D-ZERO ASSEMBLY HALL

ODH ANALYSIS

D-ZERO ENGINEERING NOTE # 3823.115 EN-463

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SUMMARY

An ODH analysis is presented which shows that the D-Zero assembly building high bay including the detector docking area is ODH class 0. Probabilities, leak rates, and fatality factors are generated for all items that are sources of inert gas. The scope of analysis included the calorimeter and gas components on the detector, the helium refrigerator/liquifier components, and the future solenoid and visible light photon counter cryogenics that will be added to the D-Zero detector. The analysis demonstrates that the calorimeter and helium refrigerator systems pose no ODH hazard to personnel.

INTRODUCTION

The ODH analysis presented here covers the high bay and assembly hall docking area of the for the D-Zero detector. It includes the STand Alone helium Refrigerator (STAR) in the building. It also includes the D-Zero detector and it's associated cryogenic and gas systems.

This analysis adds to the current set of ODH analysis for the D-Zero experiment that have been done in the past. They are listed below:

D0 EN-235: DAB South Side Analysis
D0 EN-258: D0 Detector Ass'y hall platform ODH analysis
D0 EN 332: D0 Detector Collision hall ODH analysis

At the time of writing this engineering note, the D-Zero detector is in the process of a detector upgrade. The ODH related aspects of this upgrade are: A STAR has been added to the building. A superconducting solenoid and visible light photon counter (VLPC) cryostats with associated cryogenics will be added on the detector platform. The central tracking drift chambers (CDC, FDC, Vertex, TRD) and their associated gas systems are being removed. This analysis covers all these ODH related changes as applicable to the D-Zero high bay and assembly hall docking area.

ANALYSIS: COMPONENTS AND LEAK RATES

The estimated quantities of components associated with the D-Zero detector gas and calorimeter system follows[1]:

D-Zero Detector gas and calorimeter components:

ABOVE PLATFORM:

351	pipe sections
121	elbows
41	tees
562	welds
112	screw connectors
16	plastic manifolds
112	plastic/flex lines
30	rotary bayonets

CRYO CORNER:

94	pipe sections
57	elbows
3	tees
11	valves
168	welds
12	connectors
2	brass flex hoses
10	bayonets

GAS CORNER:

122	pipe sections

NE CORNER:

25	pipe sections

[1] D0 EN# 3740.510-EN-332. D-Zero Detector Collision hall ODH analysis. 8/10/92.

29 elbows
58 tees
56 valves
267 welds
7 connectors

26 elbows
4 valves
52 welds
2 screw connections
2 plastic/flex lines

SOUTH ALCOVE:
113 pipe sections
7 elbows
17 valves
147 welds
17 swagelok hose connectors

MID SECTION:
4 pipe sections
4 welds

ALONG SOUTH WALL:
145 pipe sections
41 elbows
28 tees
26 valves
273 welds
23 hose connections
23 swagelok flexible hoses

WEST/EAST ALCOVE (EACH):
51 pipe sections
49 elbows
8 tees
2 valves
116 welds
28 connectors
2 plastic manifolds
26 plastic/flex lines

North End Calorimeter; 3200 gallons Liquid Argon [2]
Central Calorimeter; 5000 gallons Liquid Argon
South End Calorimeter; 3200 gallons Liquid Argon

Proportional Drift tube muon chambers; 222 chambers with 51 ft^3 per chamber[3]

D-Zero Detector gas and calorimeter component leak rates & probabilities:

All of the gas system lines except one have flow restrictions which limit their failure leak rates to under 1 scfm. The 2" WAMUS supply line has a maximum flow rate of 3 scfm[4], which is the highest flow rate of any of the detector gas supply/exhaust lines. As a conservative measure, all of the gas system lines will have an assumed failure leak rate of 3 scfm. The probabilities of failure for gas system components will be taken from FESHM 5064TA table 2. Pipe sections are all < 3" size so failure a rate should be 1 E^{-9} hr^{-1}. Elbows, tees, and other connections will be taken at a rate of 3 E^{-7} hr^{-1}. Welds will be taken at 3 E^{-9} hr^{-1}. Valve rupture rates are 1 E^{-8} hr^{-1}.

For cryogenic lines associated with the detector, the rupture leak rate is calculated from the largest possible flowrate in any of the pipes, which would be 100 gpm, the maximum flow of liquid nitrogen from dewar #42 to an open bayonet in the assembly hall cryo corner. This rate is equivalent to 11,000 scfm. Note that an internal leak would be a better case, with a much lower leak rate. Note that if a liquid nitrogen line were to rupture, a flow switch, DPS-560-N, would prompt the PLC to automatically shut a supply valve, limiting the total volume of escaped cryogens. The probabilities of failure for the cryogenic system components will be taken from FESHM 5064TA tables 1 & 2. Cryogenic fluid lines are given with a failure rate of 3 E^{-6} hr^{-1}. However, this rate is intended to be applied more globally such as applying to a "nitrogen supply

[2] Fermilab-Conf-93/222. Thermal Information Regarding the Cooldown and Operation of Liquid Argon Calorimeters. July 1993.

[3] D0 EN# 3740.100-EN-401. D-Zero Gas Systems: Volumes & Flows. 5/17/94.

[4] Recirculation pump maximum output at 0 psig exhaust pressure. Parker Metal bellows model MB-602.

line" rather than individual pipe sections, welds and elbows. Since tallying the individual constituents was done in the past, this method will be continued with individual component failure rates applied. Pipe section failure rates are taken as 1 E^{-9} hr^{-1}. Elbows and tees will be taken at a rate of 3 E^{-7} hr^{-1}. Welds will be taken at 3 E^{-9} hr^{-1}. Valve rupture rates are 1 E^{-8} hr^{-1}. On top of these probabilities, a factor of 1 E^{-4}, the failure rate of the pressure switch, can be applied to take credit for the high flow switch and automatic valve shut off.

The CC to EC extension piping includes a system of rotary bayonets which allow the EC's to open and close without the removal of hard piping on top of the cryostats. There are three rotary bayonets in each assembly, and each of the six lines (LAr Fill/Drain, LN2, Gar, Ar/N2 Vent, UV, and IV) contains a rotary bayonet assembly for both the ECS and the ECN. This makes a total of 36 rotary bayonets, however, since the insulating vacuum line does not contribute to an ODH hazard, only 30 of these bayonets are considered in this analysis. The leak rate of 10 scfm chosen was from EN-231 for a bayonet and flange.[5] A bayonet leak is essentially a gasket leak so a failure rate of 3 E^{-6} hr^{-1} is appropriate.

U-tube changes also are addressed because this operation adds to the probability of releasing inert gas into the building. There are a total of 6 u-tubes that connect the calorimeter cryogenic system to the detector platform. Only 5 of these carry inerting gas and will be considered. Characterizing a problem during a change as either a "small" event or "large" event, a reasonable flowrate to use would be 10 scfm (eg. isolation valve not fully closed) for a "small" event and the maximum flow of 11,000 scfm for a "large" event. The estimated failure rate of 3 E^{-2} /demand and 1 E^{-3} /demand, FESM5064TA table 1, for a "small" and "large" event will be used. The u-tubes are changed when the detector is moved, say every 4 years. The demand is 5 u-tube changes/ 4 years = 1.4 E^{-4} demands/hr, and the estimated failure rates would be 4.3 E^{-6} hr^{-1} for a small event and 1.4 E^{-7} hr^{-1} for a large event. An additional factor of 1 E^{-4}, the failure rate of the pressure switch, will be applied to the large event probability to take credit for the high flow switch and automatic valve shut off.

The leak rate from a failed calorimeter is hard to estimate. It is almost impossible to imagine a mode of probable failure. A reasonable size hole, rupture, or weld break to consider would be equivalent to a 1 1/2" pipe. This happens to be the size of the liquid argon drain line in the insulating vacuum space. It also is about the size of the beam pipe. This size hole could leak liquid argon initially at 210 gpm considering the liquid head and putting the vessel at MAWP + 3 psi. This rate is equivalent to 23, 558 scfm. Considering that the leak rate would decrease over time, it would take about an hour for the vessel to be empty. Any leak that did occur would be contained by the stainless steel vacuum vessel and directed into the liquid argon spill trough. The probability of the event is equivalent to a failure of a dewar times the failure rate of the containment system. A dewar failure rate per FESHM 5064TA table 1 is given as 3 E^{-6} hr^{-1}. The containment system failure rate is 12 flanges x 3 E^{-7} hr^{-1} plus 6 flex sections x 3 E^{-7} hr^{-1} = 5.4 E^{-5} hr^{-1}. The double failure rate to be used in the calculation is 3 E^{-6} hr^{-1} * 5.4 $E^{-5}hr^{-1}$= 1.62 $E^{-10}hr^{-1}$.

A muon chamber failure would essentially mean a rupture of the supply or return hose to the chamber, or the chamber walls rupturing. A conservative maximum leak rate to take would be that of the 2" WAMUS supply line of 3 scfm. (See above). A reasonable failure rate to take would be 1 E^{-6} hr^{-1} which is the failure rate of a tank.[6]

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[5]D0 EN# 3740.512-EN-231. Leak Analysis, Bayonet and Flange. 10/11/89.
[6]SSCL-Preprint-460. ODH, Oxygen Deficiency Hazard Cryogenic Analysis. July 1993.

D-Zero STAR, solenoid & VLPC components in DAB:

High pressure helium compressor discharge line
- 200 ft. total length pipe x 2" IPS
- 20 elbows and tees
- 10 Valves > 1/2" pipe size
- 100 welds

Low pressure helium compressor suction line
- 200 ft. total length pipe x 6" IPS
- 5 elbows and tees
- 13 Valves > 1/2" pipe size
- 100 welds

Helium to/from storage line
- 200 ft. total length pipe x 1" IPS
- 20 elbows and tees
- 3 Valves > 1/2" pipe size
- 50 welds

Liquid nitrogen supply line
- 250 ft. total length pipe x 1/2" IPS
- 8 Valves > 1/4" pipe size
- 100 welds

Nitrogen vent line
- 100 ft. total length pipe x 1 1/2" IPS
- 50 welds

GHe cooldown supply line
- 100 ft. total length pipe x 1/2" IPS
- 1 Valve > 1/4" pipe size
- 50 welds

GHe cooldown/lead flow return line
- 250 ft. total length pipe x 1/2" IPS
- 100 welds

Solenoid & VLPC transfer lines
- 400 ft. total, LN2 & LHe < 5/8" OD size

LHe storage Dewar	3000 Liter
STAR Heat exchanger	
8 Valve boxes/bayonet cans containing 22 valves	
Wet & Dry engines	2
LN2 Subcooler vessel	
22 U-tubes with 44 bayonets	

D-Zero STAR, solenoid & VLPC component leak rates & probabilities:

The maximum flow rate from the helium compressor discharge line or the helium suction line is determined from the Mycom compressor mass flow rating. This has been measured to be approximately 57 g/s or 729 scfm of helium gas. The compressor discharge and suction lines are routed below the building catwalk protected from any crane and personnel traffic. Aside from this precaution, the standard probabilities from FESHM 5064TA will be taken. The failure rate for the discharge piping will be 1 E^{-9} hr^{-1} applied to 15 sections. The failure rate for the suction piping will be 1 E^{-10} hr^{-1} applied to 15 sections. Elbows and tees will be taken at a rate of 3 E^{-7} hr^{-1}. Welds will be taken at 3 E^{-9} hr^{-1}. Valve rupture rates are 1 E^{-8} hr^{-1}.

The helium to/from storage line was sized to handle 60 g/s with 100 psi drop from the storage tank to the suction header which is about 300 feet. Not knowing where a rupture or failure may occur, and also assuming the storage pressure at 100 psig (high estimate) An estimated leak rate would be 90 g/s or 1150 scfm helium gas. The failure rate for the piping will be 1 E^{-9} hr^{-1} applied to 15 sections. Elbows and tees will be taken at a rate of 3 E^{-7} hr^{-1}. Welds will be taken at 3 E^{-9} hr^{-1}. Valve rupture rates are 1 E^{-8} hr^{-1}.

The liquid nitrogen supply line comes from dewar #39 and is 1/2" IPS inside DAB. The maximum flowrate of the liquid nitrogen supply line for a clean rupture was calculated to be 357 gph or 514 scfm nitrogen gas.[7] The failure rate of 3 E^{-6} $hr^{-1}$for a cryogenic fluid line, FESM5064TA table 1, will be taken to encompass the entire fluid line.

The nitrogen vent line has the steady state flow rates of the STAR heat exchanger, VLPC and solenoid as its maximum leak rate. They are expected to use 10 gph, 18 gph, and 2 gph LN_2 respectively. This is a total leak rate of 43 scfm nitrogen. The failure rate of 3 E^{-6} hr^{-1} for a cryogenic fluid line, FESHM 5064TA table 1, will be taken to encompass the entire fluid line.

The GHe cooldown supply line has a maximum design flow rating of 10 g/s helium gas. In actual practice, the cooldown supply is only used during the cool down of the solenoid or VLPC systems a frequency of less than 4 times per year and at flow rates of about 5 g/s. The nominal lead flow rate from the solenoid is 1 g/s. To be conservative the 10 g/s (128 scfm helium) flow rate shall also be applied to both the cooldown supply and the cooldown/lead flow return line. The failure rate of 3 E^{-6} $hr^{-1}$for a cryogenic fluid line, FESHM 5064TA table 1, will be taken to encompass each fluid line.

The estimated flow rate for the solenoid cryogenic system is 3 g/s LHe (38 scfm helium) and 2 gph LN_2 (3 scfm nitrogen). The estimated flow rate for the VLPC cryogenic system is 11.4 g/s LHe (146 scfm helium) and 18 gph LN_2 (26 scfm nitrogen). The failure rate of 3 E^{-6} $hr^{-1}$for a cryogenic fluid line, FESHM 5064TA table 1, will be taken to encompass each fluid line.

The leak rate of for a failure of the LHe storage dewar is hard to estimate. A realistic failure would result in the relief piping discharging cold gas helium into the building. Note that both the pressure vessel and vacuum vessel relief systems direct flow away from personnel. A rational leak rate to take would be the capacity rating of the rupture disc at it's burst pressure rating of 75 psig. This capacity at flowing conditions is 65,982 scfm helium. The release of helium into the building would be finite in that it would only occur until the inventory is gone. 3000 liters of liquid helium is equivalent to 80,000 scf of helium gas. If this is mixed into the 560,000 ft^3 building, then neglecting any ventilation, the final oxygen concentration would be 21% O_2 (480,000/560,000) = 18.0 % O_2. This is the value that will be used for the final oxygen concentration in the calculation. The failure rate of 1 E^{-5} hr^{-1} for a prematurely opening relief plus the failure rate of 3 E^{-6} $hr^{-1}$for a dewar will be applied for this component.

The STAR Heat exchanger has a maximum leak rate equivalent to the helium discharge leak rate and the nitrogen supply maximum flow rate. As discussed earlier, this is 729 scfm of helium gas and 514 scfm nitrogen gas. The failure rate of a cryogenic magnet or a dewar of 1 E^{-6} hr^{-1} is appropriate.

There are 3 valve boxes and 5 bayonet cans associated with the refrigerator and solenoid and VLPC transfer lines. The maximum helium leak rate comes from the refrigerator valve box at 40 g/s or 512 scfm helium. The maximum nitrogen leak rate possible is 514 scfm nitrogen gas.

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[7] DO EN# 3823.115-EN-459. Cryogenic and Safety considerations for moving the south end calorimeter to the sidewalk. 9/25/96.

These rates are upper bounds. Each box or can will have a failure rate of a cryogenic fluid line applied to it, 3 E^{-6} hr^{-1}. This will cover all the welds, elbows and pipe contained within. Only primary type valves where counted. Valve rupture rates are 1 E^{-8} hr^{-1}.

Wet and dry engines have normal operational flows of 40 g/s and 17 g/s. However for the analysis a maximum source flow rate of 57 g/s helium or 729 scfm of helium gas is used. The failure rate of a cryogenic compressor 3 E^{-5} hr^{-1} could possibly be used. However, a more accurate and conservative rate is a failure of an engine once a year (P=1 failure/365days*24 hr/day = 1.1 E^{-4} hr^{-1}. This is based on the Fermilab experience with significant piston seal leaks.

The LN_2 subcooler vessel has the potential of 514 scfm nitrogen gas. The vessel's inventory of 10 gallons is negligible. Its failure rate is that of a dewar at 1 E^{-6} hr^{-1}.

U-tubes handle a variety of flow rates of both helium and nitrogen. The u-tubes will be handled as extensions of the piping lines already taken into account above. The bayonet connections on either end will be considered to have a worst case leak rate of 10 scfm from EN-231. A bayonet leak is essentially a gasket leak so a failure rate of 3 E^{-6} hr^{-1} is appropriate.

U-tube changes also need to be addressed because this operation adds to the probability of releasing inert gas into the building. There are 18 u-tubes that carry helium and 4 that carry nitrogen. Characterizing a problem during a change as either a "small" event or "large" event, a reasonable flowrate to use would be 10 scfm (eg. isolation valve not fully closed) for a "small" event and the maximum flows of 729 scfm of helium gas or 514 scfm nitrogen gas for a "large" event. The estimated failure rate of 3 E^{-2} /demand and 1 E^{-3} /demand, FESM5064TA table 1, for a "small" and "large" event will be used. 10 u-tubes need to be changed to allow removal of equipment in the refrigerator area. Also 10 u-tubes need to be changed to disconnect/connect the detector to the STAR. Either of these activities should not occur any more frequently than once a year. The demand is 20 u-tube changes/year = 2.3 E^{-3} demands/hr, and the estimated failure rates would be 6.9 E^{-5} hr^{-1} for a small event and 2.3 E^{-6} hr^{-1} for a large event.

<u>D-Zero detector solenoid and VLPC components:</u>

Solenoid control dewar
Solenoid chimney
Solenoid main cryostat
6 Valves associated with solenoid

VLPC feed can and valve box
VLPC transfer line on platform
VLPC cryostats
4 Valves associated with VLPC

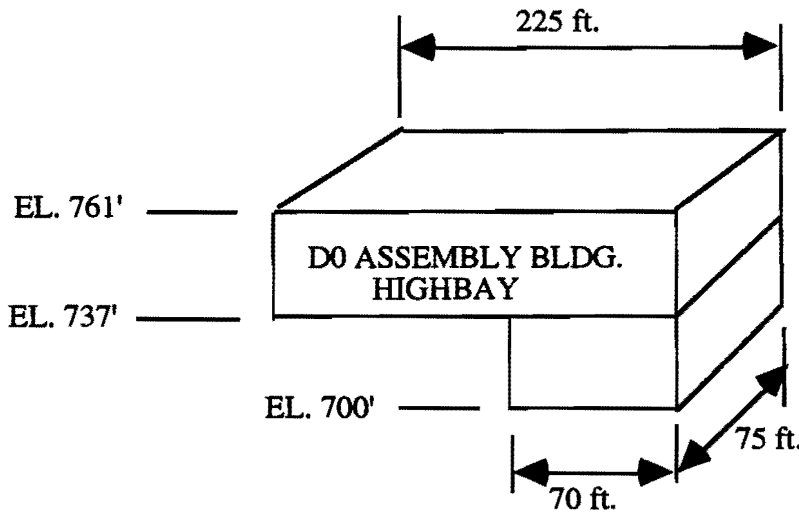
The solenoid control dewar, chimney, and main cryostat have leak rates equivalent to their normal operating flow rates. The estimated flow rate for the solenoid cryogenic system is 3 g/s LHe (38 scfm helium) and 2 gph LN_2 (3 scfm nitrogen). The failure rate of a cryogenic magnet 1 E^{-6} hr^{-1} plus the failure rate of a cryogenic fluid line, 3 E^{-6} hr^{-1} = 4 E^{-6} hr^{-1} will be applied for these components. The valves counted include full flow check valves. Valve rupture rates of 1 E^{-8} hr^{-1} will be used.

The VLPC system on the detector have leak rates equivalent to their normal operating flow rates. The estimated flow rate for the VLPC cryogenic system is 11.4 g/s LHe (146 scfm helium) and

18 gph LN_2 (26 scfm nitrogen). The failure rate of 3 E^{-6} hr^{-1} for a cryogenic fluid line will be applied to the feed can, valve box, and transfer line. The failure rate of a dewar at 1 E^{-6} hr^{-1} will be applied to each cryostat. 2 nitrogen valves and 2 helium valves are located in the valve box. Valve rupture rates of 1 E^{-8} hr^{-1} will be used.

ANALYSIS: BUILDING VOLUME & VENTILATION RATES

The assembly hall building volume is quite large. The main highbay level is 75 feet wide by 225 feet long with a height of 24 feet. The assembly hall parking area for the detector is 75 feet wide, 70 feet long, and extends 37 feet below the high bay ground level. This calculates to be approximately 600,000 cubic feet. No credit is taken for the volume occupied by the "old cleanroom" structure. The detector itself occupies about 39,000 cubic feet. Net volume is more or less 560,000 cubic feet.



Volume=(225)(24)(75)+(70)(75)(37)=599,250 ft^3

FIGURE 1. ASSEMBLY HALL VOLUME

The ventilation for the assembly hall is supplied by the building air handler unit AHU-2 and exhaust fan EF-2 each rated at 24,400 cfm. These units are on continuously. A simplified sketch showing the ducting arrangement is shown in figure 2. The fresh air intake dampers, DM-4 and DM-15 are controlled by the Johnson Controls HVAC control system based on the recirculation air and outside air temperatures. At a minimum, the fresh air intake will always be at least 3660 cfm. This is the value that has been used for the exhaust rate in calculations. The exhaust of building air goes through both the building ventilation system and the cryogenic exhaust fan EF-7.

The majority of the air supply is released at the ceiling, EL. 761' level. The remainder enters the building on the south side through two vents approx. EL. 720' and through vents in the detector docking pit, EL. 700'. The majority of the air return flow is taken through ventilation plenums on the east and north sides of the pit, EL. 700'. There are additional air return vents at EL. 749'.

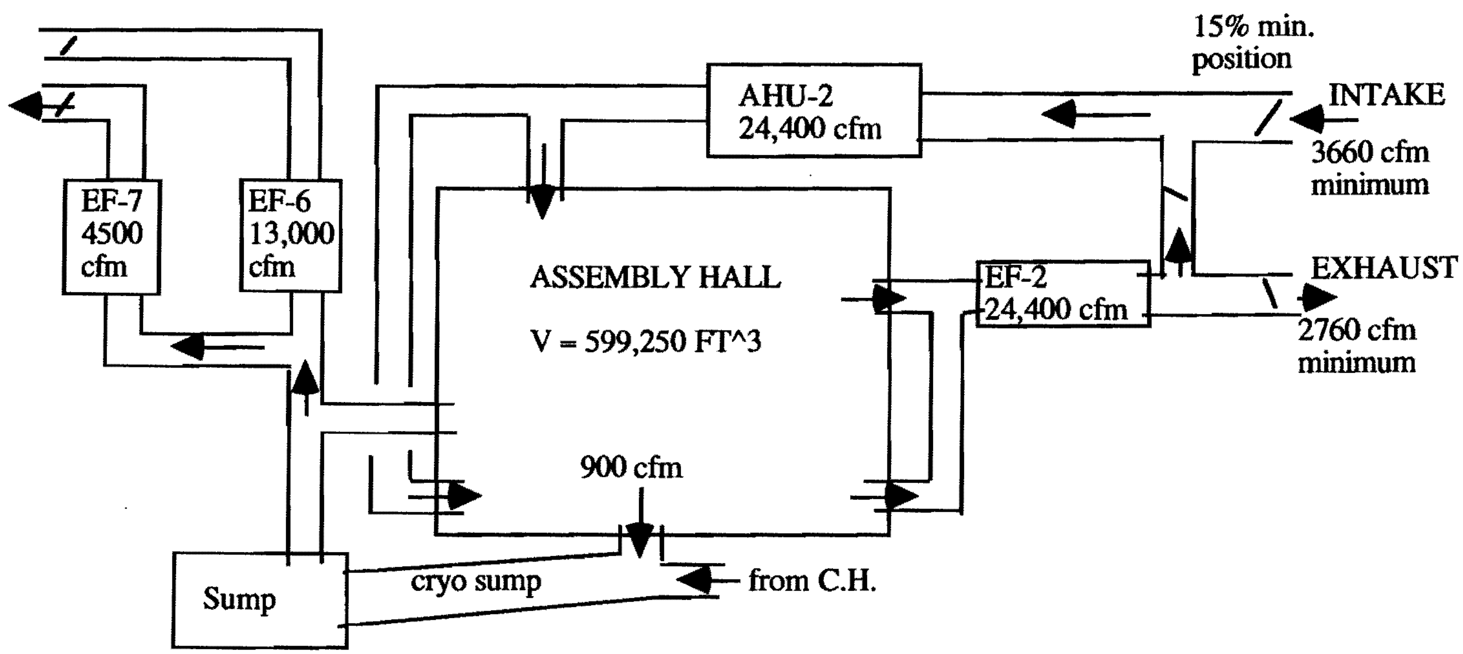


FIGURE 2: SIMPLIFIED VENTILATION DIAGRAM

The two main sources of an ODH event are helium and nitrogen. The majority of the helium components are located at the highbay floor level, EL. 737'. Any helium released would tend to rise and escape through leaks in the ceiling. The upper portion of the highbay is a large volume not occupied by personnel. Because of the building's size and construction one can recognize that natural ventilation will occur from ground level EL. 737' and above. For example, the calculated natural ventilation through the 25 ft. x 25 ft. highbay delivery door with a 5 mph wind outside is 500 cfm.[8] Because of the large surface and joint area of the building, the natural ventilation rate alone exceeds the 3660 cfm used in the analysis. These additional considerations help illustrate the conservativeness of the ODH analysis with respect to a helium release event. A nitrogen release would either mix readily with the building air or tend to fall to the pit level if it was cold. The extra ventilation discussed above is beneficial to any nitrogen release also. An additional consideration is that a non mandatory ODH head is located in the cryo niche in the pit at EL. 700' level. Other heads are located through out the detector platform. Should any of these heads be activated, horns and strobes will get the attention of personnel and start a personnel evacuation. EF-6 also will come on with 13,000 cfm of additional exhaust. These provisions are not required for the ODH class 0 result of the analysis, but illustrates that an extra level of safety precautions exist.

[8] Avallone and Baumeister, Marks' Standard Handbook for Mechanical Engineers (McGraw Hill book company, 1987)9th edition.

ANALYSIS: CALCULATION IN SPREADSHEET

The ODH analysis calculation is done by entering the summation of components, leak rates, and failure probabilities into an Excel spreadsheet. This is the same method that was used in previous D-Zero analyses. The discussion of the particular values for the rates, etc. were previously presented in this report.

Except for the LHe dewar and calorimeters which have fixed inventories, the oxygen fraction calculations assume that the leak rate continues for a long time after the event. The solution of the differential equation was for case b, in 5064TA. Restating those conditions, it is for during a release with ventilation fans drawing contaminated atmosphere from the confined volume with a ventilation rate greater than the spill rate. Summing of the ODH fatality rates results in a value of 6.4×10^{-9} hr^{-1}. The rate of 10^{-7} hr^{-1} is the threshold of a class 0 to class 1 odh classification. Thus, the D-Zero Assembly hall is ODH class 0.

The case of both an odh event and a ventilation failure is also addressed. In order to get reasonable results, a minimal exhaust rate of 500 cfm is applied. One can easily argue that the natural building ventilation will assure this rate. The probability of a ventilation failure is taken to be the same as the failure rate of an electric motor at 1×10^{-5} hr^{-1}. The probabilities of both the odh event and the ventilation failure are multiplied together and become the new group probability of failure. This value is multiplied by the fatality factor to give the fatality rate for each item. Summation of the ODH fatality rates results in a value of 3.1×10^{-9} hr^{-1}. Thus, the D-Zero Assembly hall is ODH class 0, for a scenario of a failure of the building ventilation system.

DØ ASSEMBLY HALL ODH ANALYSIS

Exhaust E	TC, min. V/E	Pressure
3,660	153.01	
Volume V	**Elevation**	**Pressure**
560,000	737 ft	741 mmHG

ITEM	TYPE	N	P FAIL RATE	GROUP FAIL RATE	L leak rate	L/E LEAK/EXH	fO2{∞} FRACT O2	F Fatal. Factor	Ø Fatal. Rate	ODH Class
Pipes <3"	Sections	520	1.00E-09	5.20E-07	3	0.000820	20.98%	9.02E-10	4.69E-16	0
Elbows		255	3.00E-07	7.65E-05	3	0.000820	20.98%	9.02E-10	6.90E-14	0
Tees		110	3.00E-07	3.30E-05	3	0.000820	20.98%	9.02E-10	2.98E-14	0
Pipes	vac jacketed	436	1.00E-13	4.36E-11	11000	3.005464	0.00%	1.00E+00	4.36E-11	0
Elbows	vac jacketed	124	3.00E-11	3.72E-09	11000	3.005464	0.00%	1.00E+00	3.72E-09	0
Tees	vac jacketed	36	3.00E-11	1.08E-09	11000	3.005464	0.00%	1.00E+00	1.08E-09	0
Valves*		59	1.00E-08	5.90E-07	33	0.009016	20.81%	1.21E-09	7.13E-16	0
Bayonets	cryo corner	10	3.00E-06	3.00E-05	10	0.002732	20.94%	9.66E-10	2.90E-14	0
* U-tube change	small event	5	4.30E-06	2.15E-05	10	0.002732	20.94%	9.66E-10	2.08E-14	0
* U-tube change	large event	5	1.40E-11	7.00E-11	11000	3.005464	0.00%	1.00E+00	7.00E-11	0
Bayonets	rotary, EC	30	3.00E-06	9.00E-05	10	0.002732	20.94%	9.66E-10	8.69E-14	0
Joints	welded/brazed	1705	3.00E-09	5.12E-06	10	0.002732	20.94%	9.66E-10	4.94E-15	0
Connectors	screw	229	3.00E-06	6.87E-04	10	0.002732	20.94%	9.66E-10	6.63E-13	0
Manifolds	plastic	20	3.00E-06	6.00E-05	10	0.002732	20.94%	9.66E-10	5.79E-14	0
Hose	plastic/flex	191	3.00E-06	5.73E-04	10	0.002732	20.94%	9.66E-10	5.53E-13	0
Calorimeter		3	1.62E-10	4.86E-10	23558	6.436612	0.00%	1.00E+00	4.86E-10	0
Muon chambers		222	1.00E-06	2.22E-04	3	0.000820	20.98%	9.02E-10	2.00E-13	0
HP Helium	pipes	15	1.00E-09	1.50E-08	729	0.199180	16.62%	1.10E-06	1.65E-14	0
	elbows/tees	20	3.00E-07	6.00E-06	729	0.199180	16.82%	1.10E-06	6.59E-12	0
	valves	10	1.00E-08	1.00E-07	729	0.199160	16.62%	1.10E-06	1.10E-13	0
	welds	100	3.00E-09	3.00E-07	729	0.199180	16.62%	1.10E-06	3.30E-13	0
LP Helium	pipes	15	1.00E-10	1.50E-09	729	0.199180	16.82%	1.10E-06	1.65E-15	0
	elbows/tees	5	3.00E-07	1.50E-06	729	0.199180	16.82%	1.10E-06	1.65E-12	0
	valves	13	1.00E-08	1.30E-07	729	0.199180	16.82%	1.10E-06	1.43E-13	0
	welds	100	3.00E-09	3.00E-07	729	0.199180	16.82%	1.10E-06	3.30E-13	0
He storage	pipes	15	1.00E-09	1.50E-08	1150	0.314208	14.40%	6.77E-05	1.02E-12	0
	elbows/tees	20	3.00E-07	6.00E-06	729	0.199180	16.82%	1.10E-06	6.59E-12	0
	valves	3	1.00E-08	3.00E-08	729	0.199180	16.82%	1.10E-06	3.30E-14	0
	welds	50	3.00E-09	1.50E-07	729	0.199180	16.82%	1.10E-06	1.65E-13	0
LN2 supply	fluid line	1	3.00E-06	3.00E-06	514	0.140437	18.05%	1.34E-07	4.02E-13	0
GN2 vent	fluid line	1	3.00E-06	3.00E-06	43	0.011749	20.75%	1.33E-09	4.00E-15	0
GHe cd supply	fluid line	1	3.00E-06	3.00E-06	128	0.034973	20.27%	3.06E-09	9.19E-15	0
GHe cd return	fluid line	1	3.00E-06	3.00E-06	128	0.034973	20.27%	3.06E-09	9.19E-15	0
Solenoid xfer	fluid line	1	3.00E-06	3.00E-06	41	0.011202	20.76%	1.31E-09	3.92E-15	0
VLPC xfer	fluid line	1	3.00E-06	3.00E-06	172	0.046995	20.01%	4.71E-09	1.41E-14	0
LHe dewar	dewar	1	1.30E-05	1.30E-05	65982	18.027869	18.00%	1.46E-07	1.90E-12	0
STAR HX		1	1.00E-06	1.00E-06	1243	0.339617	13.87%	1.68E-04	1.68E-10	0
Boxes	valve/bayonet	8	3.00E-06	2.40E-05	1026	0.280328	15.11%	2.01E-05	4.83E-10	0
Boxes	valves	22	1.00E-08	2.20E-07	514	0.140437	18.05%	1.34E-07	2.95E-14	0
Wet/dry engine		2	1.10E-04	2.20E-04	729	0.199180	16.82%	1.10E-06	2.42E-10	0
LN2 subcooler		1	1.00E-06	1.00E-06	514	0.140437	18.05%	1.34E-07	1.34E-13	0
* Bayonets	gasket leak	44	3.00E-06	1.32E-04	10	0.002732	20.94%	9.66E-10	1.27E-13	0
* U-tube change	small event	22	6.90E-05	1.52E-03	10	0.002732	20.94%	9.66E-10	1.47E-12	0
* U-tube change	large event	22	2.30E-06	5.06E-05	729	0.199180	16.82%	1.10E-06	5.56E-11	0
Solenoid	system	3	4.00E-06	1.20E-05	41	0.011202	20.76%	1.31E-09	1.57E-14	0
Solenoid	valves	6	1.00E-08	6.00E-08	38	0.010383	20.78%	1.27E-09	7.62E-17	0
VLPC	feed/vb/xfer	3	3.00E-06	9.00E-06	172	0.046995	20.01%	4.71E-09	4.24E-14	0
VLPC	cryostat	2	1.00E-06	2.00E-06	172	0.046995	20.01%	4.71E-09	9.43E-15	0
VLPC	valves	4	1.00E-08	4.00E-08	146	0.039891	20.16%	3.65E-09	1.46E-16	0
	TOTAL								6.37E-09	0 *

* REV. 5/28/97

DØ ASSEMBLY HALL ODH ANALYSIS

NO VENTILATION

Exhaust E	TC, min. V/E	
500	1120.00	
Volume V	**Elevation**	**Pressure**
560,000	737 ft	741 mmHG

ITEM	TYPE	N	P FAIL RATE	GROUP FAIL RATE	GROUP FAIL RATE * VENTIL. FAIL	L leak rate	L/E LEAK/EXH	fO2{∞} FRACT O2	F Fatal. Factor	Ø Fatal. Rate	ODH Class
Pipes <3"	Sections	520	1.00E-09	5.20E-07	5.20E-12	3	6.00E-03	20.87%	1.09E-09	5.64E-21	0
Elbows		255	3.00E-07	7.65E-05	7.65E-10	3	6.00E-03	20.87%	1.09E-09	8.30E-19	0
Tees		110	3.00E-07	3.30E-05	3.30E-10	3	6.00E-03	20.87%	1.09E-09	3.58E-19	0
Pipes	vac jacketed	436	1.00E-13	4.36E-11	4.36E-16	11000	2.20E+01	0.00%	1.00E+00	4.36E-16	0
Elbows	vac jacketed	124	3.00E-11	3.72E-09	3.72E-14	11000	2.20E+01	0.00%	1.00E+00	3.72E-14	0
Tees	vac jacketed	36	3.00E-11	1.08E-09	1.08E-14	11000	2.20E+01	0.00%	1.00E+00	1.08E-14	0
Valves*		59	1.00E-08	5.90E-07	5.90E-12	33	6.60E-02	19.61%	9.31E-09	5.49E-20	0
Bayonets	cryocorner	10	3.00E-08	3.00E-05	3.00E-10	10	2.00E-02	20.58%	1.79E-09	5.38E-19	0
* U-tube change	small event	5	4.30E-06	2.15E-05	2.15E-10	10	2.00E-02	20.58%	1.79E-09	3.85E-19	0
* U-tube change	large event	5	1.40E-11	7.00E-11	7.00E-16	11000	2.20E+01	0.00%	1.00E+00	7.00E-16	0
Bayonets	rotary, EC	30	3.00E-06	9.00E-05	9.00E-10	10	2.00E-02	20.58%	1.79E-09	1.61E-18	0
Joints	welded/brazed	1705	3.00E-09	5.12E-06	5.12E-11	10	2.00E-02	20.58%	1.79E-09	9.17E-20	0
Connectors	screw	229	3.00E-06	6.87E-04	6.87E-09	10	2.00E-02	20.58%	1.79E-09	1.23E-17	0
Manifolds	plastic	20	3.00E-06	6.00E-05	6.00E-10	10	2.00E-02	20.56%	1.79E-09	1.08E-16	0
Hose	plastic/flex	191	3.00E-06	5.73E-04	5.73E-09	10	2.00E-02	20.58%	1.79E-09	1.03E-17	0
Calorimeter		3	1.62E-10	4.86E-10	4.66E-15	23558	4.71E+01	0.00%	1.00E+00	4.86E-15	0
Muon chambers		222	1.00E-06	2.22E-04	2.22E-09	3	6.00E-03	20.87%	1.09E-09	2.41E-18	0
HP Helium	pipes	15	1.00E-09	1.50E-08	1.50E-13	729	1.46E+00	0.00%	1.00E+00	1.50E-13	0
	elbows/tees	20	3.00E-07	6.00E-06	6.00E-11	729	1.46E+00	0.00%	1.00E+00	6.00E-11	0
	valves	10	1.00E-08	1.00E-07	1.00E-12	729	1.46E+00	0.00%	1.00E+00	1.00E-12	0
	welds	100	3.00E-09	3.00E-07	3.00E-12	729	1.46E+00	0.00%	1.00E+00	3.00E-12	0
LP Helium	pipes	15	1.00E-10	1.50E-09	1.50E-14	729	1.46E+00	0.00%	1.00E+00	1.50E-14	0
	elbows/tees	5	3.00E-07	1.50E-06	1.50E-11	729	1.46E+00	0.00%	1.00E+00	1.50E-11	0
	valves	13	1.00E-08	1.30E-07	1.30E-12	729	1.46E+00	0.00%	1.00E+00	1.30E-12	0
	welds	100	3.00E-09	3.00E-07	3.00E-12	729	1.46E+00	0.00%	1.00E+00	3.00E-12	0
He storage	pipes	15	1.00E-09	1.50E-08	1.50E-13	1150	2.30E+00	0.00%	1.00E+00	1.50E-13	0
	elbows/tees	20	3.00E-07	6.00E-06	6.00E-11	729	1.46E+00	0.00%	1.00E+00	6.00E-11	0
	valves	3	1.00E-08	3.00E-08	3.00E-13	729	1.46E+00	0.00%	1.00E+00	3.00E-13	0
	welds	50	3.00E-09	1.50E-07	1.50E-12	729	1.46E+00	0.00%	1.00E+00	1.50E-12	0
LN2 supply	fluid line	1	3.00E-06	3.00E-06	3.00E-11	514	1.03E+00	0.00%	1.00E+00	3.00E-11	0
GN2 vent	fluid line	1	3.00E-06	3.00E-06	3.00E-11	43	8.60E-02	19.19%	1.91E-08	5.72E-19	0
GHe cd supply	fluid line	1	3.00E-06	3.00E-06	3.00E-11	128	2.56E-01	15.62%	8.41E-06	2.52E-16	0
GHe cd return	fluid line	1	3.00E-06	3.00E-06	3.00E-11	128	2.56E-01	15.62%	8.41E-06	2.52E-16	0
Solenoid xfer	fluid line	1	3.00E-06	3.00E-06	3.00E-11	41	8.20E-02	19.28%	1.65E-08	4.96E-19	0
VLPC xfer	fluid line	1	3.00E-06	3.00E-06	3.00E-11	172	3.44E-01	13.78%	1.97E-04	5.91E-15	0
LHe dewar	dewar	1	1.30E-05	1.30E-05	1.30E-10	65982	1.30E-09	18.00%	1.46E-07	1.90E-17	0
STAR HX		1	1.00E-06	1.00E-06	1.00E-11	1243	2.49E+00	0.00%	1.00E+00	1.00E-11	0
Boxes	valve/bayonet	8	3.00E-06	2.40E-05	2.40E-10	1026	2.05E+00	0.00%	1.00E+00	2.40E-10	0
Boxes	valves	22	1.00E-08	2.20E-07	2.20E-12	514	1.03E+00	0.00%	1.00E+00	2.20E-12	0
Wet/dry engine		2	1.10E-04	2.20E-04	2.20E-09	729	1.46E+00	0.00%	1.00E+00	2.20E-09	0
LN2 subcooler		1	1.00E-06	1.00E-06	1.00E-11	514	1.03E+00	0.00%	1.00E+00	1.00E-11	0
* Bayonets	gasket leak	44	3.00E-06	1.32E-04	1.32E-09	10	2.00E-02	20.58%	1.79E-09	2.37E-16	0
* U-tube change	small event	22	6.90E-05	1.52E-03	1.52E-08	10	2.00E-02	20.58%	1.79E-09	2.72E-17	0
* U-tube change	large event	22	2.30E-06	5.06E-05	5.06E-10	729	1.46E+00	0.00%	1.00E+00	5.06E-10	0
Solenoid	valves	6	1.00E-06	6.00E-08	6.00E-13	38	7.60E-02	19.40%	1.33E-08	7.99E-21	0
VLPC	feed/vb/xfer	3	3.00E-06	9.00E-06	9.00E-11	172	3.44E-01	13.78%	1.97E-04	1.77E-14	0
VLPC	cryostat	2	1.00E-06	2.00E-06	2.00E-11	172	3.44E-01	13.78%	1.97E-04	3.94E-15	0
VLPC	valves	4	1.00E-08	4.00E-08	4.00E-13	146	2.92E-01	14.87%	3.06E-05	1.22E-17	0
	TOTAL									3.14E-09	0 *

Ventilation failure rate taken at = 1 E-05 hr^-1

Explanation of Table Columns

E: Exhaust ventilation in cfm

TC: Time constant, minutes

Volume: Building volume in cubic feet

ITEM and TYPE: component description.

N: number of components of item.

FAIL RATE(P): probability of failure, one item, in units of hr^{-1}.

LEAK RATE(L): maximum leakage upon failure of component, in units of scfm.

L/E: ratio of leak rate to exhaust ventilation rate.

FRACTION OF OXYGEN(fO_2):

IF L/E > 1, THEN $fO_2\{\infty\} = 0$, ELSE

$fO_2\{\infty\} = 0.21\ (1 - L/E)$

p: pressure, in mmHG.

FATALITY FACTOR(F) (truncates with if-then):

IF $10^{(6.5 - (p/10)(fO2))} \geq 1$, THEN **F** = 1, ELSE

$\mathbf{F} = 10^{(6.5 - (p/10)(fO2))}$

FATALITY RATE(Ø): N(P)(F)

ODH CLASS (uses if-then-else logical operators):

IF Ø ≤ 10^{-7}, THEN ODH class = 0, ELSE
IF Ø ≤ 10^{-5}, THEN ODH class = 1, ELSE
IF Ø ≤ 10^{-3}, THEN ODH class = 2, ELSE
IF Ø ≤ 10^{-1}, THEN ODH class = 3, ELSE
ODH class = 4.

	E	F	G	H	I	J	K	L
3								
4								
5	Pressure							
6	=760-0.0262*C6+0.000							
7	P	GROUP	L	L/E	fO2(∞)	F	Ø	ODH
8	FAIL RATE	FAIL RATE	leak rate	LEAK/EXH	FRACT O2	Fatal. Factor	Fatal. Rate	Class
9	0.000000001	=D9*E9	3	=(G9/A4)	=IF(H9<1,0.21*(1-H9),0)	=IF(I9>0.08553,10^(6.5-($E$6/10)*I9),1)	=F9*(J9)	=IF(K9<=0.0000001,0,IF(K9<=0.00001,1,IF(K9<=0.001,2,IF(K9<=0.1,3,4))))
10	0.0000003	=D10*E10	3	=(G10/A4)	=IF(H10<1,0.21*(1-H10),0)	=IF(I10>0.08553,10^(6.5-($E$6/10)*I10),1)	=F10*(J10)	=IF(K10<=0.0000001,0,IF(K10<=0.00001,1,IF(K10<=0.001,2,IF(K10<=0.1,3,4))))
11	0.0000003	=D11*E11	3	=(G11/A4)	=IF(H11<1,0.21*(1-H11),0)	=IF(I11>0.08553,10^(6.5-($E$6/10)*I11),1)	=F11*(J11)	=IF(K11<=0.0000001,0,IF(K11<=0.00001,1,IF(K11<=0.001,2,IF(K11<=0.1,3,4))))
12	0.0000000000001	=D12*E12	11000	=(G12/A4)	=IF(H12<1,0.21*(1-H12),0)	=IF(I12>0.08553,10^(6.5-($E$6/10)*I12),1)	=F12*(J12)	=IF(K12<=0.0000001,0,IF(K12<=0.00001,1,IF(K12<=0.001,2,IF(K12<=0.1,3,4))))
13	0.00000000003	=D13*E13	11000	=(G13/A4)	=IF(H13<1,0.21*(1-H13),0)	=IF(I13>0.08553,10^(6.5-($E$6/10)*I13),1)	=F13*(J13)	=IF(K13<=0.0000001,0,IF(K13<=0.00001,1,IF(K13<=0.001,2,IF(K13<=0.1,3,4))))
14	0.00000000003	=D14*E14	11000	=(G14/A4)	=IF(H14<1,0.21*(1-H14),0)	=IF(I14>0.08553,10^(6.5-($E$6/10)*I14),1)	=F14*(J14)	=IF(K14<=0.0000001,0,IF(K14<=0.00001,1,IF(K14<=0.001,2,IF(K14<=0.1,3,4))))
15	0.00000001	=D15*E15	33	=(G15/A4)	=IF(H15<1,0.21*(1-H15),0)	=IF(I15>0.08553,10^(6.5-($E$6/10)*I15),1)	=F15*(J15)	=IF(K15<=0.0000001,0,IF(K15<=0.00001,1,IF(K15<=0.001,2,IF(K15<=0.1,3,4))))
16	0.000003	=D16*E16	10	=(G16/A4)	=IF(H16<1,0.21*(1-H16),0)	=IF(I16>0.08553,10^(6.5-($E$6/10)*I16),1)	=F16*(J16)	=IF(K16<=0.0000001,0,IF(K16<=0.00001,1,IF(K16<=0.001,2,IF(K16<=0.1,3,4))))
17	0.000003	=D17*E17	10	=(G17/A4)	=IF(H17<1,0.21*(1-H17),0)	=IF(I17>0.08553,10^(6.5-($E$6/10)*I17),1)	=F17*(J17)	=IF(K17<=0.0000001,0,IF(K17<=0.00001,1,IF(K17<=0.001,2,IF(K17<=0.1,3,4))))
18	0.000000003	=D18*E18	10	=(G18/A4)	=IF(H18<1,0.21*(1-H18),0)	=IF(I18>0.08553,10^(6.5-($E$6/10)*I18),1)	=F18*(J18)	=IF(K18<=0.0000001,0,IF(K18<=0.00001,1,IF(K18<=0.001,2,IF(K18<=0.1,3,4))))
19	0.000003	=D19*E19	10	=(G19/A4)	=IF(H19<1,0.21*(1-H19),0)	=IF(I19>0.08553,10^(6.5-($E$6/10)*I19),1)	=F19*(J19)	=IF(K19<=0.0000001,0,IF(K19<=0.00001,1,IF(K19<=0.001,2,IF(K19<=0.1,3,4))))
20	0.000003	=D20*E20	10	=(G20/A4)	=IF(H20<1,0.21*(1-H20),0)	=IF(I20>0.08553,10^(6.5-($E$6/10)*I20),1)	=F20*(J20)	=IF(K20<=0.0000001,0,IF(K20<=0.00001,1,IF(K20<=0.001,2,IF(K20<=0.1,3,4))))
21	0.000003	=D21*E21	10	=(G21/$A$4)	=IF(H21<1,0.21*(1-H21),0)	=IF(I21>0.08553,10^(6.5-($E$6/10)*I21),1)	=F21*(J21)	=IF(K21<=0.0000001,0,IF(K21<=0.00001,1,IF(K21<=0.001,2,IF(K21<=0.1,3,4))))