Calculation of Oxygen Deficiency Hazard Classes for RHIC

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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:

\[
\Phi = \sum N_i P_i F_i
\] (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 1  ODH Classes

<table>
<thead>
<tr>
<th>ODH Class</th>
<th>Fatality Rate (\Phi) (1/hr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unclassified</td>
<td>(\Phi &lt; 10^0)</td>
</tr>
<tr>
<td>0</td>
<td>(10^0 \leq \Phi &lt; 10^7)</td>
</tr>
<tr>
<td>1</td>
<td>(10^7 \leq \Phi &lt; 10^5)</td>
</tr>
<tr>
<td>2</td>
<td>(10^5 \leq \Phi &lt; 10^3)</td>
</tr>
<tr>
<td>3</td>
<td>(10^3 \leq \Phi &lt; 10^1)</td>
</tr>
<tr>
<td>4</td>
<td>(\Phi \geq 10^1)</td>
</tr>
</tbody>
</table>

odh.tek 8/94
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 \( \text{ft}^3 \) (\( V \)), 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:

\[
F_i = 10^{(6.5+P_{02}/10)}
\]  

(2)

where

\[
P_{02i} = cr_i \times p/100 \quad \text{Partial pressure } O_2 \,(\text{mmHg})
\]  

(3)

and

\[
cr_i = 0.21 \times [1 - R/Q \times (1 - e^{(-Q*p/V)})] \times 100 \quad \text{O}_2\% \,(\text{volumetric}) \, \text{during release}
\]  

(4)
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


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


4. Oxygen Deficiency Hazards (ODH), RHIC Project Document.
This Mathcad program calculates the ODH class when the ventilation fans are drawing from the confined volume at a rate greater than the spill rate. The methodology followed is described in the RHIC ODH standard.

\[ D := \text{READPRN}(v100r) \text{ Reads data input file "vXXXX.prn"} \]

\[ v0 := D^{20} \]

\[ \text{AREACODE} := D_{28} \]

\[ \text{Area in Question} = \text{AREACODE} = 100 \]

**DATA**

- \[ R := D_2 \]
- \[ R_6 := D_8 \] (SCFM He)
- \[ R_1 := D_3 \]
- \[ R_7 := D_9 \] (SCFM He)
- \[ R_2 := D_4 \]
- \[ R_8 := D_{10} \] (SCFM He)
- \[ R_3 := D_5 \]
- \[ R_9 := D_{11} \] (SCFM He)
- \[ R_4 := D_6 \]
- \[ R_{10} := D_{12} \] (SCFM He)
- \[ R_{11} := D_{13} \] (SCFM He)
- \[ R_{12} := D_{14} \] (SCFM He)
- \[ R_{13} := D_{15} \] (SCFM He)

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

- **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.....

\[ \text{DATA} \]

**Equip. #1 failure rate (P1)**
- \[ P_1 := D_{16} \] (per hr.)

**Quantity of Equip. #1 (N1)**
- \[ N_1 := D_{17} \] (ea.)

** Equip. #2 failure rate (P2)**
- \[ P_2 := D_{18} \] (per hr.)

**Quantity of Equip. #2 (N2)**
- \[ N_2 := D_{19} \] (ea.)

** Equip. #3 failure rate (P3)**
- \[ P_3 := D_{20} \] (per hr.)

**Quantity of Equip. #3 (N3)**
- \[ N_3 := D_{21} \] (ea.)

** Equip. #4 failure rate (P4)**
- \[ P_4 := D_{22} \] (per hr.)

**Quantity of Equip. #4 (N4)**
- \[ N_4 := D_{23} \] (ea.)

** Equip. #5 failure rate (P5)**
- \[ P_5 := D_{24} \] (per hr.)

**Quantity of Equip. #5 (N5)**
- \[ N_5 := D_{25} \] (ea.) (FANS)

** Equip. #6 failure rate (P6)**
- \[ P_6 := D_{26} \] (per hr.)

**Quantity of Equip. #6 (N6)**
- \[ N_6 := D_{27} \] (ea.)

\[ R_i := R_{i-1} \]

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

- \[ R := 0 \text{ if } t \leq 5 \]
- \[ R_1 := .5 \text{ if } t < 1.0 \]
- \[ R_2 := 1.0 \text{ if } t < 1.0 \]
- \[ R_3 := 1.5 \text{ if } t < 2.0 \]
- \[ R_4 := 2.0 \text{ if } t < 3.0 \]
- \[ R_5 := 2.5 \text{ if } t < 4.0 \]
- \[ R_6 := 3.0 \text{ if } t < 4.0 \]
- \[ R_7 := 3.5 \text{ if } t < 4.0 \]
- \[ R_8 := 4.0 \text{ if } t < 4.0 \]
- \[ R_9 := 4.5 \text{ if } t < 4.0 \]
- \[ R_{10} := 5.0 \text{ if } t < 4.0 \]
- \[ R_{11} := 5.5 \text{ if } t < 4.0 \]
- \[ R_{12} := 6.0 \text{ if } t < 4.0 \]
- \[ R_{13} := 6.5 \text{ if } t < 4.0 \]

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

\[ cr_i := \text{if}(cr_i \geq 0, cr_i, 0) \quad \text{eqs. calculate O2 \% by vol. and constrain to } > 0\% \]

\[ Cr_1 := \text{if}(cr_1 \geq 2 \cdot Cr_6, \sqrt{\frac{Cr_0 + Cr_1}{2}}, Cr_1) \]

\[ Cr_2 := \text{if}(cr_2 \geq 2 \cdot Cr_1, \sqrt{\frac{Cr_1 + Cr_2}{2}}, Cr_2) \]

\[ Cr_3 := \text{if}(cr_3 \geq 2 \cdot Cr_2, \sqrt{\frac{Cr_2 + Cr_3}{2}}, Cr_3) \]

\[ Cr_4 := \text{if}(cr_4 \geq 2 \cdot Cr_3, \sqrt{\frac{Cr_3 + Cr_4}{2}}, Cr_4) \]

\[ Cr_5 := \text{if}(cr_5 \geq 2 \cdot Cr_4, \sqrt{\frac{Cr_4 + Cr_5}{2}}, Cr_5) \]

\[ Cr_6 := \text{if}(cr_6 \geq 2 \cdot Cr_5, \sqrt{\frac{Cr_5 + Cr_6}{2}}, Cr_6) \]

\[ Cr_7 := \text{if}(cr_7 \geq 2 \cdot Cr_6, \sqrt{\frac{Cr_6 + Cr_7}{2}}, Cr_7) \]

\[ Cr_8 := \text{if}(cr_8 \geq 2 \cdot Cr_7, \sqrt{\frac{Cr_8 + Cr_7}{2}}, Cr_8) \]

\[ Cr_9 := \text{if}(cr_9 \geq 2 \cdot Cr_8, \sqrt{\frac{Cr_8 + Cr_9}{2}}, Cr_9) \]

\[ Cr_{10} := \text{if}(cr_{10} \geq 2 \cdot Cr_9, \sqrt{\frac{Cr_9 + Cr_{10}}{2}}, Cr_{10}) \]

\[ Cr_{11} := \text{if}(cr_{11} \geq 2 \cdot Cr_{10}, \sqrt{\frac{Cr_{10} + Cr_{11}}{2}}, Cr_{11}) \]

\[ Cr_{12} := \text{if}(cr_{12} \geq 2 \cdot Cr_{11}, \sqrt{\frac{Cr_{12} + Cr_{11}}{2}}, Cr_{12}) \]

\[ Cr_{13} := \text{if}(cr_{13} \geq 2 \cdot Cr_{12}, \sqrt{\frac{Cr_{12} + Cr_{13}}{2}}, Cr_{13}) \]

\[ PO_2 := \frac{Cr_{760} \cdot 100}{100} \quad \text{PP O2} \]

\[ G_i := 10 \left( 6.5 - \frac{PO_2}{10} \right) \]
\[ F_i := \text{if} \left( G_i \geq 1, 1, \text{if} \left( G_i \leq 1 \cdot 10^{-7}, 0, \text{if} \left( G_i > 1 \cdot 10^{-7}, G_i, 1 \right) \right) \right) \]

\[ \phi_i := P_i \cdot F_i + P22 \cdot F_i + P33 \cdot F_i + P44 \cdot F_i + P55 \cdot F_i + P66 \cdot F_i \]

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

\[ P_i = P_i \cdot 1 \cdot 10^6 \]

\[ F_i := F_i \cdot 1 \cdot 10^7 \]

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

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

<table>
<thead>
<tr>
<th>Spill Rate (SCFM)</th>
<th>T (min)</th>
<th>O2 (%)</th>
<th>PP (mmHg)</th>
<th>Fatality Factor ( F_i ) (10E-7)</th>
<th>Event Rate ( P_i ) (10E-6) (per hr.)</th>
<th>ODH Rate ( \phi_i ) (per hr.)</th>
<th>ODH Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>126000</td>
<td>0</td>
<td>21</td>
<td>159.6</td>
<td>0</td>
<td>7919.15</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>133.5</td>
<td>1.422</td>
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<td>0.011</td>
<td>0</td>
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<td>0</td>
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<tr>
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<td>20.7</td>
<td>157</td>
<td>0</td>
<td>7919.15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>4.5</td>
<td>20.6</td>
<td>156.5</td>
<td>0</td>
<td>7919.15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>5</td>
<td>20.6</td>
<td>156.3</td>
<td>0</td>
<td>7919.15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>5.5</td>
<td>20.5</td>
<td>156.1</td>
<td>0</td>
<td>7919.15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
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<td>20.5</td>
<td>155.9</td>
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<td>7919.15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>6.5</td>
<td>20.5</td>
<td>155.8</td>
<td>0</td>
<td>7919.15</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>20.5</td>
<td>155.7</td>
<td>0</td>
<td>7919.15</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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

O2 (%) vs. Time (min.)
ODHCLASS := if(ODH < ODH, ODH, if(ODH < ODH, ODH, if(ODH < ODH, ODH, if(ODH < ODH, ODH, ODH, ODH))}

The equation above selects the highest ODH class.

For: AREACODE = 100, the ODHCLASS = 0

O := ODHCLASS

APPEND(output) := O  \(\text{W}r\) \(\text{i}t\es\) \(\text{e}t\) output to file "output.dat"
### OXYGEN DEFICIENCY HAZARD CLASS FOR RHIC BUILDINGS DURING NORMAL OPERATIONS

<table>
<thead>
<tr>
<th>BLDG NO</th>
<th>BUILDING NAME</th>
<th>ODH CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1005H</td>
<td>Compressor Bldg.</td>
<td>0</td>
</tr>
<tr>
<td>1005R</td>
<td>Cryogenic Bldg.</td>
<td>1</td>
</tr>
<tr>
<td>1001</td>
<td>RME-1:00</td>
<td>0</td>
</tr>
<tr>
<td>1003</td>
<td>RME-3:00</td>
<td>0</td>
</tr>
<tr>
<td>1005</td>
<td>RME-5:00</td>
<td>0</td>
</tr>
<tr>
<td>1007</td>
<td>RME-7:00</td>
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</tr>
<tr>
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<td>RME-11:00</td>
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</tr>
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