ARGONNE NATIONAL LABORATORY

HIGH ENERGY PHYSICS DIVISION

AWA

ARGONNE WAKEFIELD ACCELERATOR

OXEYGEN-DEFICIENCY ANALYSIS IN THE AWA BUNKER (REVISED IN MAY 2002)

Approved:

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Oxygen-Deficiency Analysis in the AWA Bunker

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The hazard of interest is the liquid nitrogen in a standard 80-liter dewar. This dewar will be brought into the AWA bunker only when it is necessary to vent the AWA vacuum system. It is estimated that this will happen, in average, once every two months. On these occasions the dewar will remain in the AWA bunker for a period of approximately two to six hours.

The AWA bunker is housed in Building 366 and built by large concrete blocks. It is about 75 ft long, 10 ft wide, and 7.5 ft high, with a total internal volume of 5722 ft^3 (162 m^3). Figure 1 shows the layout of the bunker and the location of its two doors, each one being 7 ft high and 33 inches wide. Three floor fans are normally situated on the positions marked in Figure 1, and provide air circulation when the machine is not in operation. These fans should be set to "high" when the liquid nitrogen dewar is brought into the bunker, in order to guarantee a high air exchange between the bunker and the rest of the building. Under these conditions the air flow through the doors was measured (Fig. 2), yielding a total exhaust rate of 1500 CFM (0.71 m^3/s).

The analysis in this document is based on a similar analysis shown in the Physics Division Cryogenic Safety Manual. The goal of the Oxygen Deficiency Hazard (ODH) risk assessment is to estimate the rate at which fatalities will occur as a result of exposure to reduced-oxygen atmospheres. The oxygen deficiency hazard fatality rate (D) for a given event is defined as the product of the expected rate of that event (P) by the fatality factor for the event (F):

$$D = P\ F$$

Since there will be no liquid nitrogen transfer in the bunker, the worst credible accident is one in which the main liquid nitrogen tube at the top of the dewar is accidentally severed. This would require a massive blow, since the tube is solid stainless steel and is well protected by the structure of the dewar. According to the Physics Division Cryogenic Safety Manual, the probability of such an accident can be estimated from the experience in the Physics Division, where no such accident has ever occurred in over 40 years of experience. At least 10 dewars are present in the building on an average. Thus, the accident rate P is

$$P \leq (400\ yr)^{-1} = 2.5 \times 10^{-3}\ yr^{-1}$$

The value of the fatality factor (F) depends on the oxygen concentration, the duration of exposure and the difficulty of escape. For convenience of calculation we will use the same relationship that was used in the Physics Division Cryogenic Safety Manual, relating F to the lowest attainable oxygen concentration (C_{oxy}):

(a) for $C_{oxy} \geq 18\%$, $F = 0$

(b) for $8.8\% \leq C_{oxy} \leq 18\%$, $F = 10^{(6.5 - PO_2/10)}$, where PO_2 is the partial pressure of oxygen

(c) for C_{oxy} less than 8.8%, $F = 1$

The concentration of oxygen can be calculated using the following expressions (also found in the Physics Division Cryogenic Safety Manual):

(i) during the release: $$C_R(t) = \frac{0.21}{Q+R}\left(Q + R\,\exp\left(\frac{Q+R}{-V}\,t\right)\right)$$

(ii) after the release: $$C_E(t) = 0.21\left(1 - \exp\left(\frac{Q}{-V}t\right)\right) + C_R(t_e)\exp\left(\frac{Q}{-V}t\right)$$

where Q (m^3/s) is the air exhaust rate for the room
R (m^3/s) is the nitrogen gas emission rate
V (m^3) is the volume of the room
t_e (s) is the duration of the nitrogen gas emission

The lowest attainable oxygen concentration, assuming complete mixing for the nitrogen and air, is given by:

$$C_{oxy} = \frac{0.21}{1 + \frac{Q}{R}}\left\{\frac{Q}{R} + \exp\left[-\left(\frac{Q}{R} + 1\right)\frac{V_{nitr}}{V}\right]\right\}$$

where V_{nitr} (m^3) is the total volume of nitrogen gas that results from the initial liquid nitrogen.

In our case of worst credible accident (in which the main liquid nitrogen tube at the top of the dewar is accidentally severed), we estimate, again based on the Physics Division Cryogenic Safety Manual, that the emission rate of liquid nitrogen would not be higher than 12.7 liters per second. This corresponds to an emission rate of nitrogen gas of 8.57 m^3/s, and it would last for about 6.3 s.

Under these conditions the lowest reached oxygen concentration (C_{oxy}) is 15.1 %, corresponding to a partial pressure of 112 Torr, and a fatality factor (F) of 2.0×10^{-5}. Figure 3(a) shows the time evolution of the oxygen concentration in these conditions.

Therefore, the fatality rate (D) for the worst credible accident is

$$D = P\,F = 2.5 \times 10^{-3}\,yr^{-1} \times 2.0 \times 10^{-5} = 5.0 \times 10^{-8}\,yr^{-1}$$

This very low number puts the analyzed hazard as an Oxygen Deficiency Hazard Class 0, which requires no protective measures to further reduce the risk of fatality. This would be the case even if the dewar were kept in the bunker all the time.

Even if worse scenarios are considered — for example a reduction of the exhaust rate by a factor two, as shown in Fig. 3(b), or a catastrophic explosion of the dewar, releasing all the liquid nitrogen in a fraction of a second — the lowest attainable oxygen concentration would have approximately the same value we just calculated. Thus, the hazard would still be classified as an Oxygen Deficiency Hazard Class 0.

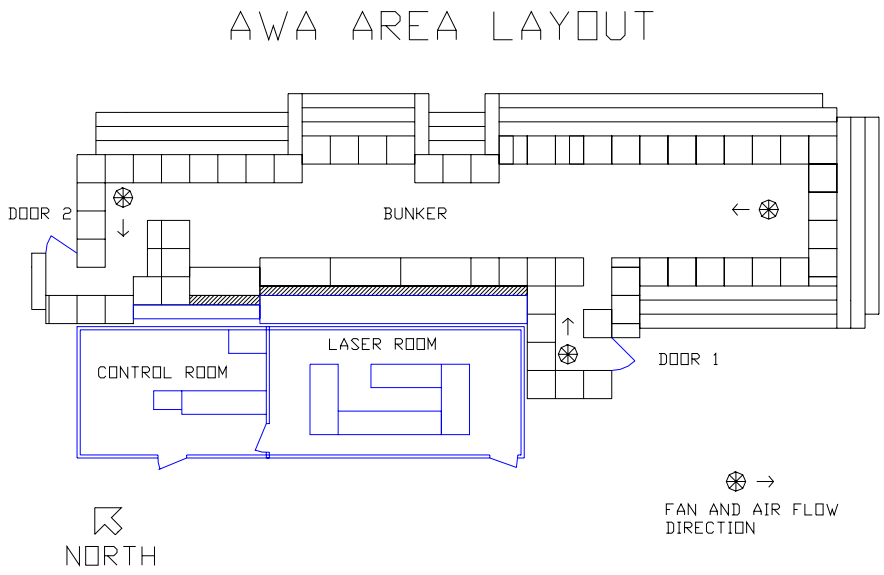

Figure 1: Layout of the AWA Bunker, showing the location of the two doors and the three fans.

40	90	85
60	70	85
70	70	85
70	80	100
80	90	90
70	90	80
85	85	70

Figure 2: Measured air flow through Door #2 of AWA Bunker. Each rectangle is 11 inches wide and 12 inches high. The numbers correspond to the air flow in ft/min measured by an Alnor air flow gauge model #9870.

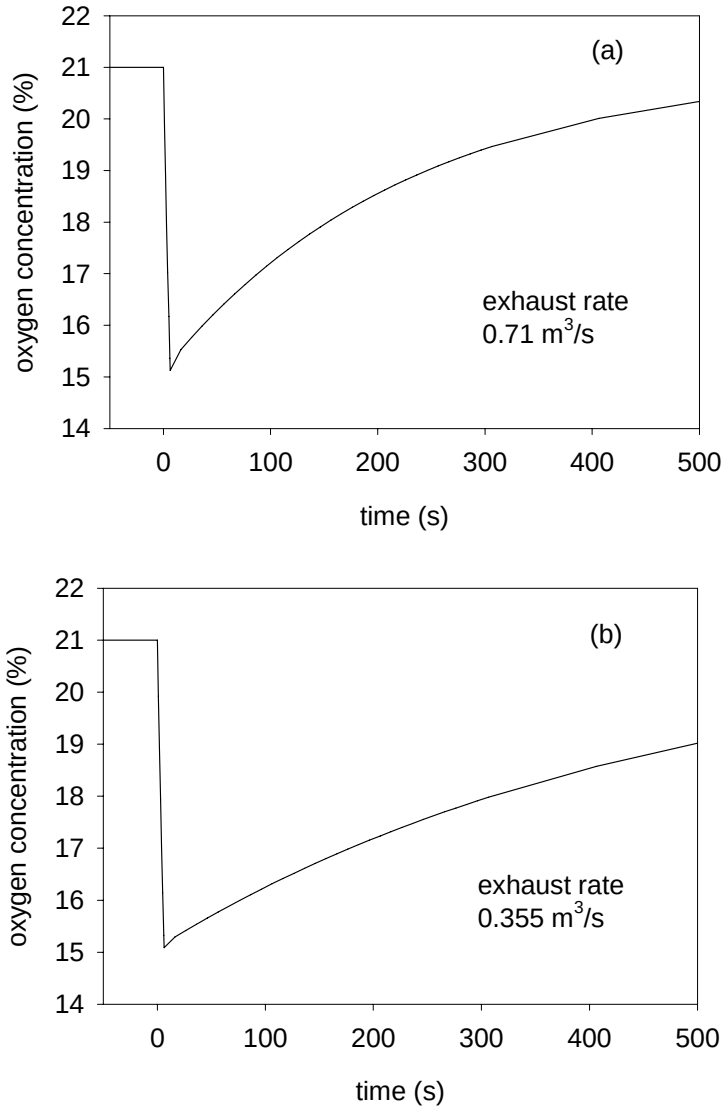

Figure 3: Oxygen concentration in the AWA bunker as a function of time, in the event of a catastrophic dewar breakage: (a) for the measured exhaust rate; (b) for an exhaust rate half as big.