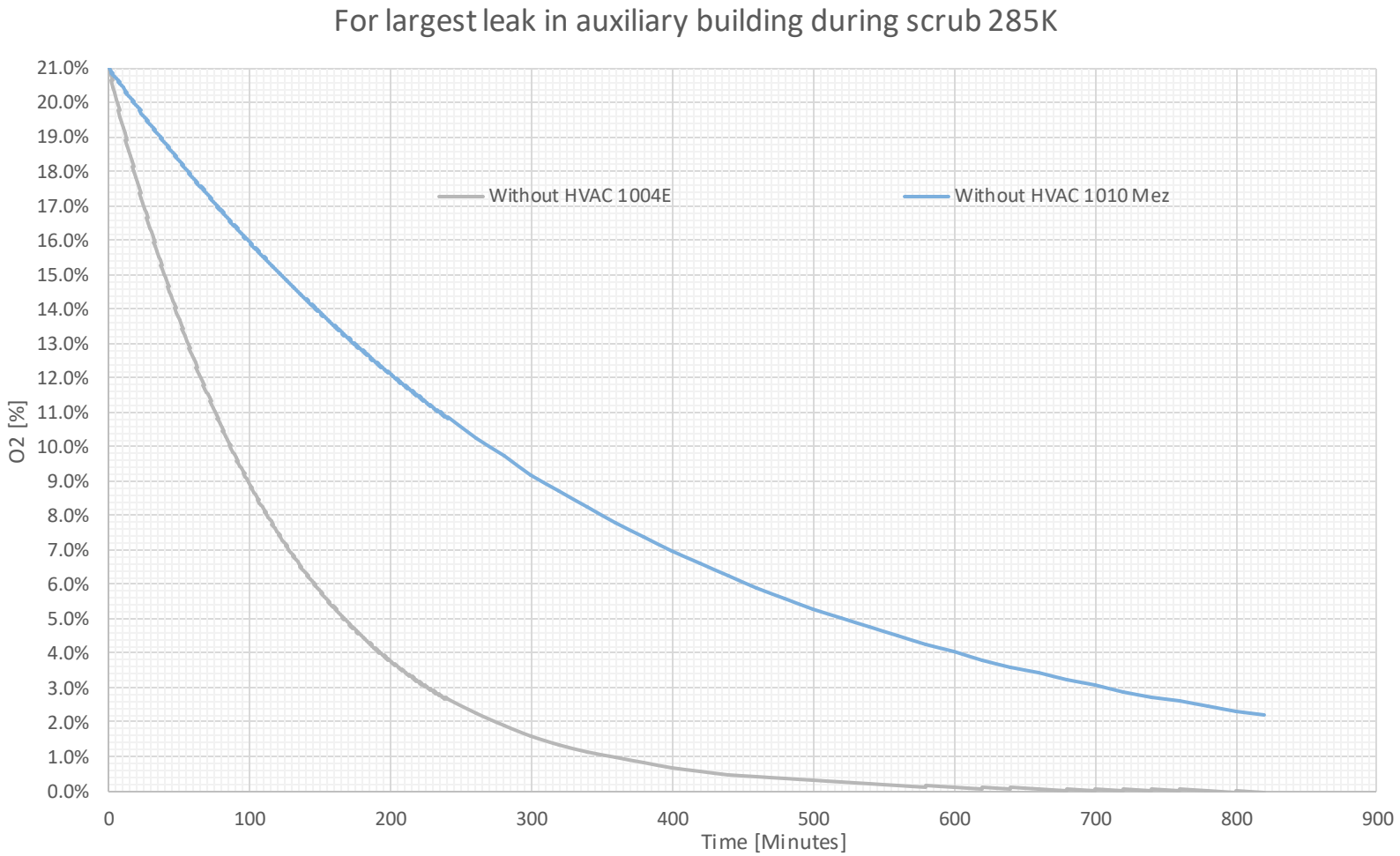
For 285K scrub mode



Maximum leak rate is 23.7 SCFM

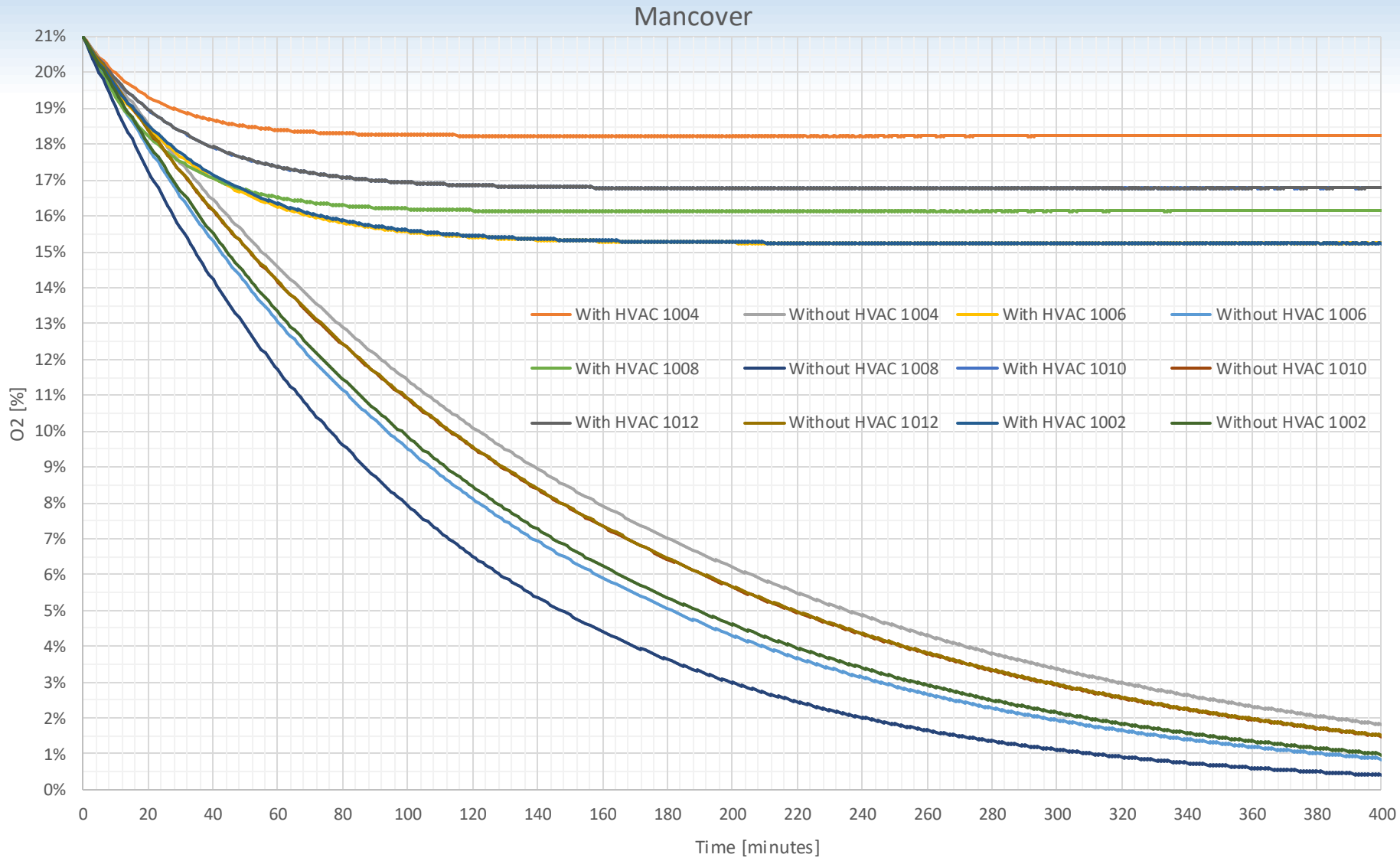
Total inventory 21,000 CF.

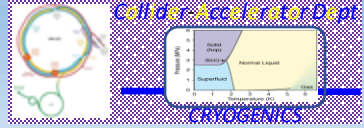
For Auxiliary building



Maximum leak rate is 25.6 SCFM
Total inventory 21,000 CF.

40 K cooldown mode ODH Results





Conclusion

- ODH evaluation has been re-done for the Service Buildings
- The service buildings require credited controls of ODH sensing & Ventilation to get ODH 0 classification for 45K cooldown mode and 4.5K Normal operational mode and room temperature scrub.
- The auxiliary buildings require credited controls of ODH sensing & Ventilation to get ODH 0 classification for 45K cooldown mode and 4.5K Normal operational mode.
- During Room temperature scrub service buildings and auxiliary buildings falls in category of ODH 0 but O2 concentration is between 16% to 0%.

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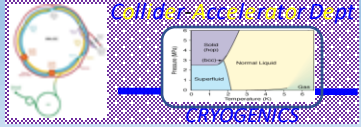
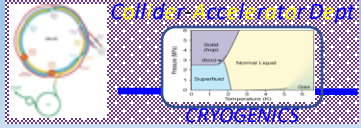


Thank you



Backup slides

The oxygen concentration in the building during a release of a gas is approximated by solving the following differential equations:

$$\frac{dC}{d\tau} = \frac{O_{2\_in} - O_{2\_out}}{V}$$

$$\frac{dC}{d\tau} = \frac{0.21 \cdot Q_{in} - C \cdot Q_{out}}{V} = \frac{0.21 \cdot Q_{in}}{V} - \frac{C \cdot Q_{out}}{V}$$

Where
V = building volume (CF)
C = oxygen concentration (mole fraction)
t = time (minutes)
Q_{out} = the flow rate out of building
Q_{in} = the flow rate into building of fresh air
Q = exhaust fan(s) flow rate (CFM)
R = inert gas spill rate into building (CFM)

When fans are drawing from the volume.
Q_{out} = Q
Q_{in} = Q-R
For the case where R>Q the effective Qin becomes zero and the Qout becomes R
When fans are blowing into the volume.
Q_{in} = Q
Q_{out} = Q+R

Substituting for Qin and Qout using Q and R one can come up with the following equations.

Minimum Oxygen concentration without ventilation
This assumes the air gets displaced by the release gas, with the resulting remaining air mixing with the released gas resulting in the calculated concentration.

$$C_{\min\_no\_ventilation} = 0.21\frac{V - R}{V}$$

CASE 1 Ventilation fan(s) blowing into the confined volume.

$$V\frac{dC}{d\tau} = 0.21Q - (R + Q)C$$

$$C(\tau)_{case\_1} = \frac{0.21}{Q + R}\left[Q + R \cdot e^{\frac{-(Q+R)\tau}{V}}\right]$$

CASE 2 Ventilation fan(s) drawing and the spill rate of inert gas (R) is less than the exhaust fan capacity (Q):

$$V\frac{dC}{dt} = 0.21(Q - R) - QC$$

$$C(\tau)_{case\_2} = 0.21\left[1 - \frac{R}{Q} \cdot \left(1 - e^{\frac{-Q\tau}{V}}\right)\right]$$

CASE 3 If the exhaust fan is off or if the inert gas spill rate (R) is greater than the exhaust fan capacity (Q)

$$V\frac{dC}{dt} = -RC$$

$$C(\tau)_{case\ 2} = 0.21 \cdot e^{\frac{-R\tau}{V}}$$

Isentropic

DIM involves evaluating thermodynamic properties of the relieving stream at a number of state points and then numerically integrating the nozzle equation to determine the maximum mass flux

$$G^2 = -2\rho_t^2 \int_{p_0}^{p} v\, dp$$

$$\int_{p_i}^{p_{i+1}} v\, dp = \frac{(v_{i+1} + v_i)}{2} * (p_{i+1} - p_i)$$

Auxiliary Buildings

Auxiliary Buildings with 1 ODH fan								
Location	Volume	Equipment	Net Free Volume	Fan SCFM	Release Flow SCFM	O2 Concentration	Fatality rate 1/hr	ODH class
1004E	3000	20	2980	3000	128	9.0%	1.0E-8	0
1002A	22500	--	22500	3000	230	16.9%	9.0E-12	0
1010Mez	10500	1200	9300	--	128	0%	2.0E-8	0

Auxiliary Buildings							
Location	Volume	Equipment	Net Free Volume	Failure rate 1/hr	O2 Concentration	Fatality rate 1/hr	ODH class
1004E	3000	20	2980	1.3E-8	0%		0
1002A	22500	--	22500	3E-8	0%		0
1010Mez	10500	1200	9300	2E-8	0%		0