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Calculation of Oxygen Deficiency Hazard Classes for RHIC

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USDOE Office of Science (SC)

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AD/RHIC/RD-72

RHIC PROJECT

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INTRODUCTION

The calculation of Oxygen Deficiency Hazard (ODH) Classifications was completed for the Magnet Enclosure Building which encloses equipment that may release cryogen or pressurized gas to the building internal volume[1]. Calculation of ODH Classifications was also completed for any other buildings enclosing equipment that may release cryogen or pressurized gas to the building internal volume[2]. This sudden release[3] could then expose personnel in that building to an oxygen deficient atmosphere.

The criteria, guidelines, and methods for the calculation of ODH classifications, are defined in the Rhic Project Document "Oxygen Deficiency Hazards (ODH)[4]." The classifications are quantified from "0" to "4", for no hazard to the most severe hazard respectively, by calculating the ODH fatality rate (per hour) as defined by:

$$\Phi = \Sigma N_i P_i F_i \qquad (1)$$

where N_i = number of i-type components
P_i = probability of the i-th component failure per hour
F_i = fatality factor or O_2%.

The value of the ODH fatality rate is used to determine the ODH classification.

Table I ODH Classes

ODH Class	Fatality Rate Φ (1/hr.)
Unclassified	$\Phi < 10^{-9}$
0	$10^{-9} \leq \Phi < 10^{-7}$
1	$10^{-7} \leq \Phi < 10^{-5}$
2	$10^{-5} \leq \Phi < 10^{-3}$
3	$10^{-3} \leq \Phi < 10^{-1}$
4	$\Phi \geq 10^{-1}$

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DISCUSSION

To prepare for a specific ODH calculation the following data and calculations are required:

1- The quantity of each different type of component, contained in the building volume, that could fail and cause a spill. N_1, N_2, N_3, etc.

2- The probability of the i-th component failure and human error rate estimates (per hour) shown in Reference 3 tables B-IV, B-V, B-VI, and B-VII. P_1, P_2, P_3, etc.

3- The building volume in ft^3 (V), from Reference 1 and calculations of building volumes from architectural drawings, Reference 2.

4- The fan ventilation rate in CFM (Q).

5- The spill rate in SCFM (R), from Reference 2 and/or manufacturer's data.

6- Spill time in minutes (t).

7- Atmospheric pressure in Torr (p)

8- The fatality factor (F) per hour as defined by:

$$F_i = 10^{(6.5 - P02i/10)} \qquad (2)$$

where

$$P0_{2i} = cr_i * p/100 \qquad \text{Partial pressure } O_2 \text{ (mmHg)} \qquad (3)$$

and

$$cr_i = 0.21*[1-R/Q*(1-e^{(-Q*t/V)})]*100 \qquad O_2\% \text{ (volumetric) during release} \qquad (4)$$

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CALCULATIONS

The building volumes requiring ODH classifications were numerous and calculations to arrive at the most optimum ventilation rates were repetitive. In addition a parametric study, with variable fan rates, was performed to assure the optimal number of fan(s) were selected for a given enclosure. For each building volume three sets of calculations were made as follows: 1- full fans, 2- one fan off, and 3- no fan. To expedite the calculations a Mathcad program was developed (see Appendix I). The equations from Reference 4 were utilized, in this program, to conduct the parametric study and calculate all ODH classifications.

RESULTS

The results of the ODH calculations, for full fan operation, can be found in Appendix II.

REFERENCES

1. D.P. Brown, ", RHIC Project Technical Note AD/RHIC/RD-78, Nov. 1994.

2. RHIC Cryogenic System Safety Analysis Report, Introduction; Table 4, calculated from P.E. Architectural Drawings.

3. K.C. Wu, "Estimation of Helium Discharge Rates for RHIC ODH Calculations", RHIC Project Technical Note AD/RHIC/RD-79, Nov. 1994.

4. Oxygen Deficiency Hazards (ODH), RHIC Project Document.

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APPENDIX 1

This mathcad program calculates the ODH class when the ventilation fans are drawing from the the confined volume at a rate greater than the spill rate. The methodology followed is described in the RHIC ODH standard.

$D := READPRN(v100r)$ Reads data input file "vXXXX.prn"

$v0 := D^{<0>}$

$AREACODE := D_{28}$

Area in Question= $AREACODE = 100$

DATA : R...,V,Q,P1...,N1....

DATA

Gas Spill Rate (R) [f(t)]

DATA

$R := D_2$	$R6 := D_8$	(SCFM He)
$R1 := D_3$	$R7 := D_9$	(SCFM He)
$R2 := D_4$	$R8 := D_{10}$	(SCFM He)
$R3 := D_5$	$R9 := D_{11}$	(SCFM He)
$R4 := D_6$	$R10 := D_{12}$	(SCFM He)
$R5 := D_7$	$R11 := D_{13}$	(SCFM He)
	$R12 := D_{14}$	(SCFM He)
	$R13 := D_{15}$	(SCFM He)

Confined Volume (V) $V := D_0$ (CF)

Fan Vent Rate (Q) $Q := D_1$ (CFM)

Note: failure rates below obtained from the ODH standard. If the variety of equipment numbers less then 6, enter "0" for N..... DATA

Equip. #1 failure rate (P1)	$P1 := D_{16}$	(per hr.)
Quantity of Equip. #1 (N1)	$N1 := D_{17}$	(ea.)
Equip. #2 failure rate (P2)	$P2 := D_{18}$	(per hr.)
Quantity of Equip. #2 (N2)	$N2 := D_{19}$	(ea.)
Equip. #3 failure rate (P3)	$P3 := D_{20}$	(per hr.)
Quantity of Equip. #3 (N3)	$N3 := D_{21}$	(ea.)
Equip. #4 failure rate (P4)	$P4 := D_{22}$	(per hr.)
Quantity of Equip. #4 (N4)	$N4 := D_{23}$	(ea.)
Equip. #5 failure rate (P5)	$P5 := D_{24}$	(per hr.)
Quantity of Equip. #5 (N5)	$N5 := D_{25}$	(ea.)(FANS)
Equip. #6 failure rate (P6)	$P6 := D_{26}$	(per hr.)
Quantity of Equip. #6 (N6)	$N6 := D_{27}$	(ea.)

Note: R - R13 above are time (t in min.) dependant spill rates as follows:

R:	$0 \le t \le .5$	
R1:	$.5 < t \le 1.0$	
R2:	$1.0 < t \le 1.5$	
R3:	$1.5 < t \le 2.0$	
R4:	$2.0 < t \le 2.5$	
R5:	$2.5 < t \le 3.0$	ETC.

$i := 0, 1 .. 14$

$t_i := \frac{i}{2}$

$R_i := R \cdot 1 \quad R1_i := R1 \cdot 1 \quad R2_i := R2 \cdot 1 \quad R6_i := R6 \cdot 1 \quad R7_i := R7 \cdot 1 \quad R8_i := R8 \cdot 1 \quad R12_i := R12 \cdot 1$

$R3_i := R3 \cdot 1 \quad R4_i := R4 \cdot 1 \quad R5_i := R5 \cdot 1 \quad R9_i := R9 \cdot 1 \quad R10_i := R10 \cdot 1 \quad R11_i := R11 \cdot 1 \quad R13_i := R13 \cdot 1$

$R_i := if(t_i \le .5, R_i, if(t_i \le 1.0, R1_i, if(t_i \le 1.5, R2_i, if(t_i \le 2.0, R3_i, if(t_i \le 2.5, R4_i, if(t_i \le 3.0, R5_i, if(t_i \le 3.5, R6_i, if(t_i \le 4.0, R7_i, if(t_i \le 4.5, R8_i, if(t$

$A_i := if(t_i \le .5, R1_i, if(t_i \le 1.0, R2_i, if(t_i \le 1.5, R3_i, if(t_i \le 2.0, R4_i, if(t_i \le 2.5, R5_i, if(t_i \le 3.0, R6_i, if(t_i \le 3.5, R7_i, if(t_i \le 4.0, R8_i, if(t_i \le 4.5, R9_i, if($

$P11 := N1 \cdot P1 \quad P44 := N4 \cdot P4 \quad P22 := N2 \cdot P2 \quad P33 := N3 \cdot P3 \quad P55 := N5 \cdot P5 \quad P66 := N6 \cdot P6$

$$cr_i := 21 \cdot \left[1 - \frac{R_i + A_i}{2 \cdot Q} \cdot \left(1 - e^{-Q \cdot \frac{t_i}{V}} \right) \right]$$

$$Cr_i := \mathrm{if}\left(cr_i \ge 0, cr_i, 0\right)$$

eqs. calculate O2 % by vol. and constrain to >0%

$$Cr_1 := \mathrm{if}\left(Cr_1 \ge 2 \cdot Cr_0, \frac{\sqrt{Cr_0 + Cr_1}}{2}, Cr_1\right)$$

$$Cr_2 := \mathrm{if}\left(Cr_2 \ge 2 \cdot Cr_1, \frac{\sqrt{Cr_1 + Cr_2}}{2}, Cr_2\right)$$

$$Cr_3 := \mathrm{if}\left(Cr_3 \ge 2 \cdot Cr_2, \frac{\sqrt{Cr_2 + Cr_3}}{2}, Cr_3\right)$$

$$Cr_4 := \mathrm{if}\left(Cr_4 \ge 2 \cdot Cr_3, \frac{\sqrt{Cr_3 + Cr_4}}{2}, Cr_4\right)$$

$$Cr_5 := \mathrm{if}\left(Cr_5 \ge 2 \cdot Cr_4, \frac{\sqrt{Cr_4 + Cr_5}}{2}, Cr_5\right)$$

$$Cr_6 := \mathrm{if}\left(Cr_6 \ge 2 \cdot Cr_5, \frac{\sqrt{Cr_5 + Cr_6}}{2}, Cr_6\right)$$

$$Cr_7 := \mathrm{if}\left(Cr_7 \ge 2 \cdot Cr_6, \frac{\sqrt{Cr_6 + Cr_7}}{2}, Cr_7\right)$$

$$Cr_8 := \mathrm{if}\left(Cr_8 \ge 2 \cdot Cr_7, \frac{\sqrt{Cr_8 + Cr_7}}{2}, Cr_7\right)$$

$$Cr_9 := \mathrm{if}\left(Cr_9 \ge 2 \cdot Cr_8, \frac{\sqrt{Cr_8 + Cr_9}}{2}, Cr_9\right)$$

$$Cr_{10} := \mathrm{if}\left(Cr_{10} \ge 2 \cdot Cr_9, \frac{\sqrt{Cr_9 + Cr_{10}}}{2}, Cr_{10}\right)$$

$$Cr_{11} := \mathrm{if}\left(Cr_{11} \ge 2 \cdot Cr_{10}, \frac{\sqrt{Cr_{10} + Cr_{11}}}{2}, Cr_{11}\right)$$

$$Cr_{12} := \mathrm{if}\left(Cr_{12} \ge 2 \cdot Cr_{11}, \frac{\sqrt{Cr_{12} + Cr_{11}}}{2}, Cr_{12}\right)$$

$$Cr_{13} := \mathrm{if}\left(Cr_{13} \ge 2 \cdot Cr_{12}, \frac{\sqrt{Cr_{12} + Cr_{13}}}{2}, Cr_{13}\right)$$

$$PO2_i := Cr_i \cdot \frac{760}{100}$$ PP O2

$$G_i := 10^{\left(6.5 - \frac{PO2_i}{10}\right)}$$

$F_i := \text{if}\left(G_i \ge 1, 1, \text{if}\left(G_i \le 1\cdot 10^{-7}, 0.0, \text{if}\left(G_i > 1\cdot 10^{-7}, G_i, 1\right)\right)\right)$

Eq. at left calculates fatality factor and sets limits between 0 and 1. Nested "if" statement.

$\phi_i := P11\cdot F_i + P22\cdot F_i + P33\cdot F_i + P44\cdot F_i + P55\cdot F_i + P66\cdot F_i$

$P_i := (P11 + P22 + P33 + P44 + P55 + P66)\cdot 1$

ODH fatality Rate.

$P_i := P_i \cdot 1\cdot 10^{6}$ $F_i := F_i \cdot 1\cdot 10^{7}$

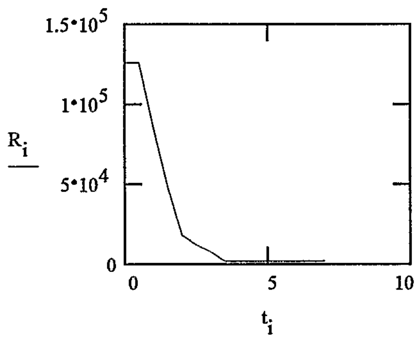
$ODH_i := \text{if}\left(\phi_i \le 1\cdot 10^{-7}, 0, \text{if}\left(\phi_i \le 1\cdot 10^{-5}, 1, \text{if}\left(\phi_i \le 1\cdot 10^{-3}, 2, \text{if}\left(\phi_i \le 1\cdot 10^{-1}, 3, 4\right)\right)\right)\right)$

$\phi_i := \phi_i \cdot 1\cdot 10^{7}$

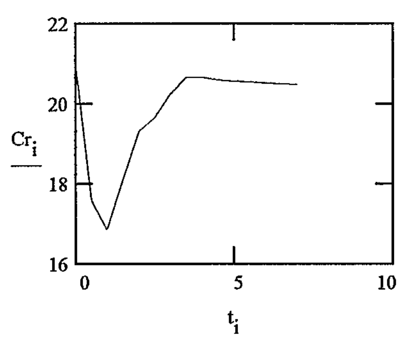
The eq. above calculates the ODH class. Nested "if" statement.

Spill Rate (SCFM) R_i	T (min) t_i	O2 (%) Cr_i	PP (mmHg) $PO2_i$	Fatality Factor Fi (10E-7) F_i	Event Rate Pi (10E-6) (per hr.) P_i	ODH Fatality Rate phi (10E-7) (per hr.) ϕ_i	ODH Class ODH_i
126000	0	21	159.6	0	7919.15	0	0
126000	0.5	17.6	133.5	1.422	7919.15	0.011	0
87000	1	16.8	128	5.007	7919.15	0.04	0
48000	1.5	18.1	137.5	0	7919.15	0	0
18000	2	19.3	146.8	0	7919.15	0	0
12000	2.5	19.7	149.5	0	7919.15	0	0
7800	3	20.2	153.9	0	7919.15	0	0
2000	3.5	20.7	157	0	7919.15	0	0
2000	4	20.7	157	0	7919.15	0	0
2000	4.5	20.6	156.5	0	7919.15	0	0
2000	5	20.6	156.3	0	7919.15	0	0
2000	5.5	20.5	156.1	0	7919.15	0	0
2000	6	20.5	155.9	0	7919.15	0	0
2000	6.5	20.5	155.8	0	7919.15	0	0
2000	7	20.5	155.7	0	7919.15	0	0

Spill rate (CFM) vs. Time (min.)



O2 (%) vs. Time (min.)



$ODHCLASS := if(ODH_2 < ODH_1, ODH_1, if(ODH_3 < ODH_2, ODH_2, if(ODH_4 < ODH_3, ODH_3, if(ODH_5 < ODH_4, ODH_4, if(ODH_6 < ODH_5,$

The equation above selects the highest ODH class.

For: $AREACODE = 100$ **,the** $ODHCLASS = 0$

$O := ODHCLASS$

$APPEND(output) := O$ **Writes output to file "output.dat"**

OXYGEN DEFICIENCY HAZARD CLASS FOR RHIC BUILDINGS DURING NORMAL OPERATIONS

BLDG NO	BUILDING NAME	ODH CLASS
1005H	Compressor Bldg.	0
1005R	Cryogenic Bldg.	1
1001	RME-1:00	0
1003	RME-3:00	0
1005	RME-5:00	0
1007	RME-7:00	0
1009	RME-9:00	0
1011	RME-11:00	0
1002B	2:00 Service Bldg	0
1004B	4:00 Service Bldg	0
1006B	6:00 Service Bldg	0
1008B	8:00 Service Bldg	0
1010A	10:00 Service Bldg	0
1012A	12:00 Service Bldg	0

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