## ATTACHMENT H SAMPLE CALCULATIONS OF ENCLOSED AC ARC OVERPRESSURES

### INTRODUCTION

Converting copper conductors into a plasma as a consequence of short circuit energy can be approximated using a few assumptions. Calculations which use these assumptions can give an estimated pressure change for a fixed volume.

### CONDITIONS

Initial conditions consist of an electric circuit that has sustained a solid/bolted polyphase fault of 110 kA which is presumed to flow for 5 cycles within an enclosed cubicle. Shock wave effects are neglected in favor of a uniform pressure rise. This event is presumed to occur adiabatically.

### CHARACTERISTICS OF COPPER

Melting Point ..... 1085°C
Boiling Point ..... 2567°C
Specific Heat, Solid ..... 0.0923 Calories/gram at 20°C (varies with temperature)
Specific Heat, liquid ..... 0.118 Calories/gram
Latent heat of fusion ..... 49.0 Calories/gram
Latent Heat of Vaporization ..... 1130.3 Calories/gram
Atomic Weight ..... 63.5 grams/mole
Density ..... 8.92 grams/$cc^3$

### EQUIVALENCIES

238.9 Calories/gram ..... 1.0 kilojoule/gram
61.3 $in^3$ ..... 1.0 Liter volume
1 Mole ..... 6.02 x $10^{23}$ $Atoms_{Cu}$ (Molecules)
1 Mole Volume ..... 22.4 Liters at standard conditions

### CALCULATIONS

1. To vaporize 1 gram of Copper from 20°C ($C_P$ = 0.0923) to 1085°C ($C_P$ = 0.1189); ($C_{Pavg}$ = 0.1056)
   $Q_{total} = Q_1 + Q_2 + Q_3 + Q_4$

   $Q_1$ = 0.1056 x (1085 - 20) = 112.5 Calories
   At 1085°C, $Q_2$ = 49.0 Calories
   From 1085°C to 2567°C
   $Q_3$ = 0.118 x (2567 - 1085) = 174.9 Calories
   $Q_4$, heat of vaporization = 1130.3 Calories

   $Q_{total}$ = 1466.7 Calories/gram

2. Converting: Calories/gram to Kilojoules/gram

$$\frac{1466.7 \text{ Calories/gram}}{238.9 \text{ Calories/Kilojoule}} = 6.14 \text{ kJ/gram}$$

3. Presuming 100% offset, then $I_{max}$ = 110 kA and the average fault current $I_{avg}$ = 55 kA.
The duration of the arc is 5 cycles, such that t = 5/60 sec. = 0.0833 sec.
The voltage drop across the arc is $E_{arc}$ = 200 volts.

4. Converting $I_{sc}$ to equivalent weight of copper, $W_{cu}$

$Q = I_{sc} \times E_{arc} \times t$ (duration of arc in seconds)

$Q = 55 \times 10^3$ amps x 200 volts x 0.0833 sec. = 916.3 kJ

$$W_{cu} = 916.3 \text{ kJ} \times \left( \frac{1 \text{ gram}_{cu}}{6.14 \text{ kJ}} \right) = 149.3 \text{ gram}_{cu}$$

5. Determine quantity of moles (M)
M = Weight / Atomic weight = 149.3 gram x (63.5 grams/Mole)$^{-1}$ = 2.35 $\text{Mole}_{cu}$

6 Equal volumes of gasses at the same temperature and pressure contain the same number of molecules. Therefore, to find the volume (V) of the copper plasma at 2567°C:

$$V = 2.35 \text{ Moles} \times \left( \frac{22.4 \text{ liters}}{1 \text{ Mole}} \right) \times \left( \frac{2567°C + 273°C}{273°C} \right) = 548 \text{ liters}$$

$$548 \text{ liters} \times \left( \frac{61.3 \text{ in}^3}{1 \text{ liter}} \right) = 33{,}590 \text{ in}^3; \text{ or } 33{,}590 \text{ in}^3 \times \left( \frac{1 \text{ ft}^3}{1728 \text{ in}^3} \right) = 19.4 \text{ ft}^3$$

7. The change in pressure ($\Delta P$) within a fixed volume, for example, 5000 liters at 2567°C is:

$$\Delta P = \left( \frac{548 \text{ liters}}{5{,}000 \text{ liters}} \right) \times 14.7 \text{ psi} = 1.61 \text{ psi}$$

**REFERENCES**

1. Handbook of Physics and Chemistry, 1989 and 1992
2. Metals Reference Handbook, 9th Ed. 1979; American Society of Metals