ODH Analysis for Service and Auxiliary Buildings

RHIC Recovery review

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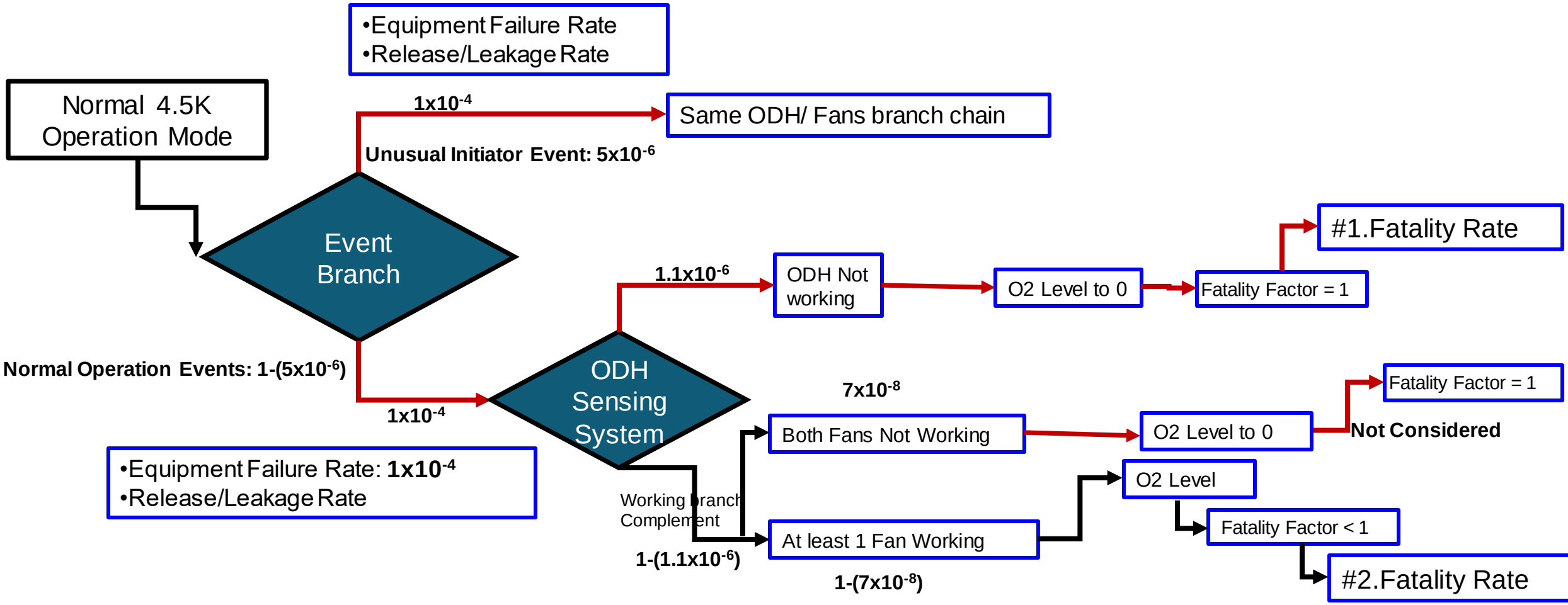
Outline

- 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

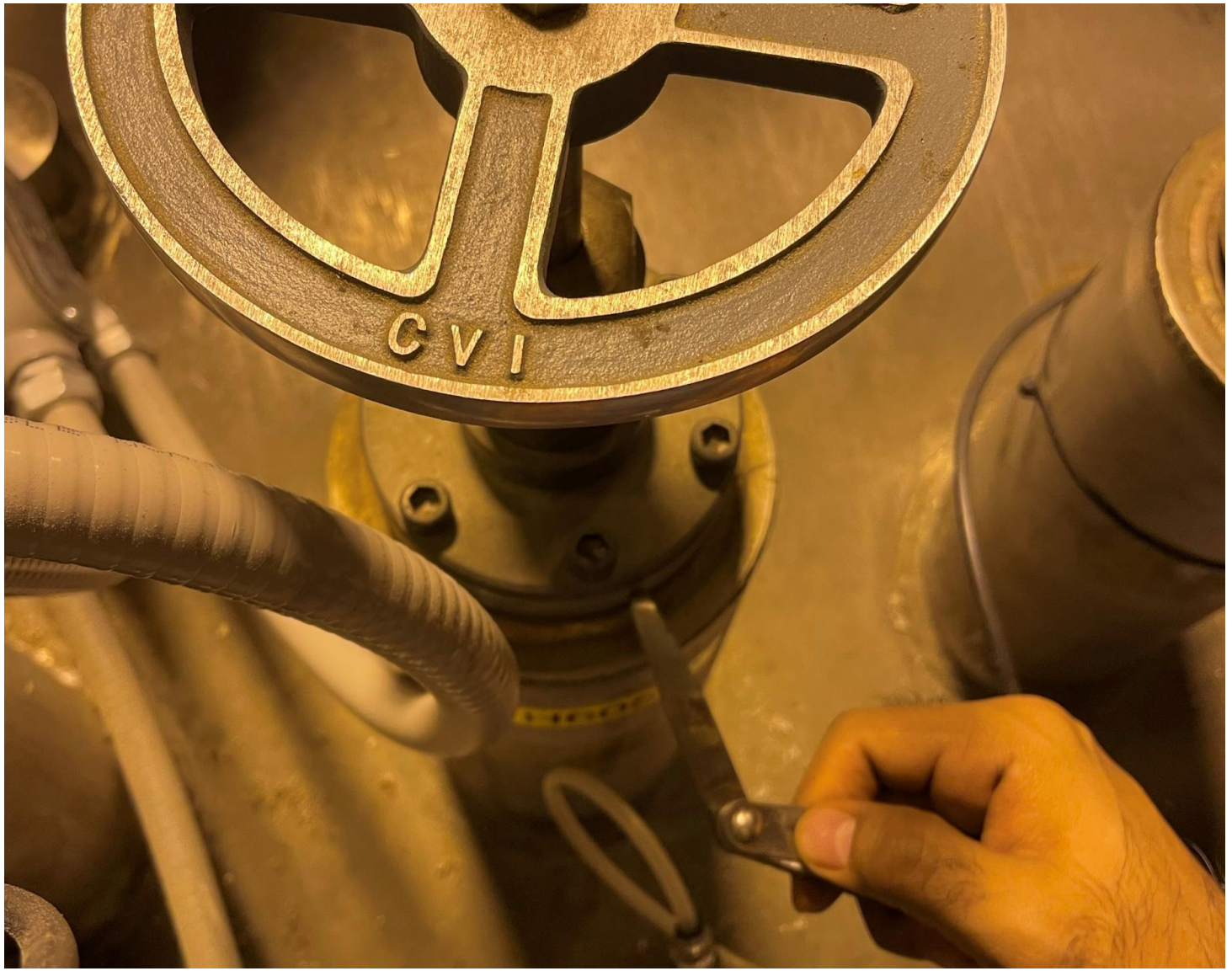
Analysis Methodology

Probability Tree



Calculation Inputs

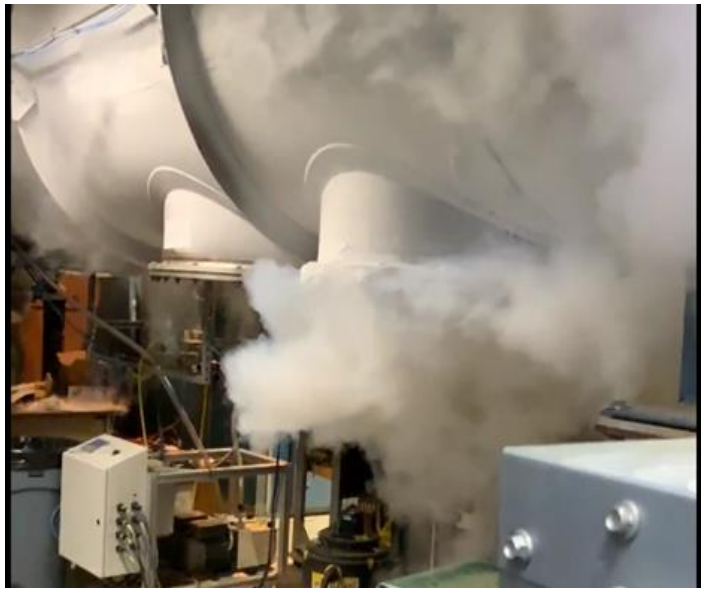
Valve Stem & Valve bonnet



Leakage during 1004B valve box event

- 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



Valve box Components: Type & Quantities

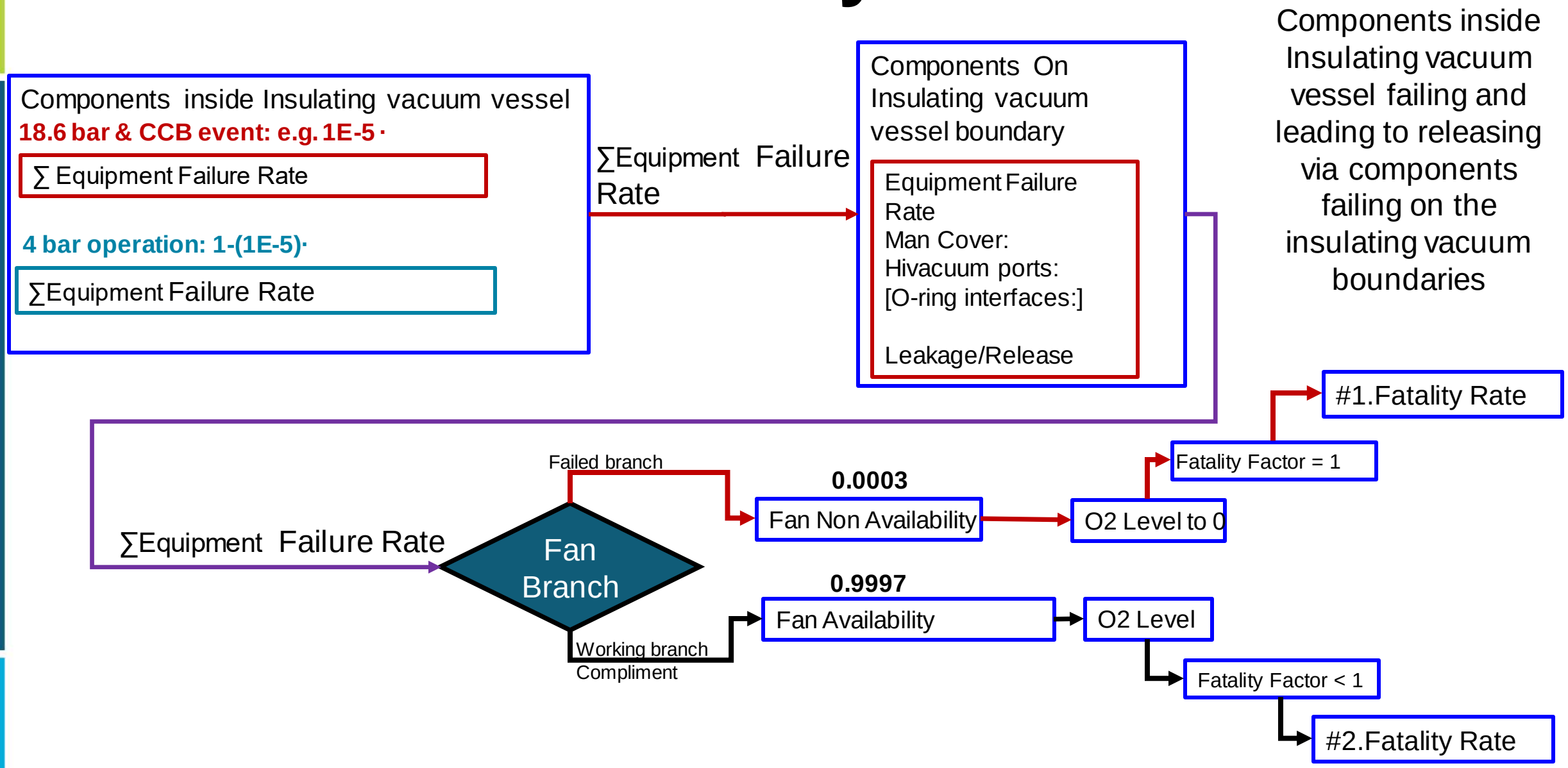
	6:00	6:00	4:00	4:00	2:00	2:00	12:00	12:00	10:00	10:00	8:00	8:00
	Blue	Yel	Blue	Yel	Blue	Yel	Blue	Yel	Blue	Yel	Blue	Yel
	VB	VB	VB	VB	VB	VB	VB	VB	VB	VB	VB	VB
Valves total	41	41	18	18	18	18	23	23	18	18	18	18
Valves M-Line	10	10	2	2	2	2	2	2	2	2	2	2
Valves S-Line	11	11	6	6	6	6	8	8	6	6	6	6
Valves H-Line	7	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

Normal event and unusual events leak rates

			Molar Flow Release Rate	
Line	**Components**	**Leak Area Inch²**	**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

Normal operation/Unusual Events Initiator

Probability Tree



Results

4.5K case, Fatality rate without ODH Fan

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

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

Building	Gross [Feet^3]	Equipment [Feet^3]	Net [Feet^3]	ODH capacity for 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

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

For 45K Cooldown mode without ODH fan

Building	Gross [Feet3]	Equipment [Feet3]	Net [Feet3]	Min O2 level	Fatality rate	ODH class
1004B	86433	13309	73124	1.5%	6.34E-04	2
1006B	71176	2280	68896	1.2%	8.81E-04	2
1008B	57843	3345	54498	0.6%	5.75E-04	2
1010A	85877	4885	80991	1.9%	6.57E-04	2
1012A	86128	2614	83514	2.0%	6.47E-04	2
1002B	74362	3310	71052	1.4%	5.75E-04	2
Auxiliary Buildings for largest leak						
1004E	3000	20	2980	0%	1.3E-8	0
1010Mez	10500	1200	9300	0%	2.0E-8	0

For 270K scrub mode without ODH fan

Building	Gross [Feet^3]	Equipment [Feet^3]	Net [Feet^3]	Min O2 level	Fatality rate	ODH class
1004B	86433	13309	73124	15.0%	6.0E-10	0
1006B	71176	2280	68896	14.7%	1.4E-09	0
1008B	57843	3345	54498	13.4%	9.4E-09	0
1010A	85877	4885	80991	15.5%	2.6E-10	0
1012A	86128	2614	83514	15.7%	2.0E-10	0
1002B	74362	3310	71052	14.9%	7.1E-10	0
Auxiliary Buildings for largest leak						
1004E	3000	20	2980	0.0%	1.3E-8	0
1010Mez	10500	1200	9300	1.6%	2E-8	0

Conclusion

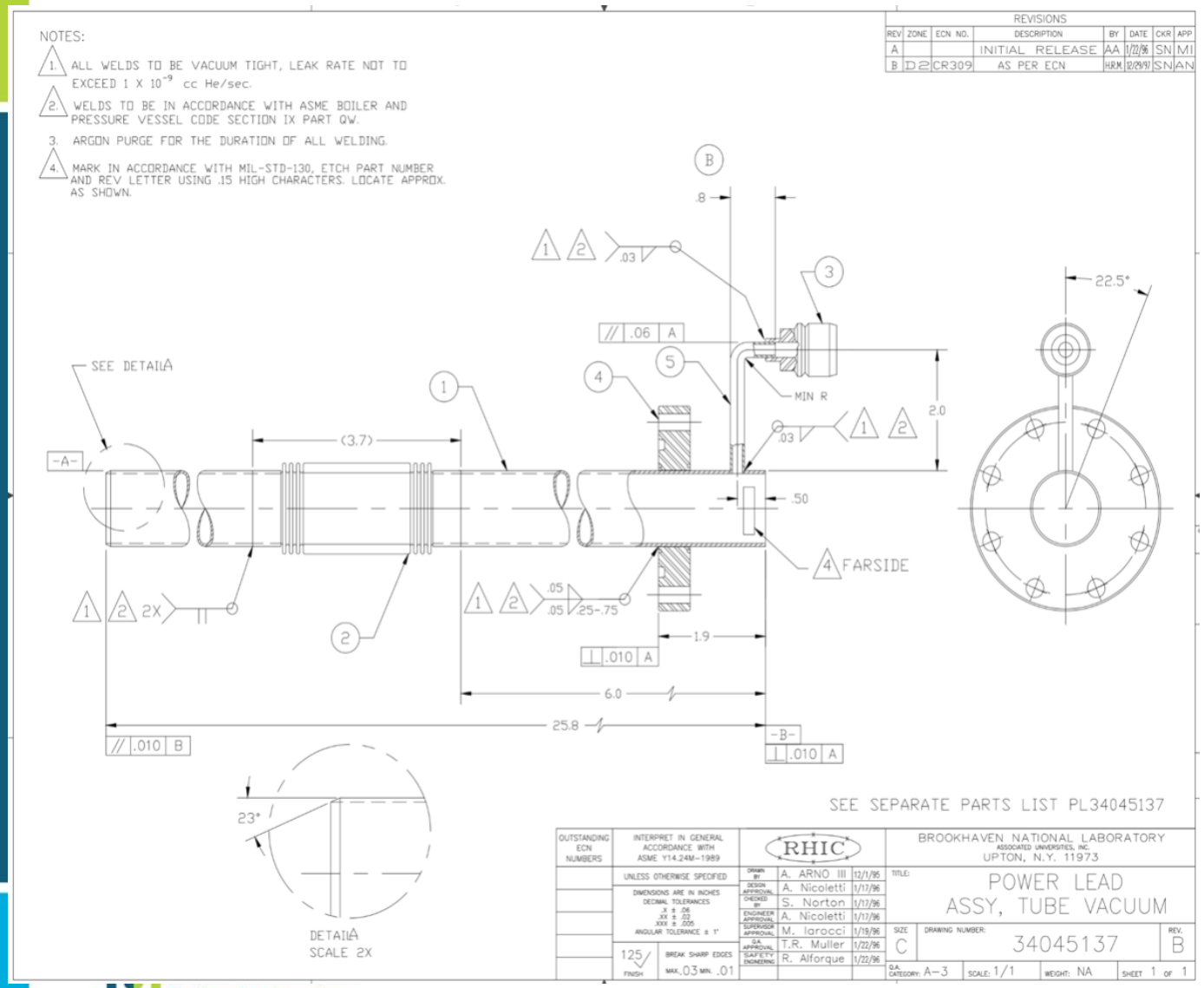
Conclusion

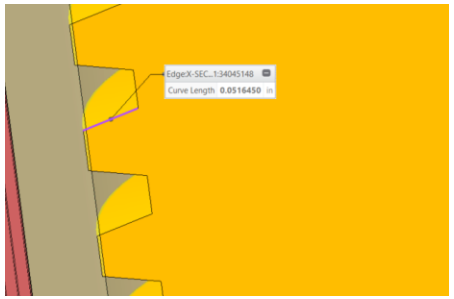
- ODH evaluation has been re-done for the Service Buildings
- The service buildings require credited controls of ODH sensing & ventilation to get ODH 0 classification for 4.5K normal operational mode and 45K cooldown mode.
- During room temperature scrub service buildings falls in category of ODH 0 but O2 concentration is between 13% to 16% without any ODH fan hence do not require credited controls of ODH system.
- The auxiliary buildings are in ODH 0 classification for 4.5K normal operational mode, 45K cooldown mode and room temperature scrub but O2 concentration can fall to 0%.
- During room temperature scrub auxiliary buildings falls in category of ODH 0 but O2 concentration is between 2% to 0%.

Thank you

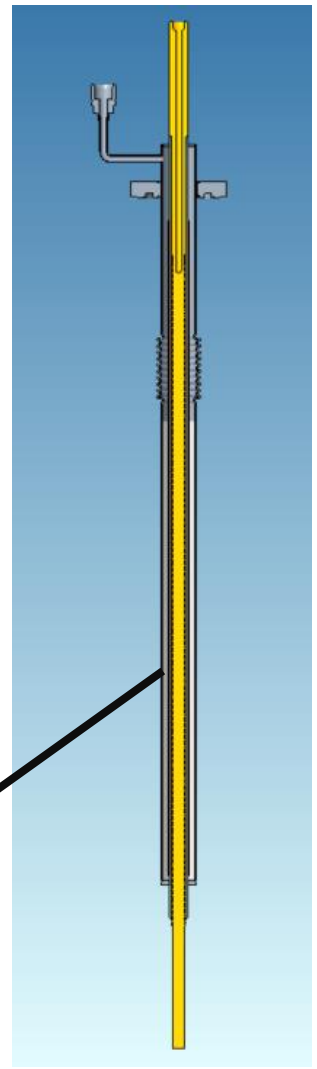
Backup Slides

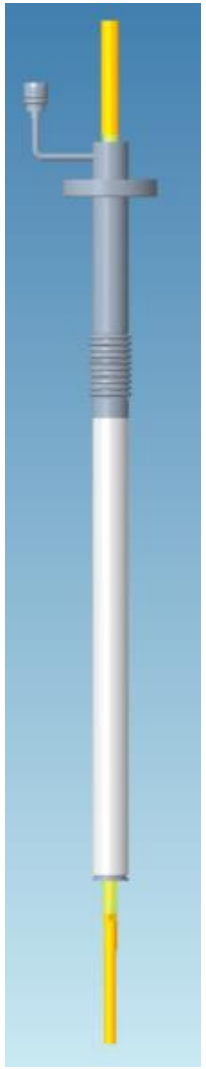
1600 Amp Current Lead





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





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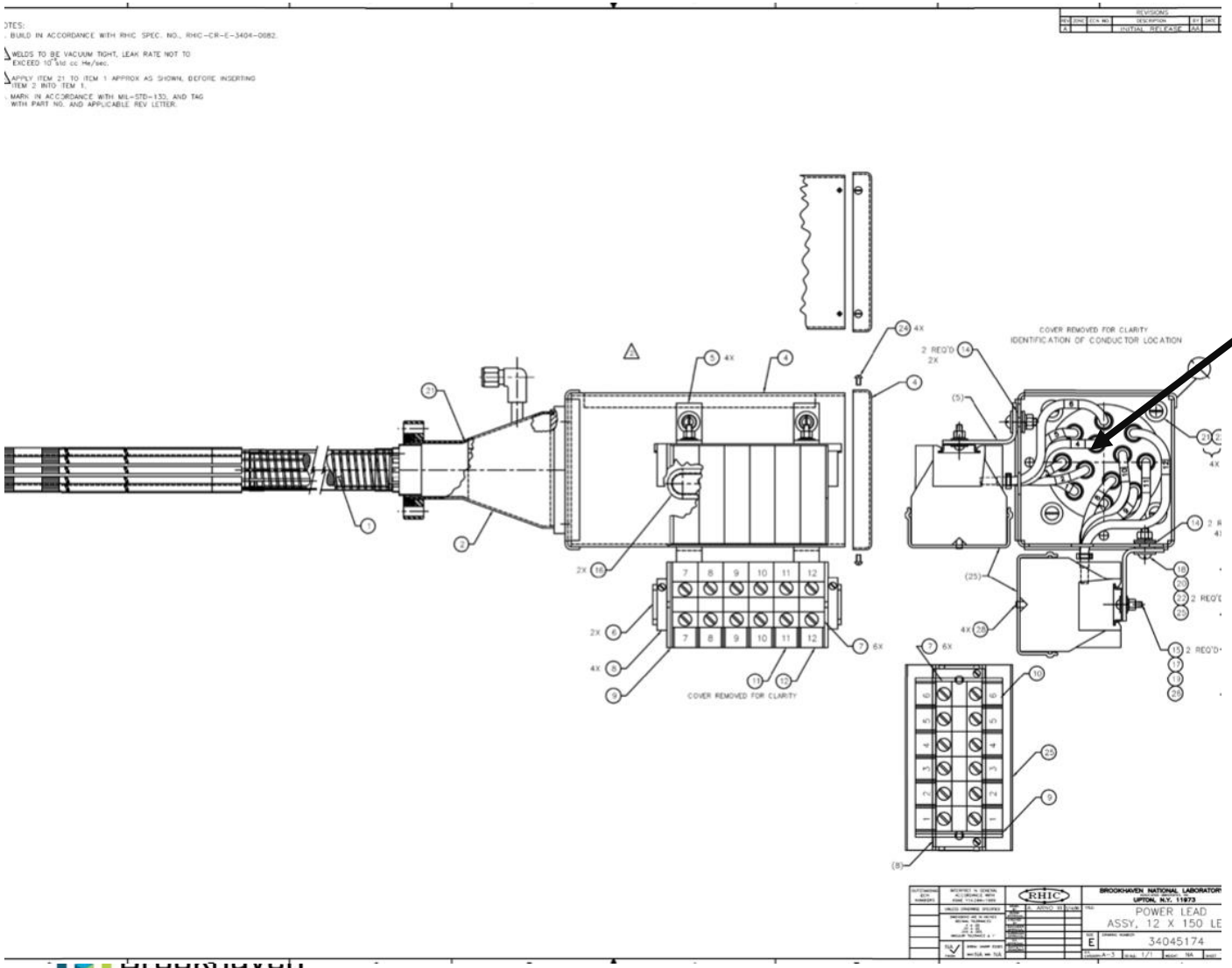
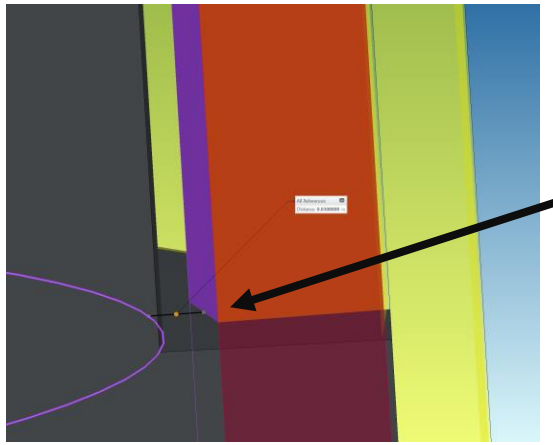
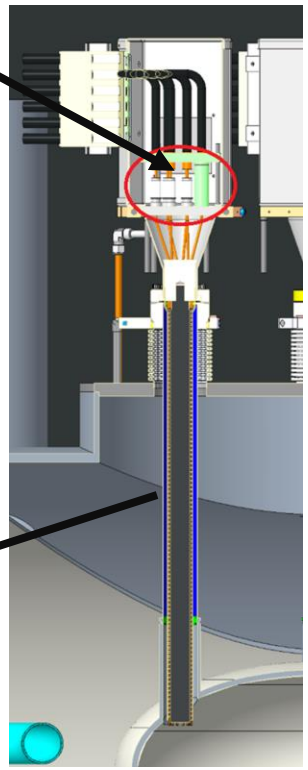
150 Amp Current Lead



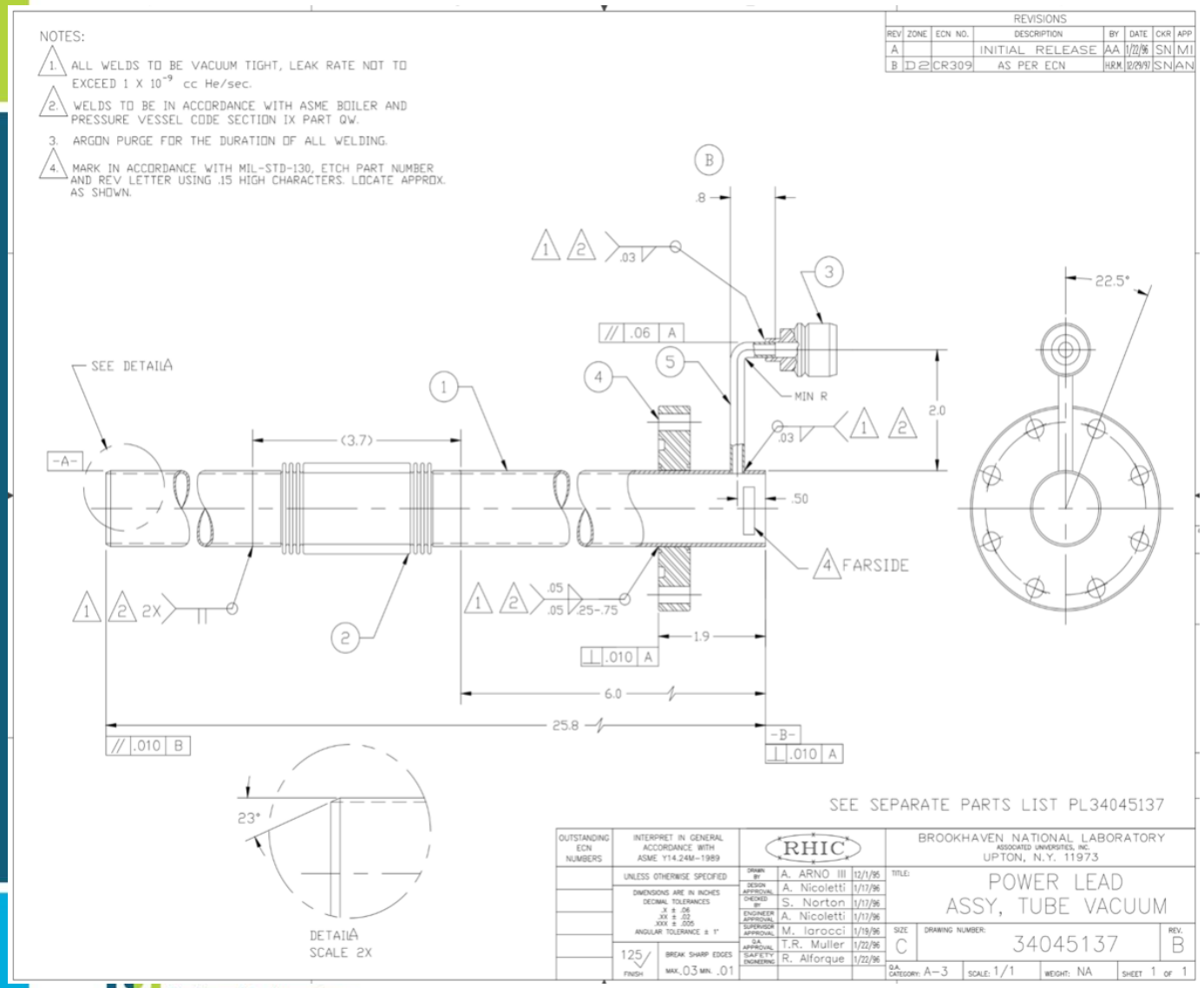
Leak through ceramic break will see same amount of He flow as the Spiral Leak since they share the same flow path.



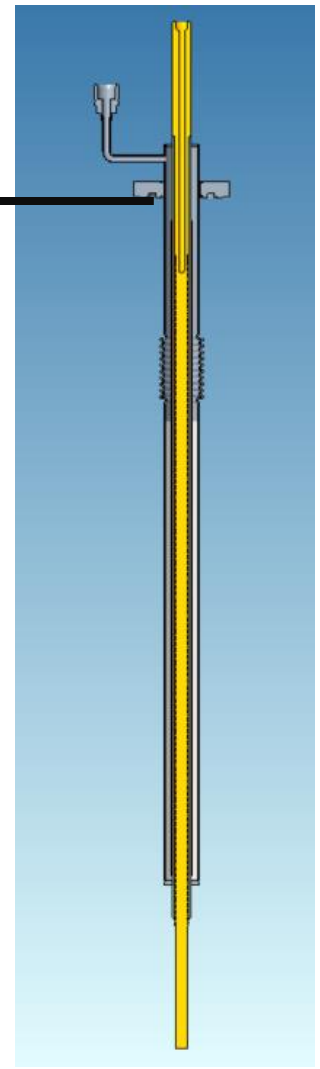


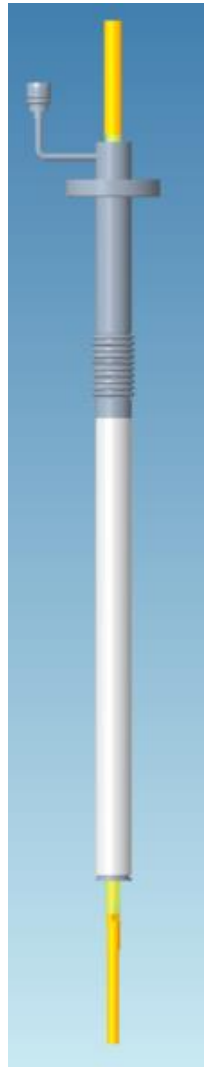
Spiral Leak
Cross Sectional Area:
0.035”x0.19” = 0.00665in^2

1600 Amp Current Lead



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





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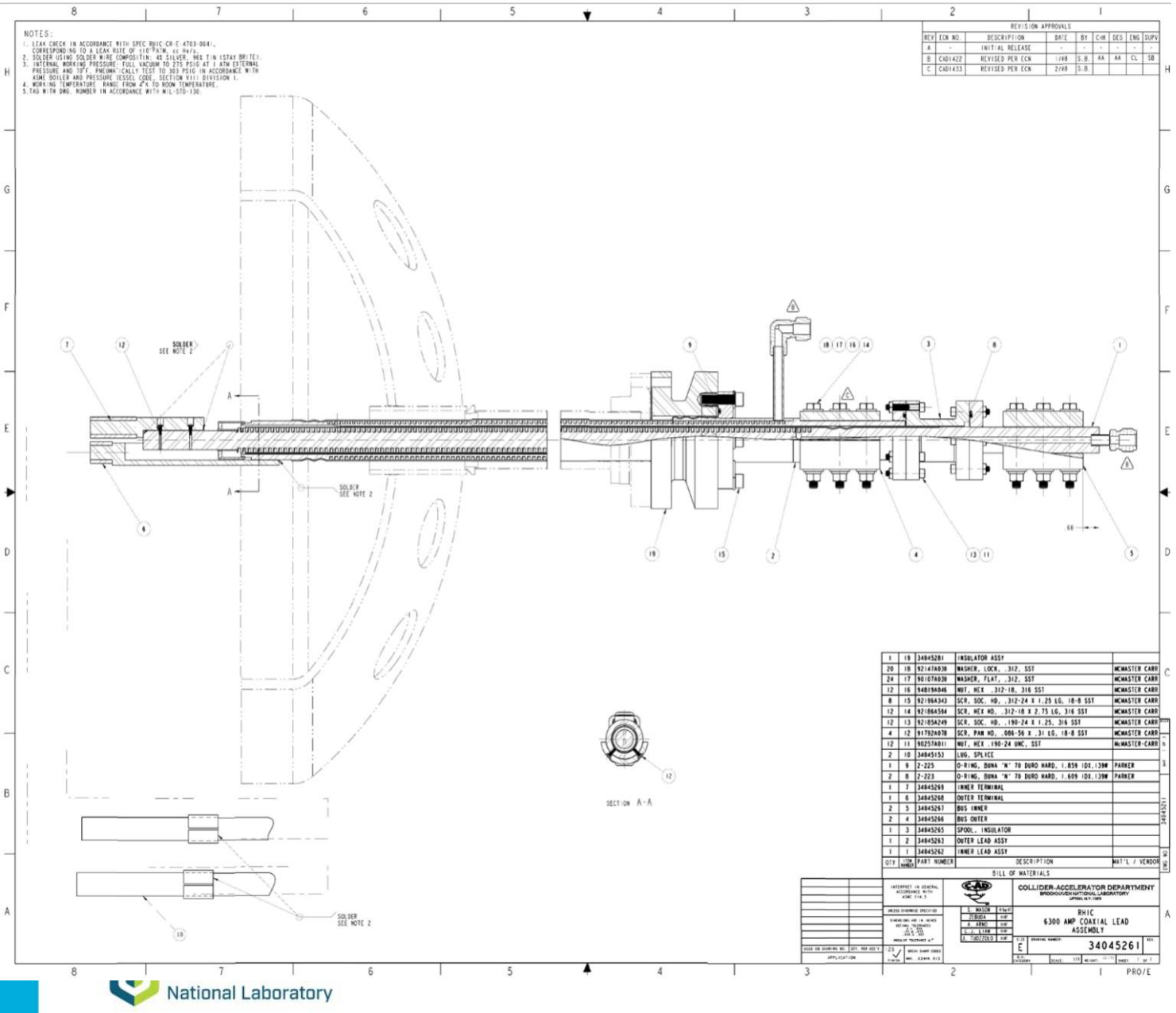
6300 Amp Current

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

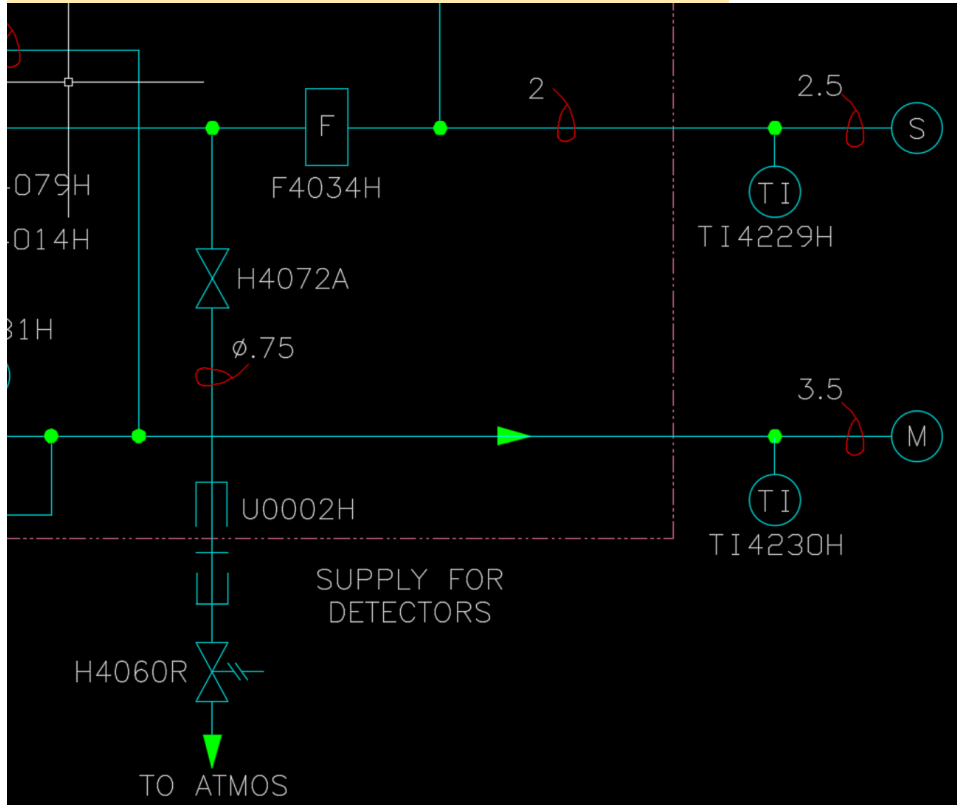
Bayonet, Capped {S-Line}

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

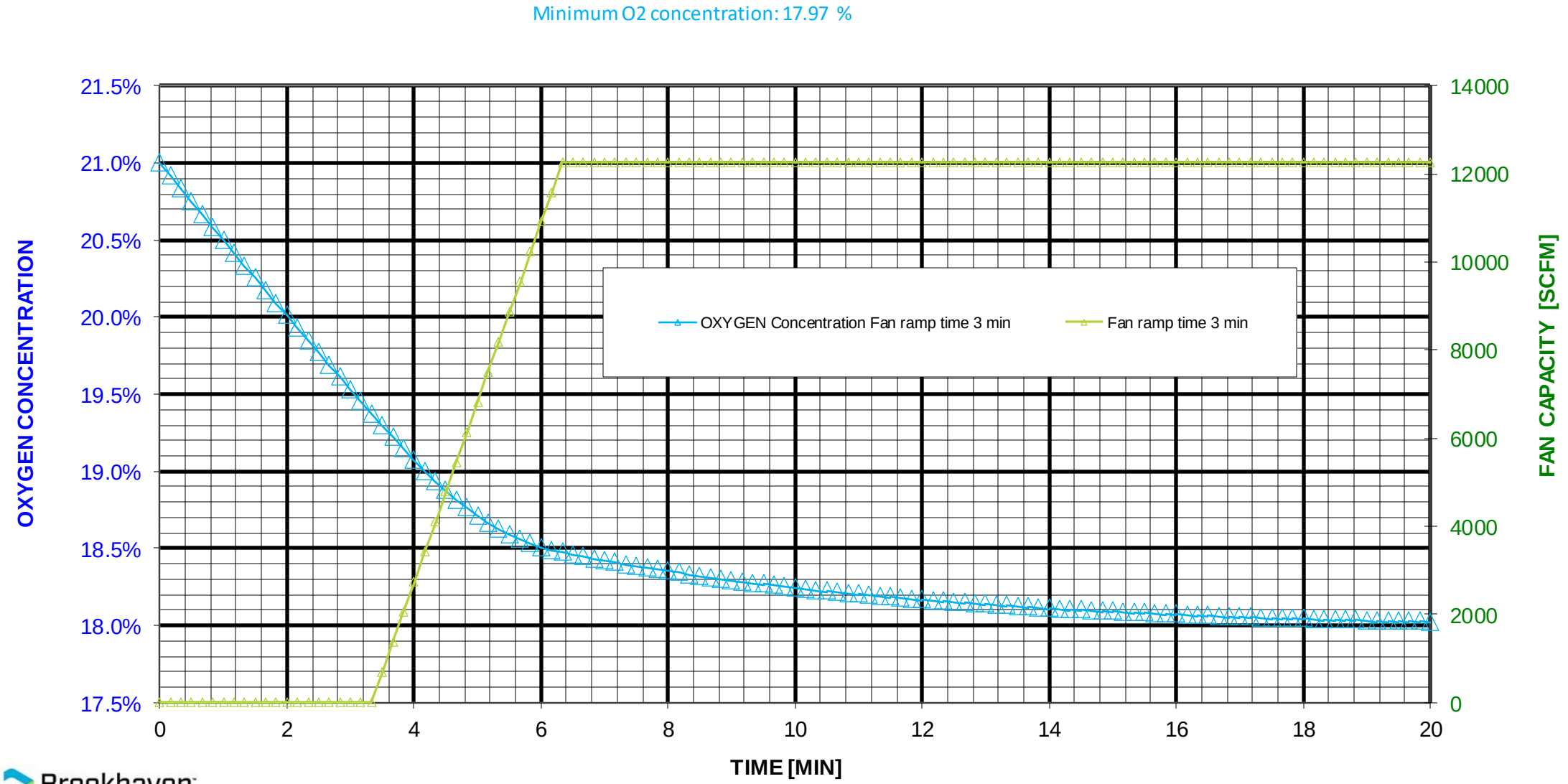


Flanges
{Relief pipe}

Dia 2.1" Gap 0.002"

Relef Area 0.0132 Inch^2

1004B transient for 1 ODH fan



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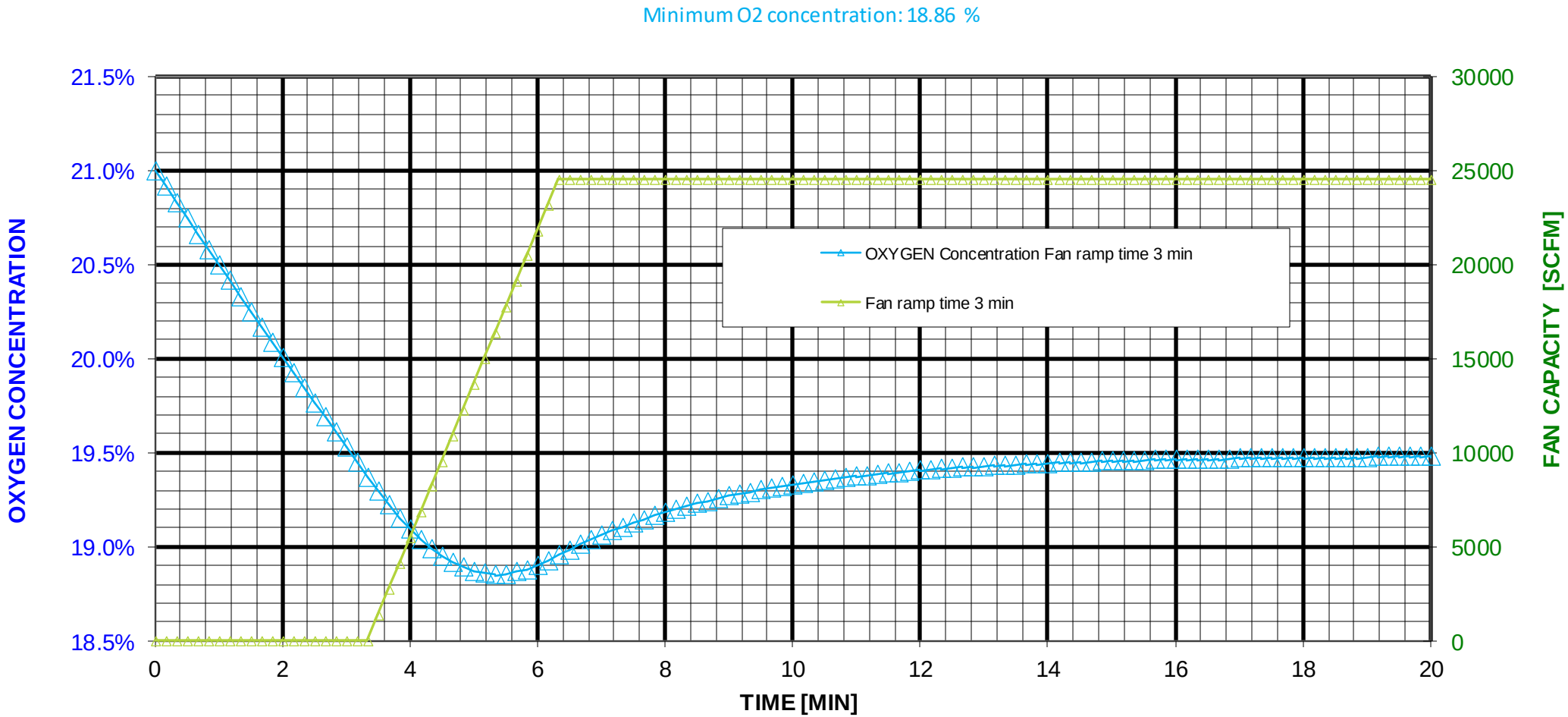
1004B transient for 2 ODH fan



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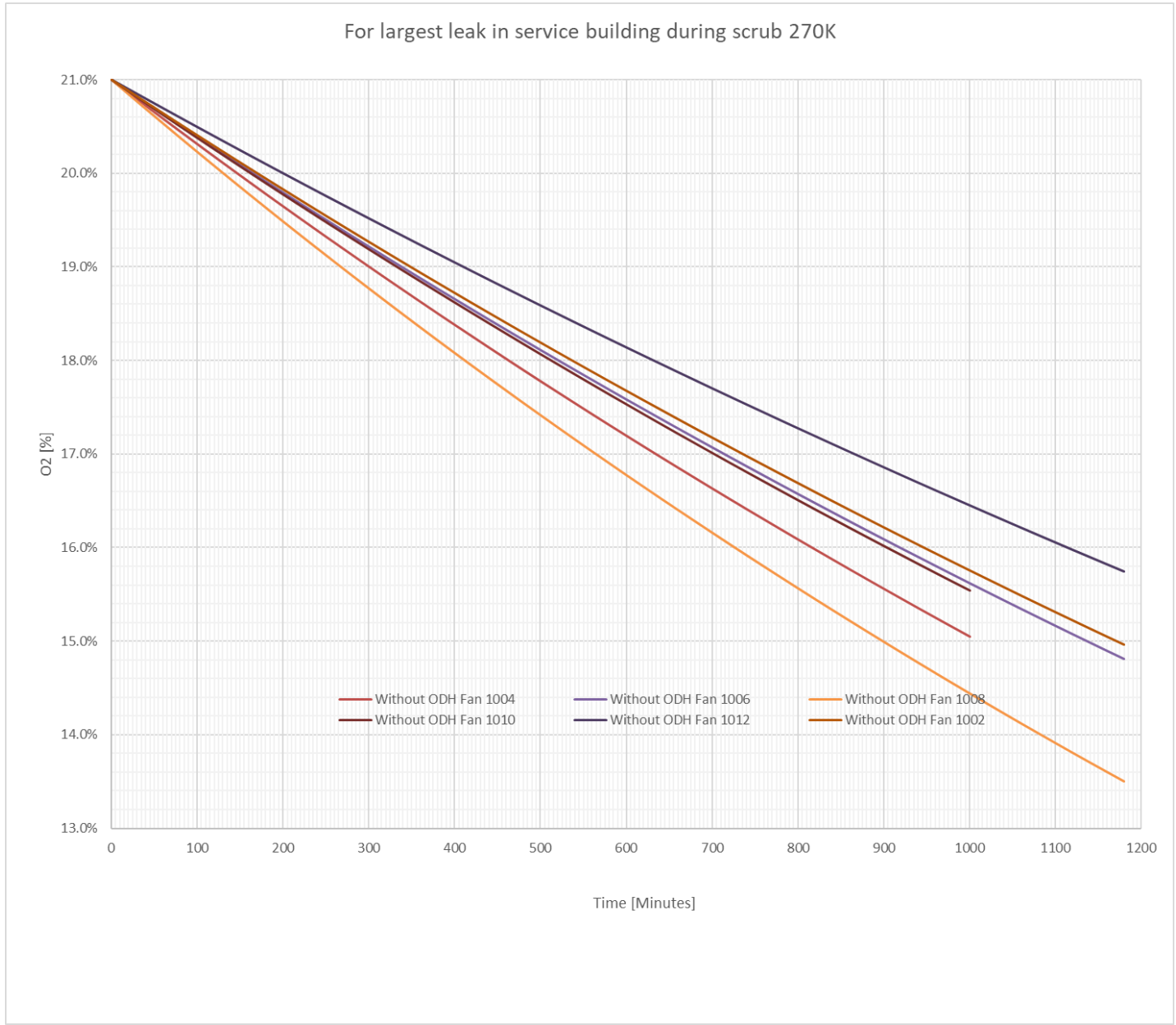
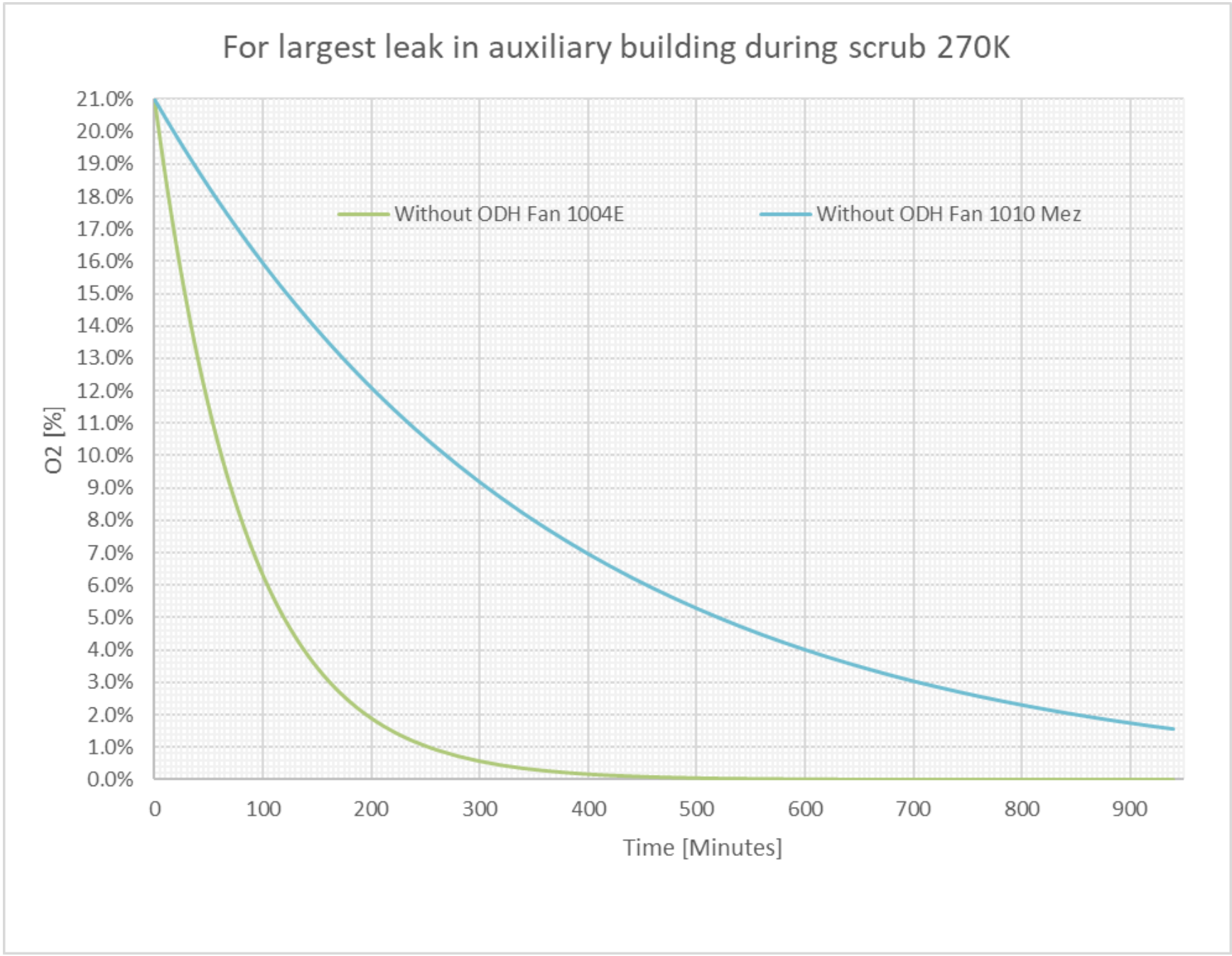
For 270K scrub mode without ODH fan

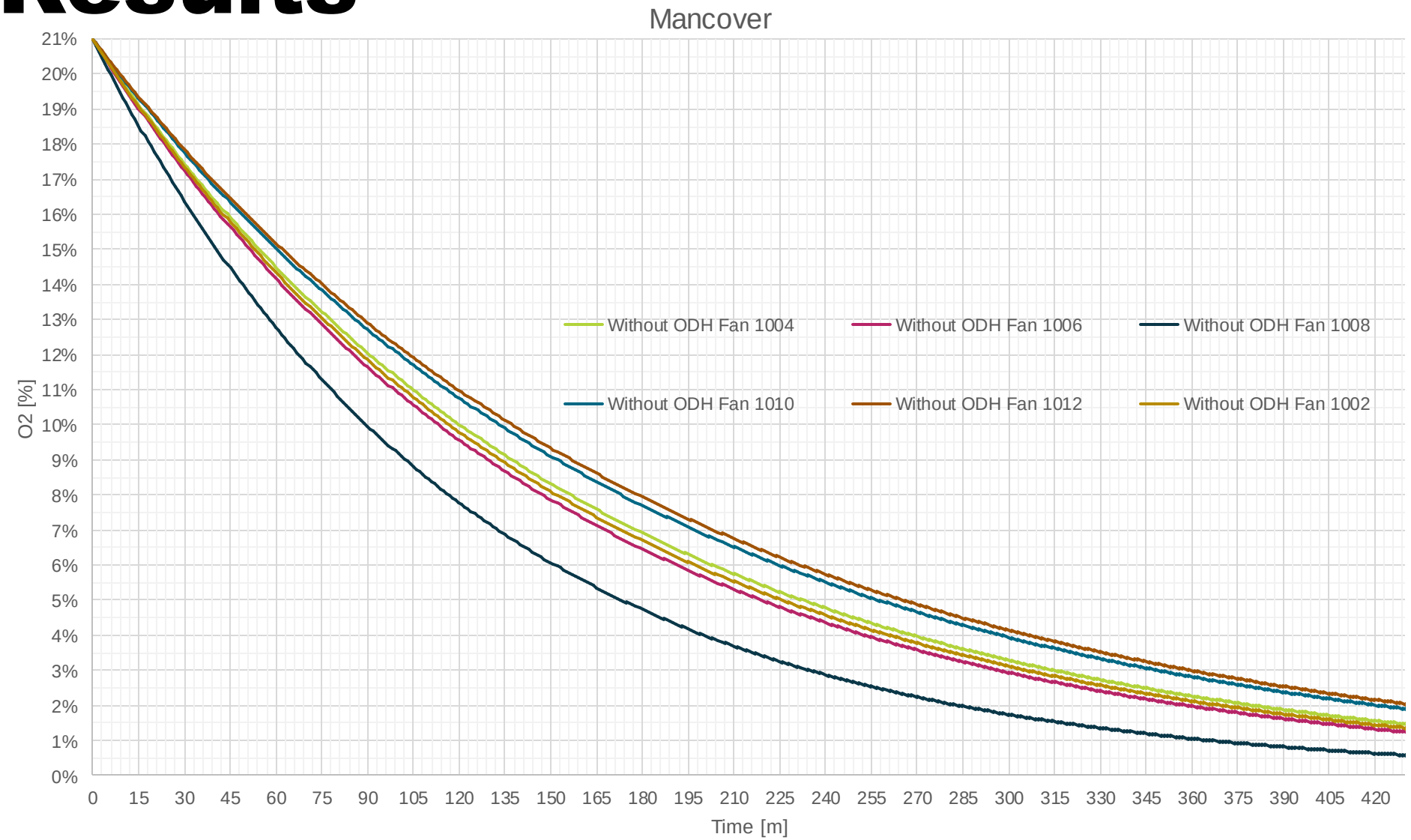


Maximum leak rate is 24.4 SCFM
Total inventory 24,394 CF.

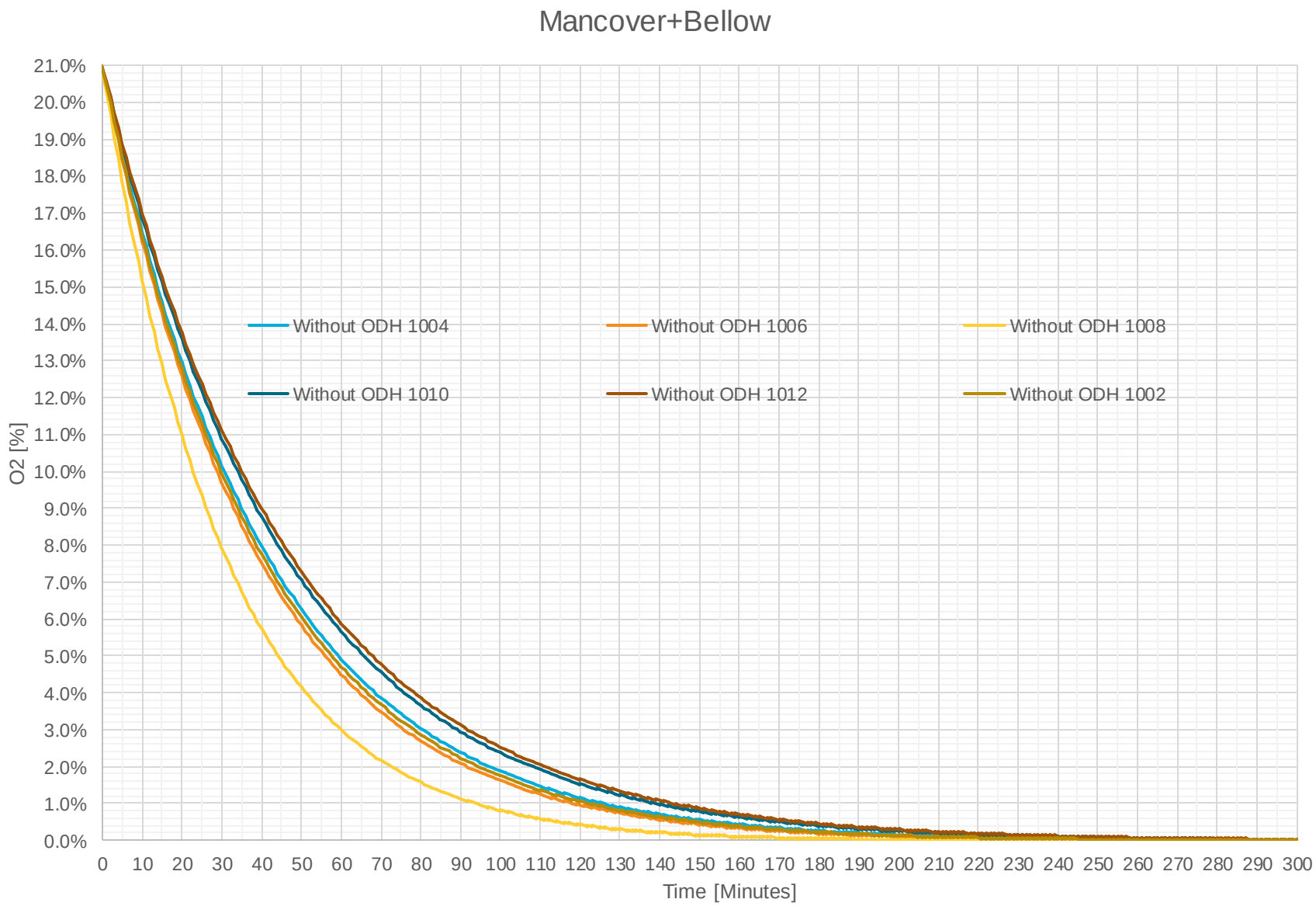


Maximum leak rate is 25.6 SCFM
Total inventory 24,394 CF

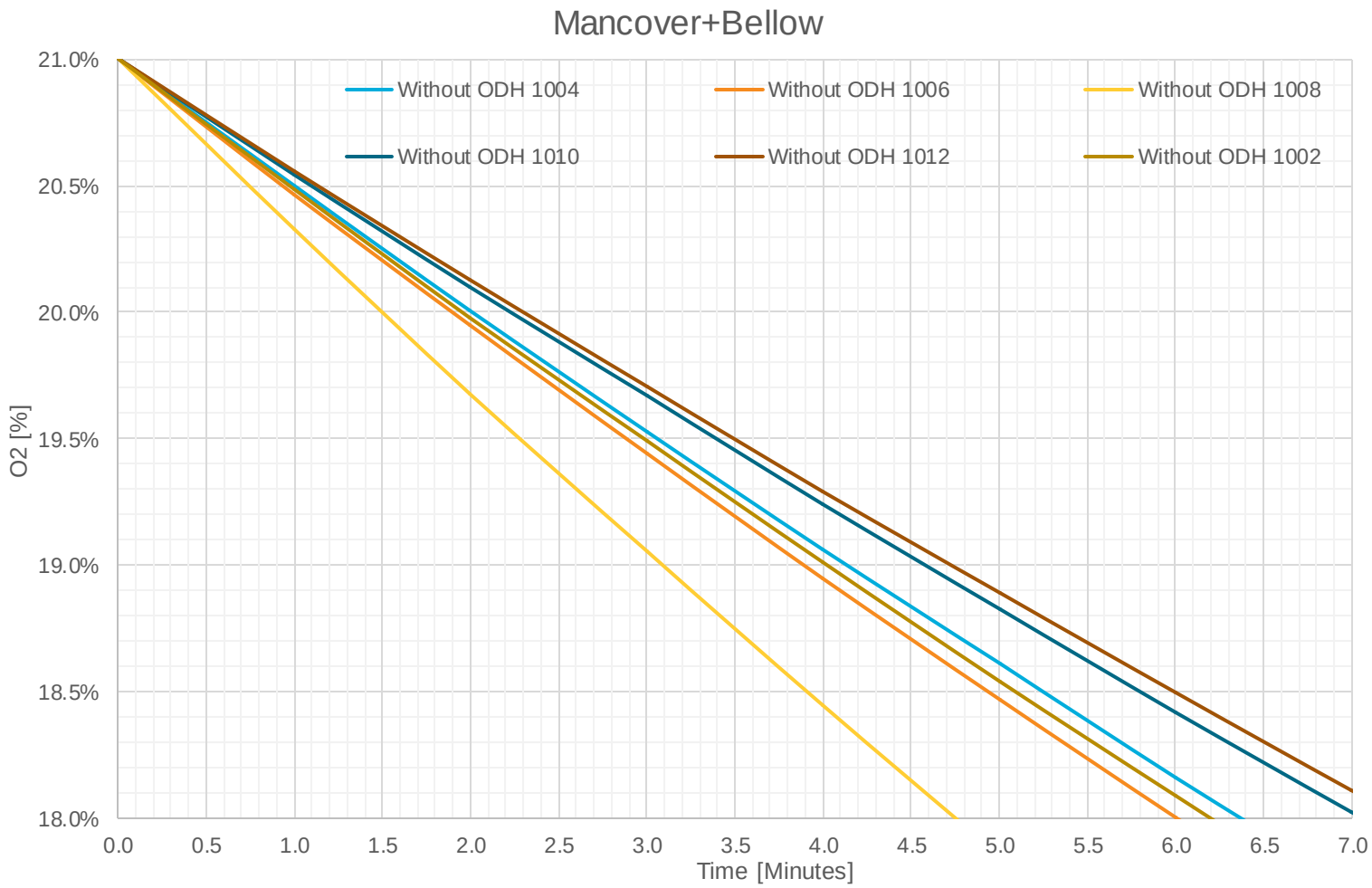
45 K cooldown mode ODH Results



O2 concentration without ODH fan



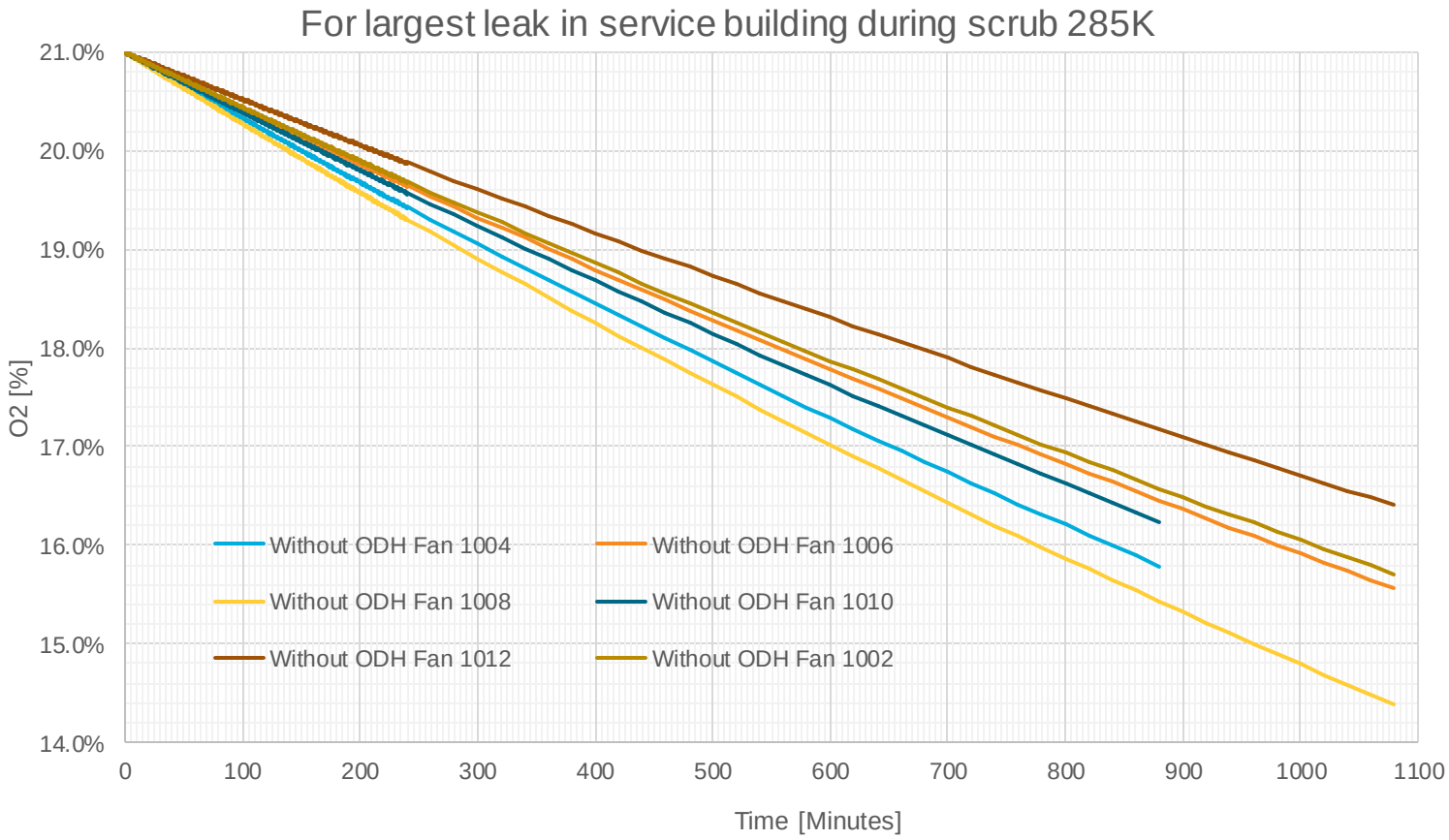
O2 concentration without ODH fan



For 285K scrub mode without ODH fan

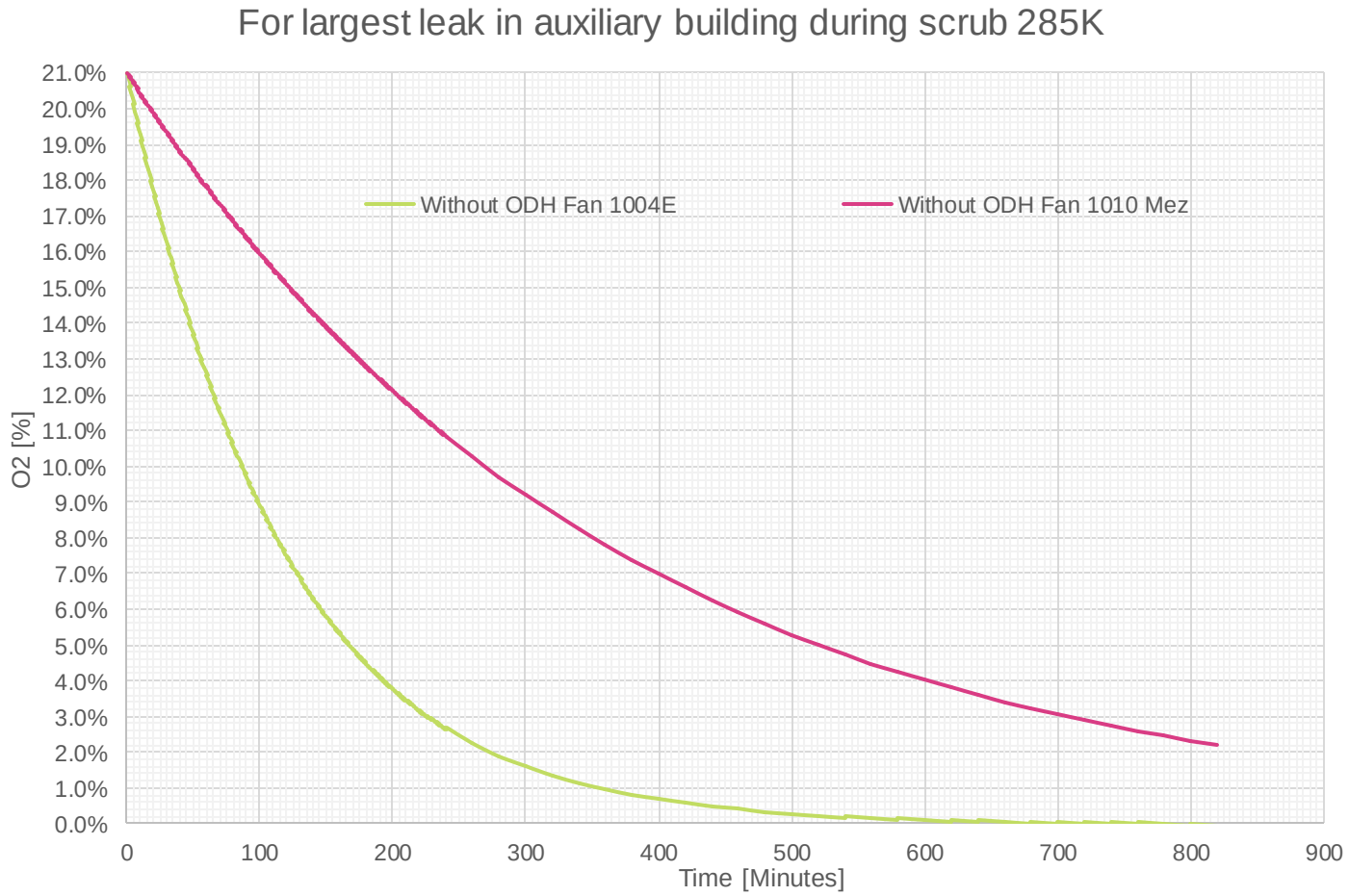
Building	Gross [Feet^3]	Equipment [Feet^3]	Net [Feet^3]	Min O2 level	Fatality rate	ODH class
1004B	86433	13309	73124	15.0%	1.7E-10	0
1006B	71176	2280	68896	15.3%	3.9E-10	0
1008B	57843	3345	54498	14.1%	2.1E-09	0
1010A	85877	4885	80991	16.1%	8.1E-11	0
1012A	86128	2614	83514	16.2%	6.5E-11	0
1002B	74362	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 without ODH fan



Maximum leak rate is 23.7 SCFM
Total inventory 21,000 CF.

For Auxiliary building without ODH fan



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

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

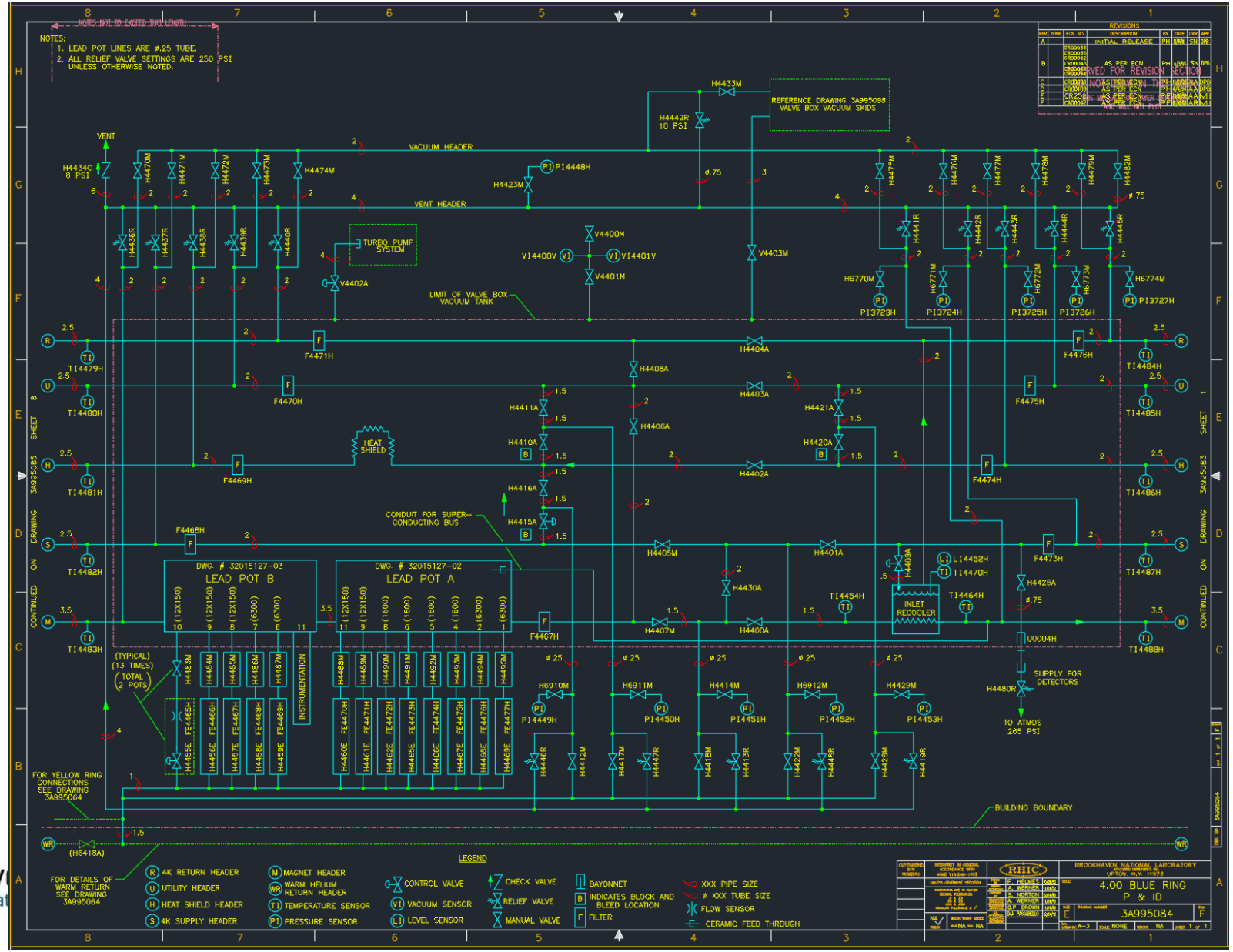
Helium Inventory in RHIC

Mode	Magnet Circuit [SCF]	R, U, S, H [SCF]	1-Ring [SCF]	2-Rings [SCF]	Plant [SCF]	Total [SCF]
Scrub	525	385	5,463	10,927	13,467	24,394
45K Wave	9,844	7,219	102,381	204,763	54,615	259,378
4.5K Mode	302,717	55,498	2,149,294	4,298,588	286,381	4,584,969
Warmup Drift 45K	756	555	7,866	15,732	0	15,732

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

1004B – Blue Valve Box P&ID



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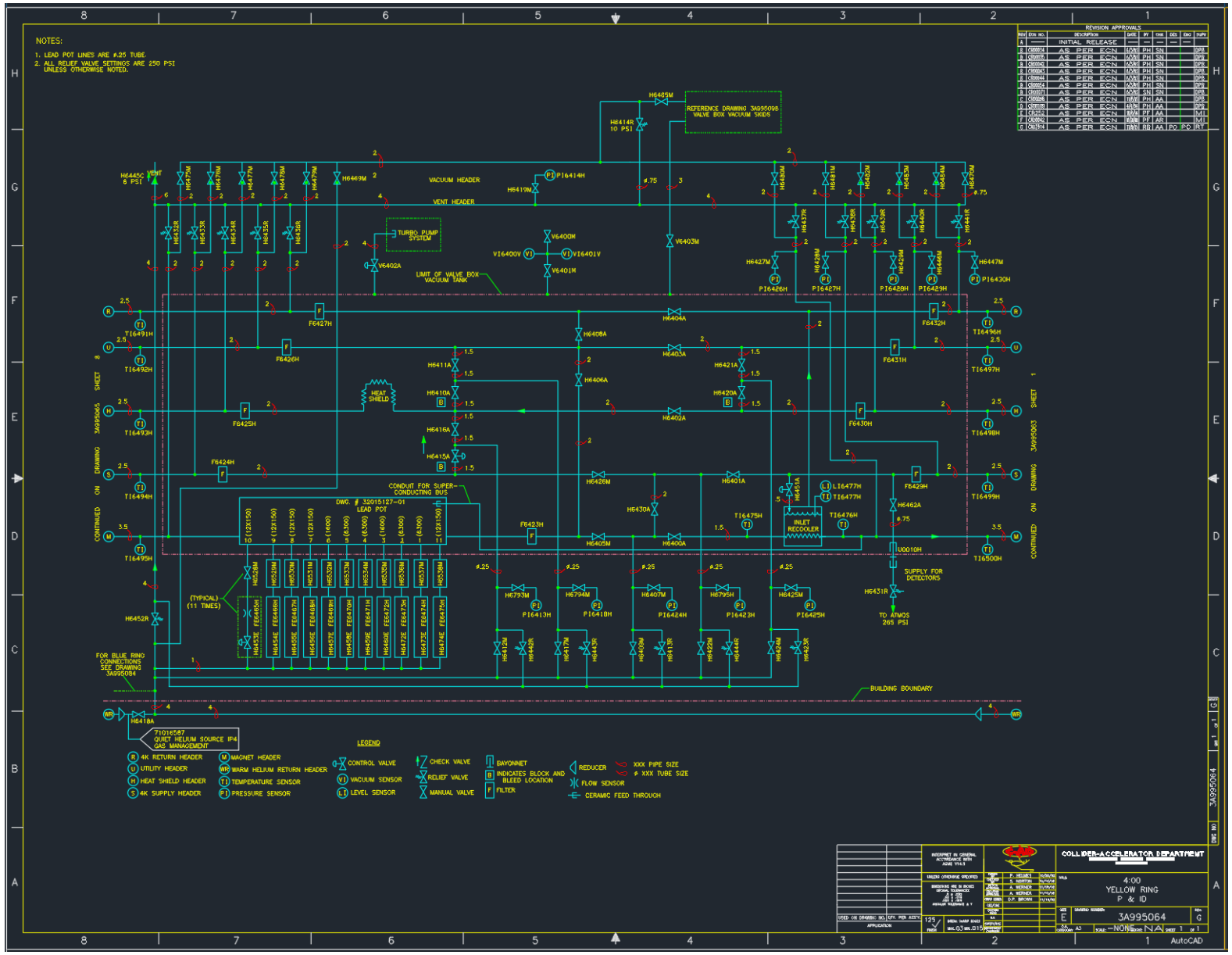
1004B – Yellow Valve Box P&ID



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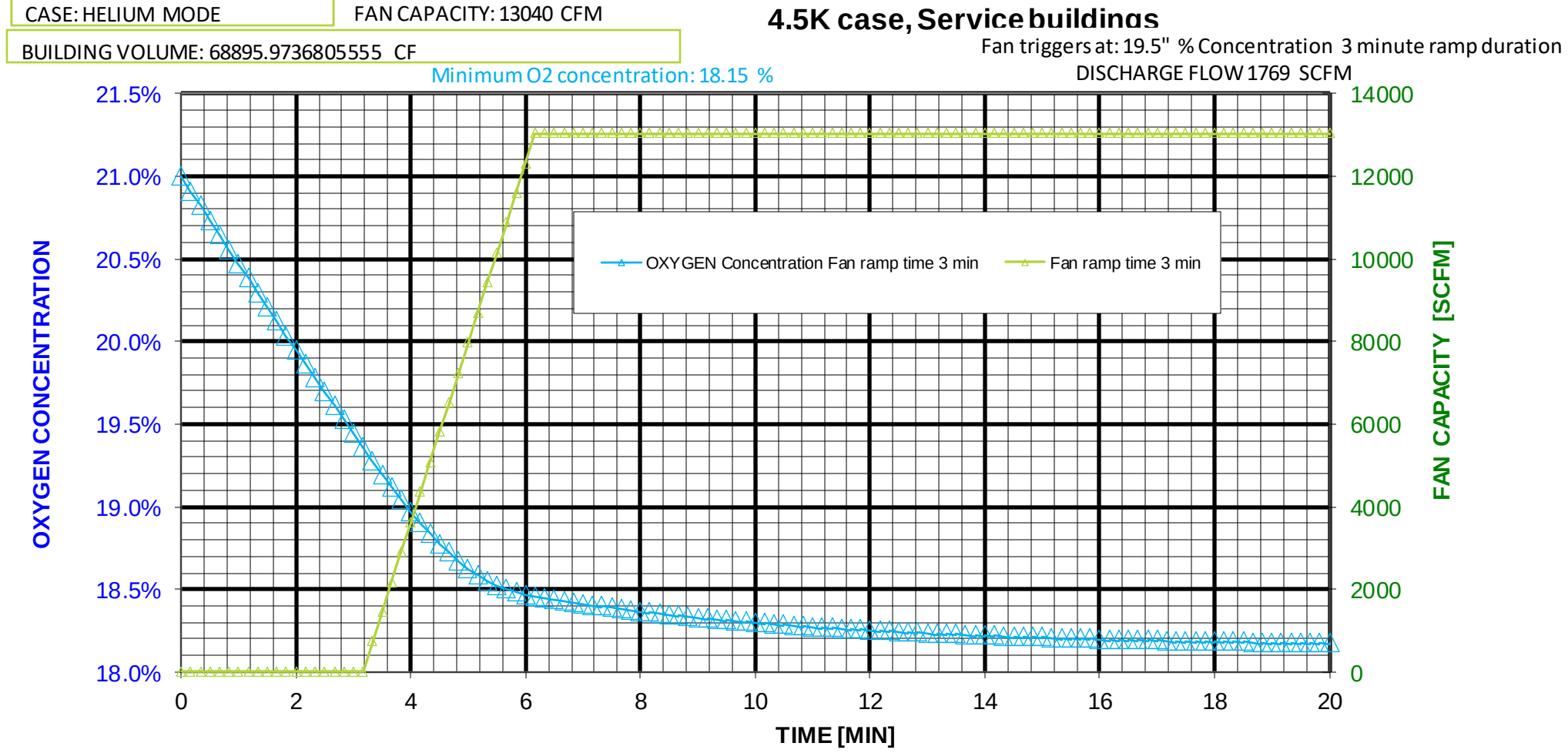
1006B transient for 1 ODH fan

CASE: HELIUM MODE

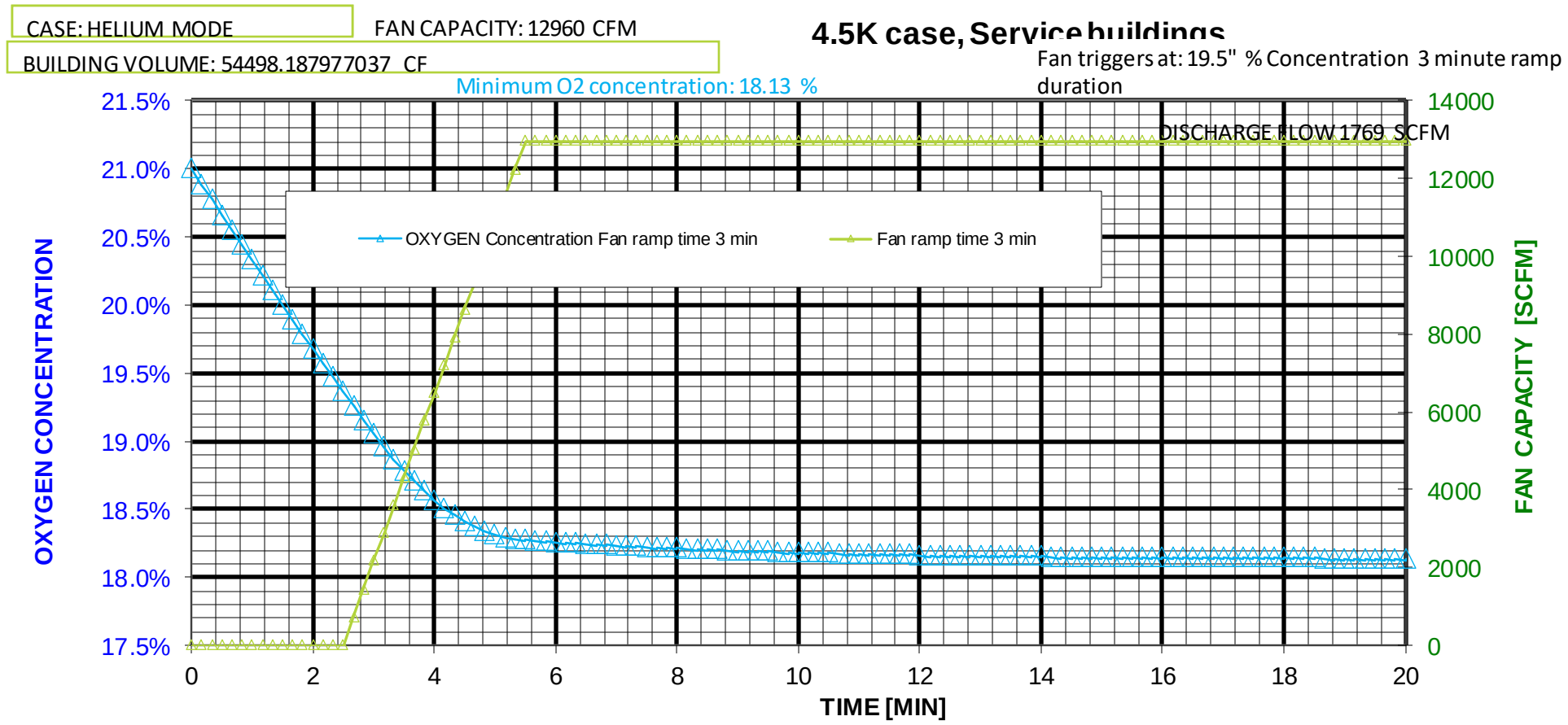
FAN CAPACITY: 13040 CFM

BUILDING VOLUME: 68895.9736805555 CF



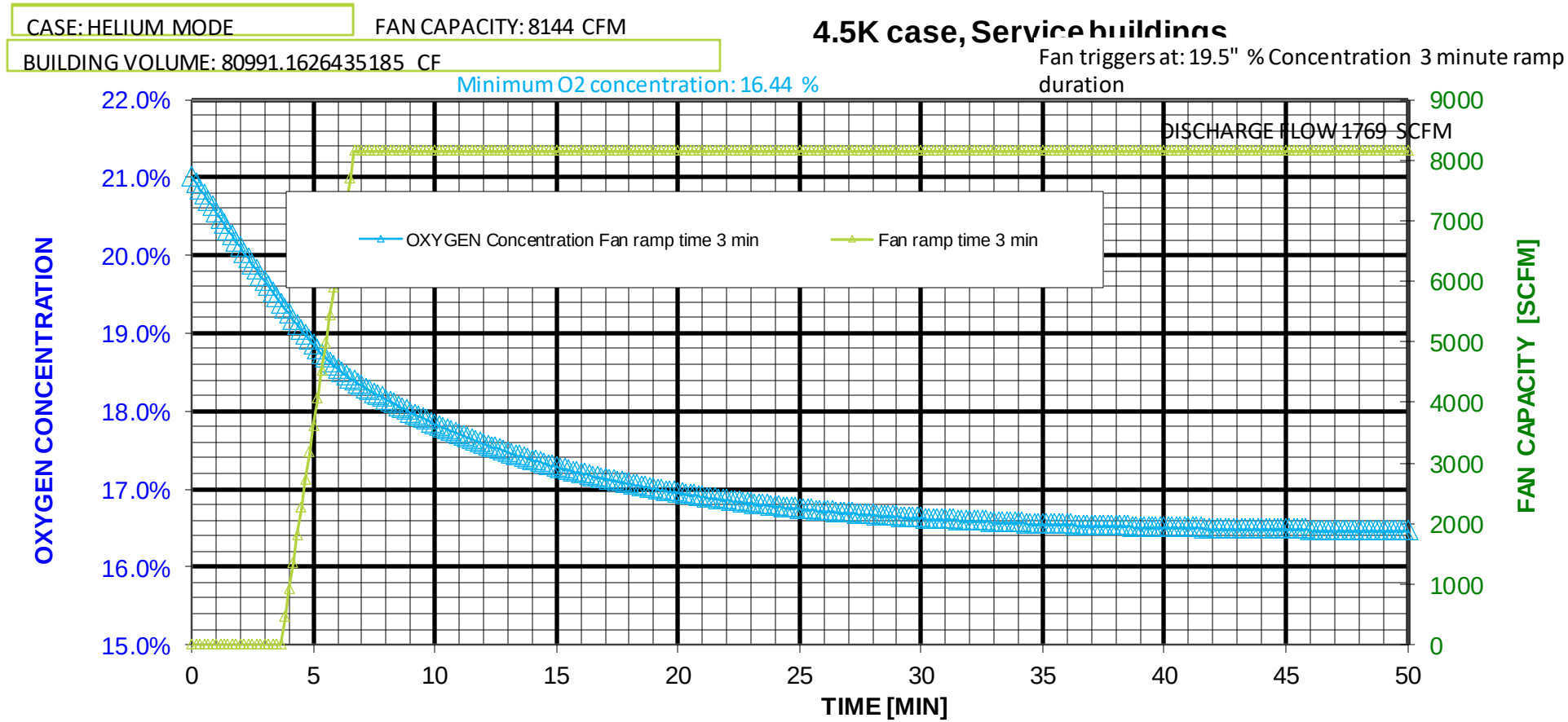
Brookhaven National Laboratory

1008B transient for 1 ODH fan



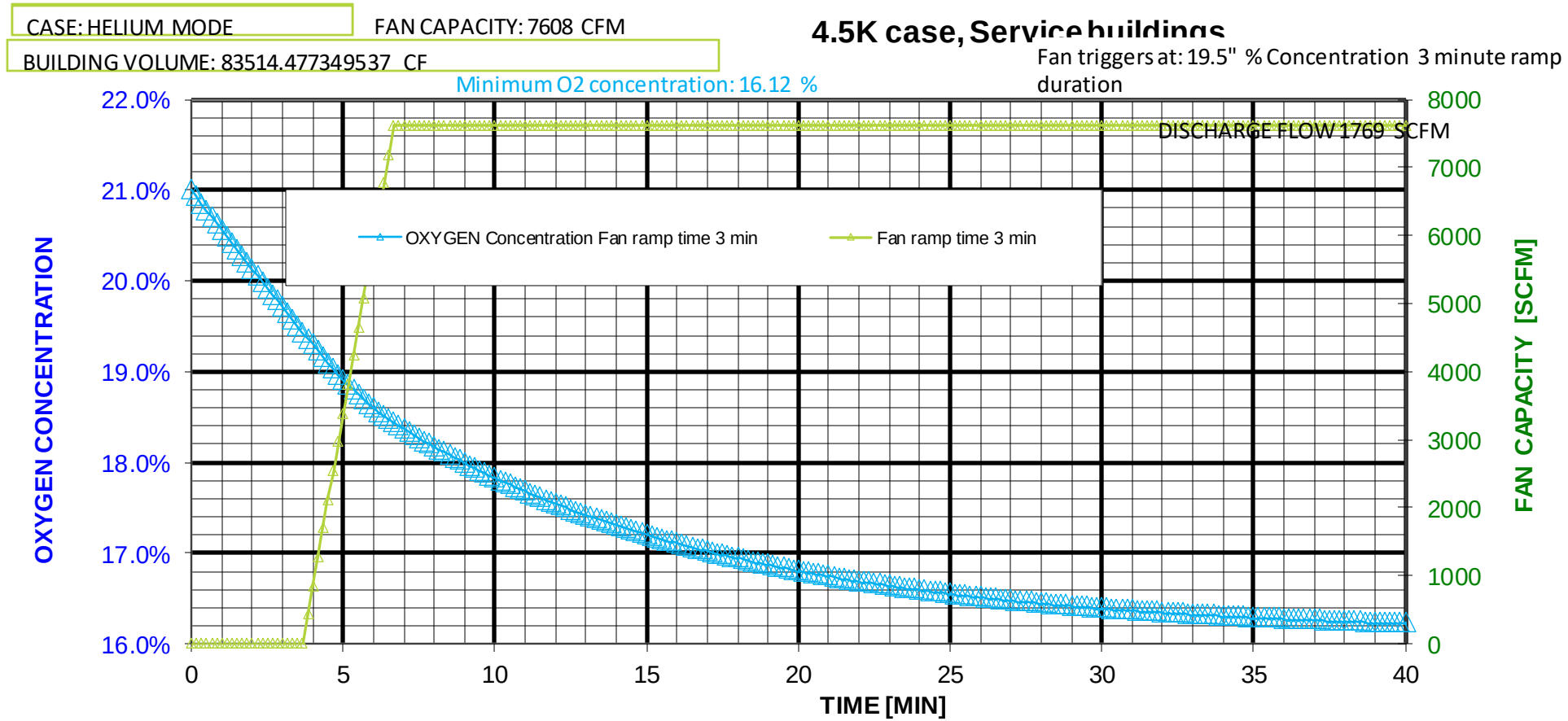
Brookhaven National Laboratory

1010A transient for 1 ODH fan



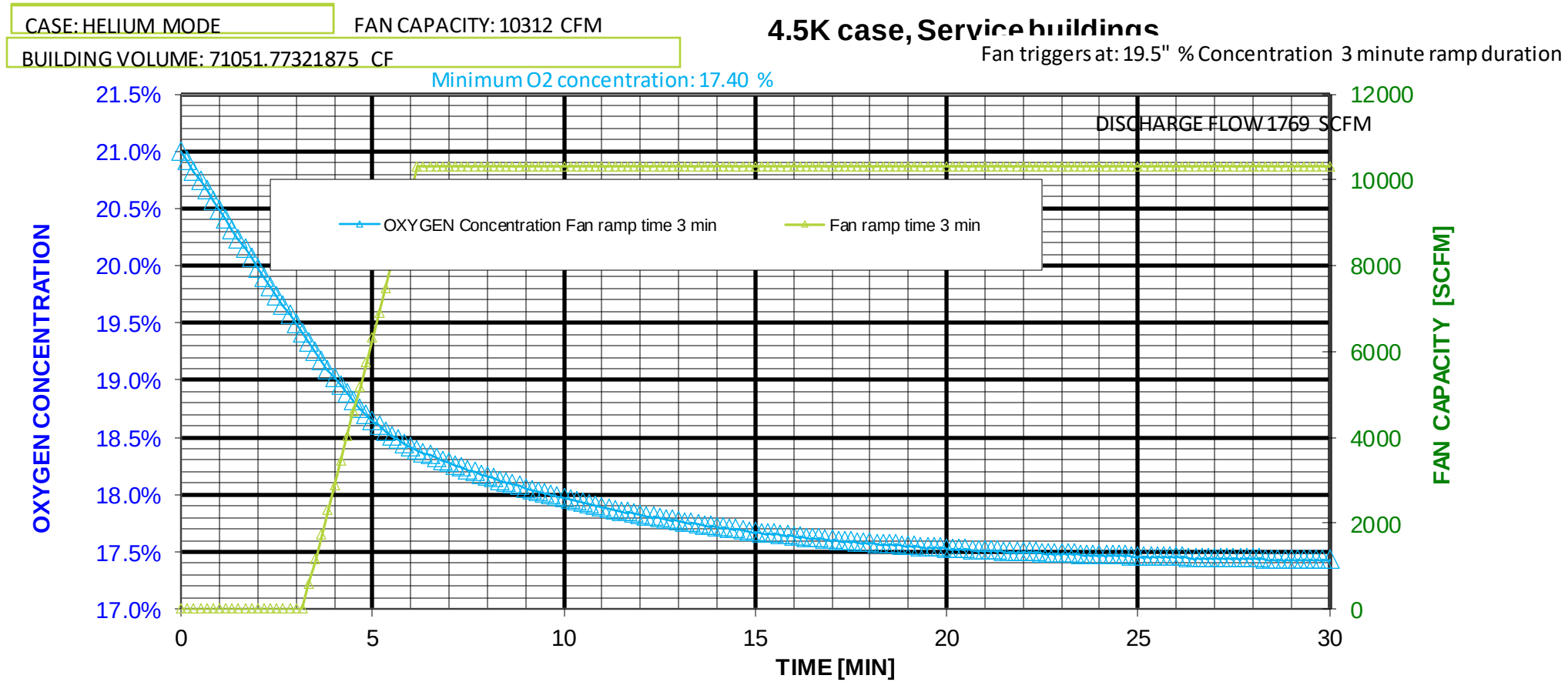
Brookhaven National Laboratory

1012A transient for 1 ODH fan



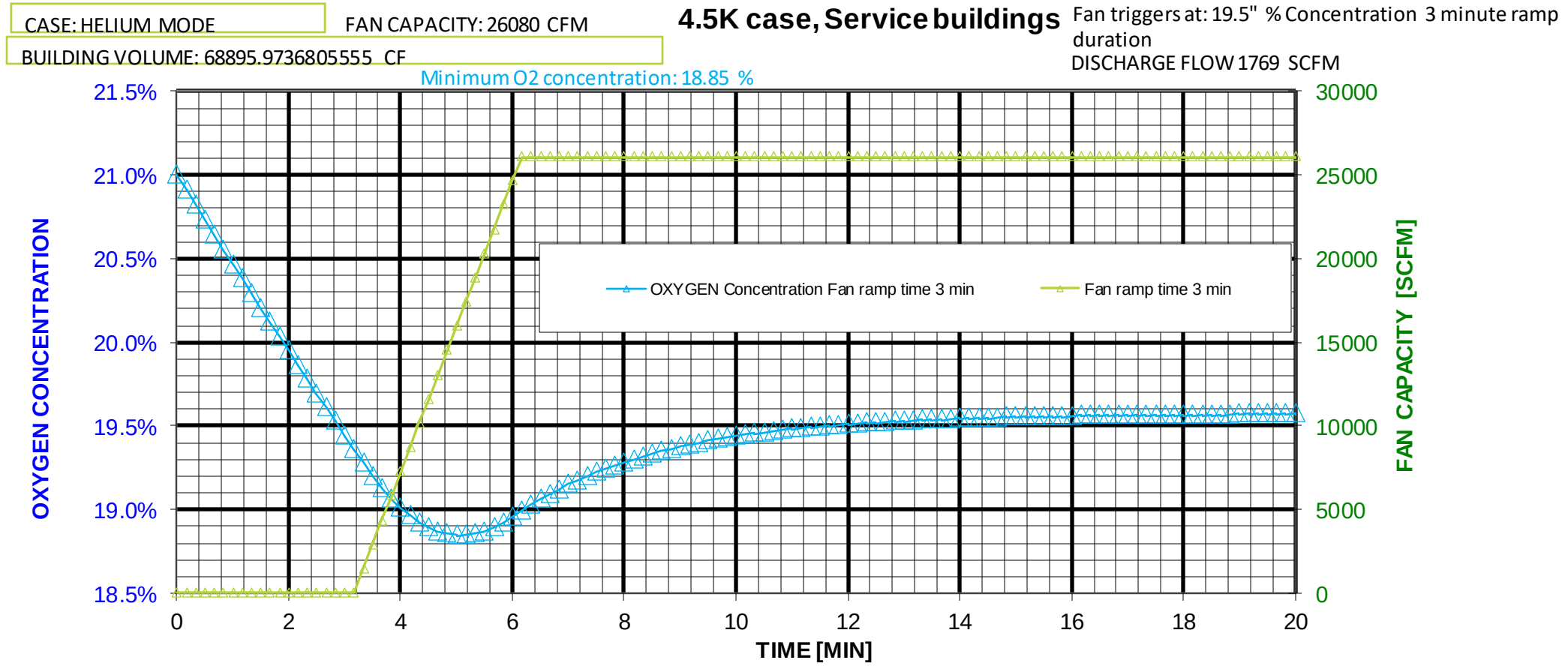
Brookhaven National Laboratory

1002B transient for 1 ODH fan



Brookhaven National Laboratory

1006B transient for 2 ODH fan



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1008B transient for 2 ODH fan

CASE: HELIUM MODE

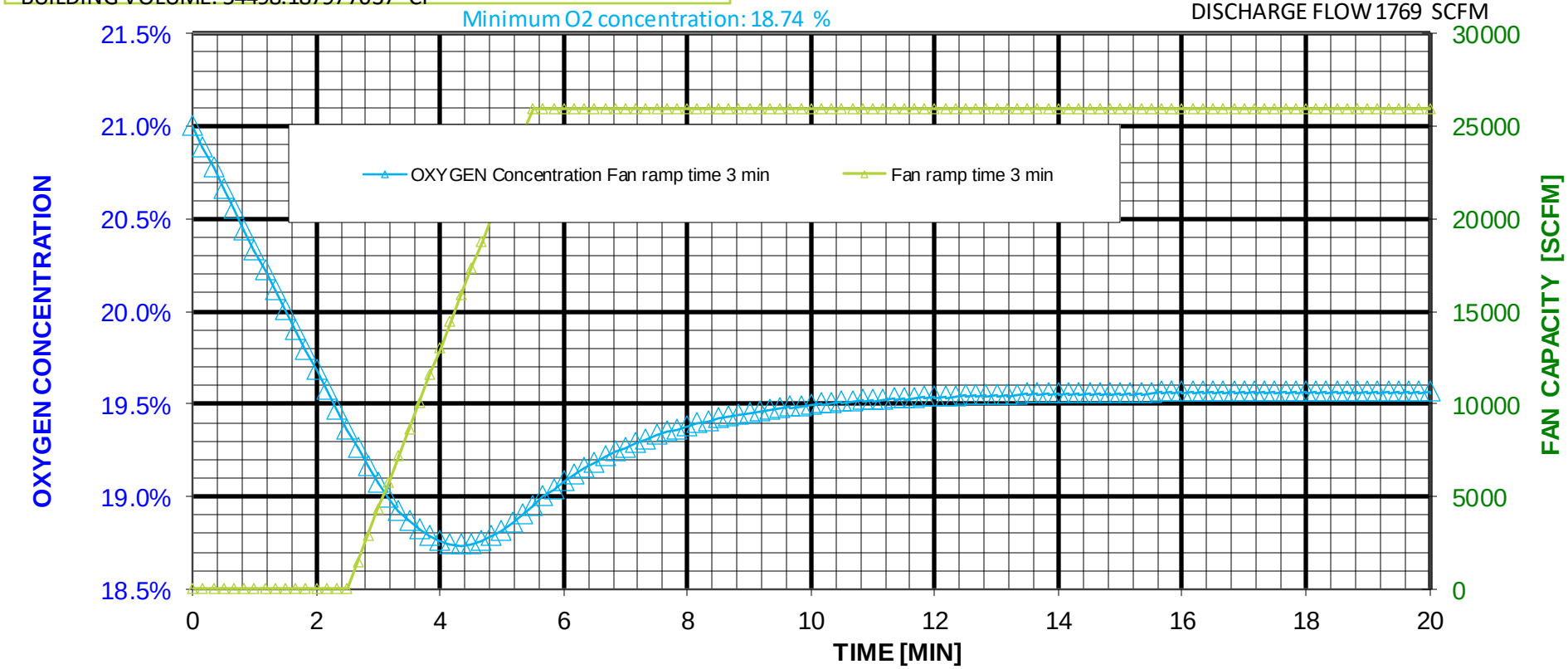
FAN CAPACITY: 25920 CFM

BUILDING VOLUME: 54498.187977037 CF

4.5K case, Service buildings

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

DISCHARGE FLOW 1769 SCFM



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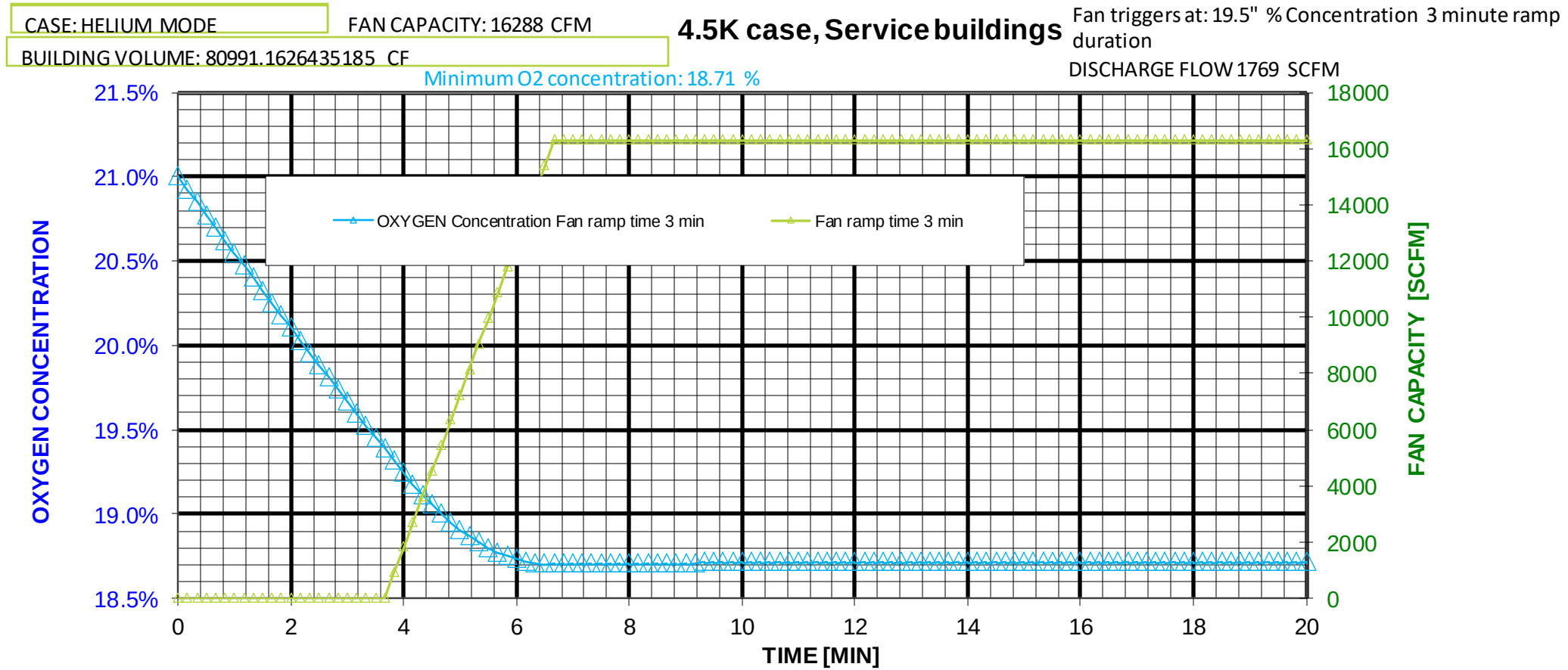
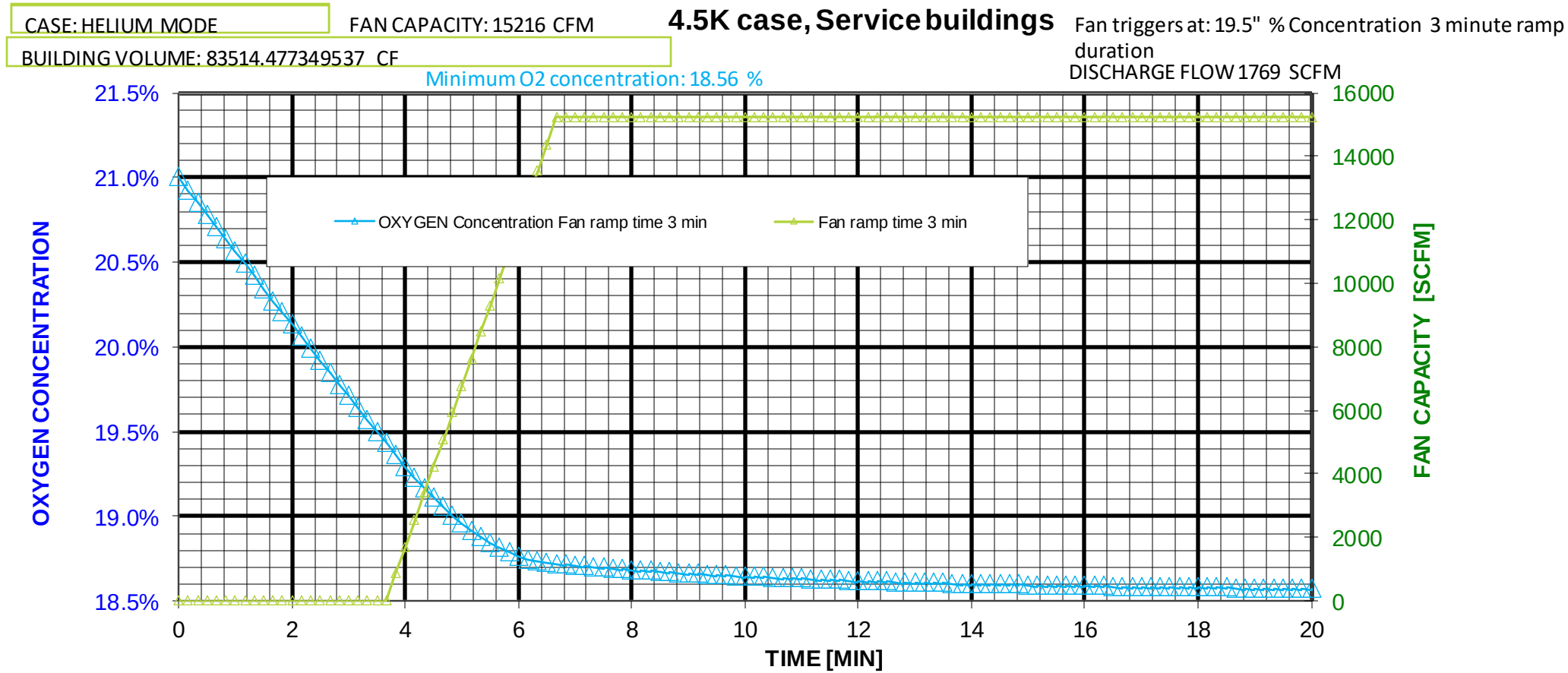
1010A transient for 2 ODH fan



Brookhaven National Laboratory

1012A transient for 2 ODH fan



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1002B transient for 2 ODH fan

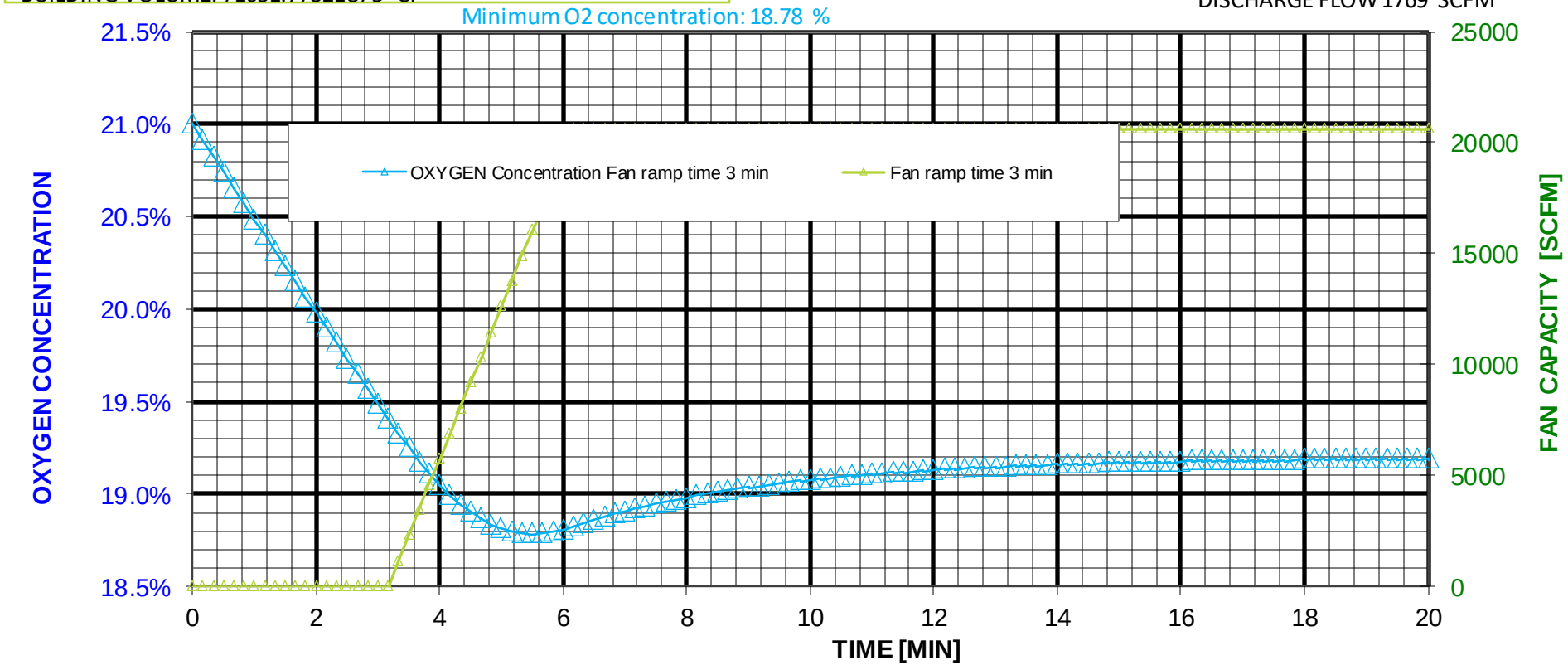
CASE: HELIUM MODE FAN CAPACITY: 20624 CFM

BUILDING VOLUME: 71051.77321875 CF

4.5K case, Service buildings

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

DISCHARGE FLOW 1769 SCFM



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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 nozzle equation:

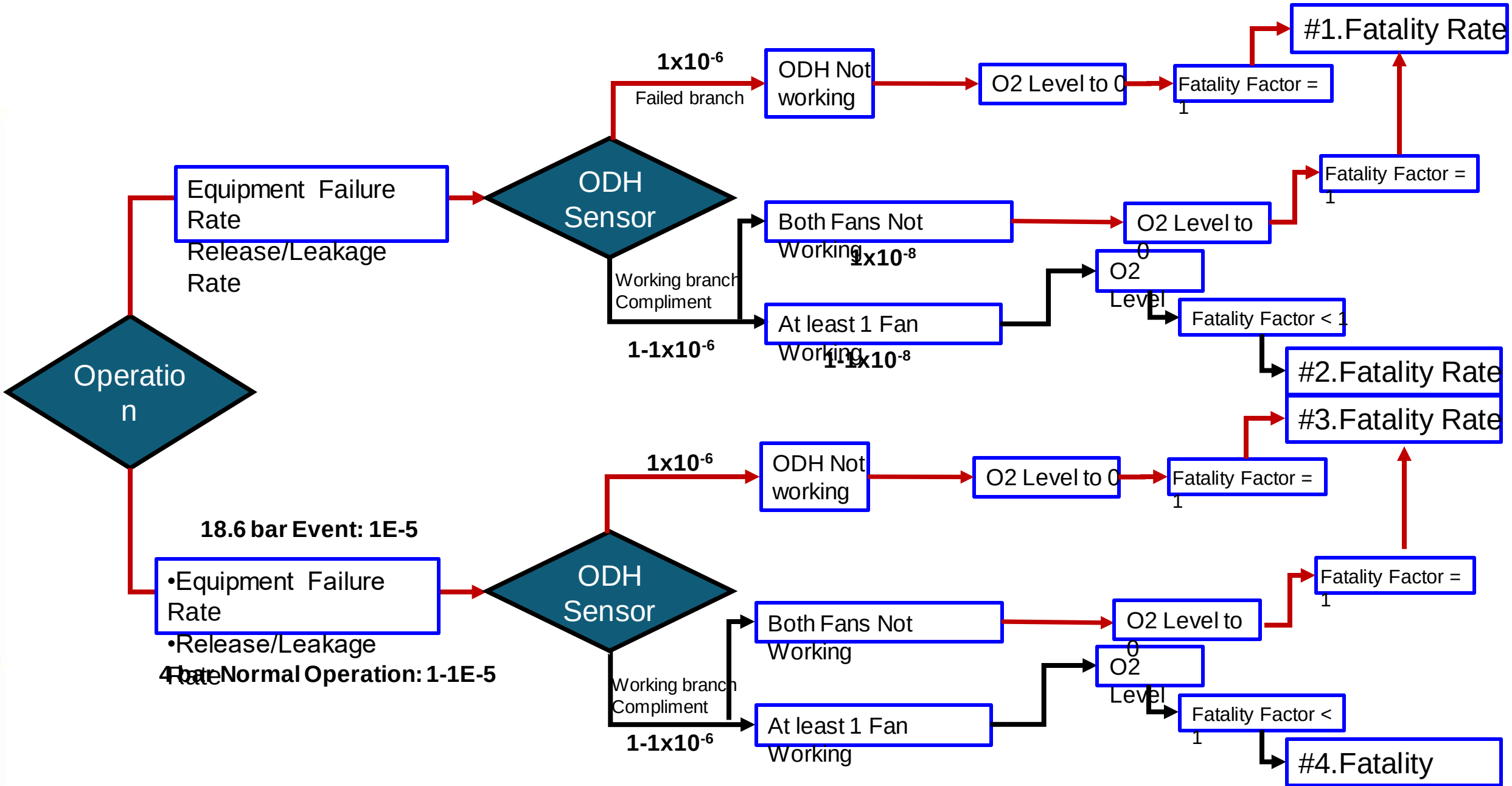
DIM involves evaluating thermodynamic properties of the relieving stream at a number of state points and then numerically integrating the nozzle equation to determine the maximum mass flux

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

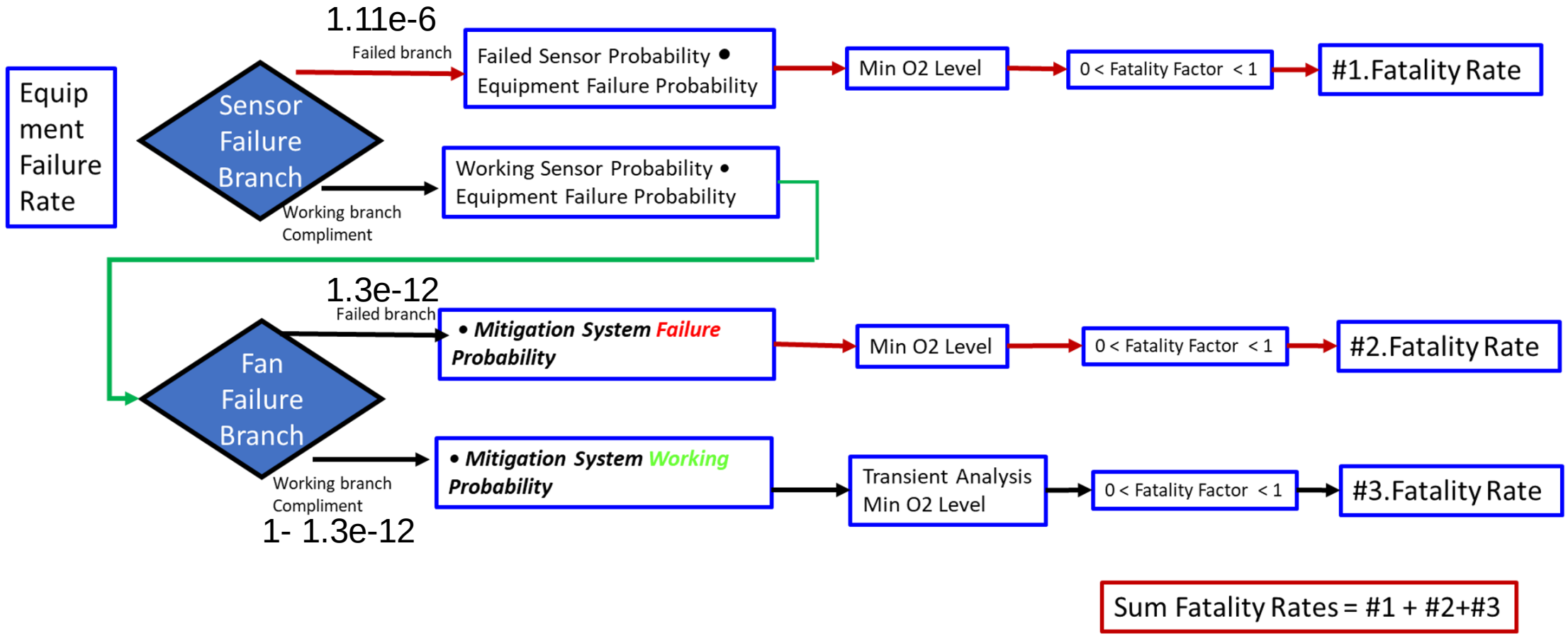
$$\int_{p_i}^{p_{i+1}} v\,dp = \frac{(v_{i+1} + v_i)}{2} * (p_{i+1} - p_i)$$

Cd=0.65

```
Const atmpa As Double = 101325#
Const pie As Double = 3.14159265
Const Bar_Pascal As Double = 100000#
Dim He_entropy As Double
Dim He_spv As Double

Dim p_i1 As Double
Dim pi As Double
Dim g As Double



Function helium_leakflux(Temp_K As Double, Pres_pa_in As Double, Pres_pa_out As Double, nloop As Integer)

He_entropy = hecalc(8, 0, 1, Pres_pa_in, 2, Temp_K, 1)
He_spv = hecalc(4, 0, 8, He_entropy, 1, Pres_pa_in, 1)


Dp = (Pres_pa_in - Pres_pa_out) / nloop
pi = Pres_pa_in
intl = 0

g = 0
For i = 1 To nloop
p_i1 = pi - Dp
He_spv1 = hecalc(4, 0, 8, He_entropy, 1, p_i1, 1)
He_spvavg = (He_spv + He_spv1) / 2

intl1 = He_spvavg * Dp + intl
intl = intl1
g1 = (2 * (1 / He_spv) ^ 2 * intl1) ^ 0.5


If (g1 < g) Then Exit For

g = g1
pi = p_i1
He_spv = He_spv1
If (p_i1 <= Pres_pa_out) Then Exit For



Next i
helium_leakflux = g

End Function
```


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
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

GENERAL FAILURE TREE DIAGRAM



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