FOLLOWING IS A CALCULATION OF THE MAXIMUM LEAK RATE THROUGH A CRD PENETRATION AT NMP-1.

A. APPROACH

THE FLOW RATE THROUGH THE LEAKING PENETRATION IS CALCULATED BASED ON THE CRITICAL FLOW RATE CORRELATION FROM REFERENCE 1,

$$\dot{M}_L = \dot{G}_c A_F$$

WHERE,

$\dot{G}_c$ = CRITICAL FLOW RATE, LB/SEC-FT^2

A_F = LEAK FLOW AREA, FT^2

THE CRITICAL FLOW RATE IS CALCULATED BASED ON THE VESSEL ENTHALPY AND THE STAGNATION PRESSURE AT THE END OF THE LEAK PATH.

THIS PRESSURE IS GIVEN BY,

$$P_{ox} = P_o - \left(K + \frac{fL}{D_H}\right) \frac{G_c^2}{2 g_c \rho \cdot 144} \qquad (A)$$

WHERE,

P_o = VESSEL PRESSURE, PSIA

K = LOSS COEFFICIENT FOR FLOW CONTRACTION

ρ = FLUID DENSITY, LB/FT^3

f = FRICTION COEFFICIENT

L = LENGTH OF FLOW PATH, IN.

D_H = HYDRAULIC DIAMETER OF FLOW PATH, IN.

B. PARAMETERS

THE CONFIGURATION OF A CRD PENETRATION IS SHOWN IN REFERENCE 2. ALSO, FROM REFERENCE 3, THE VESSEL/STUB TUBE BORE DIAMETER FOR THE MAJORITY OF THE PENETRATIONS IS 5.995 IN. THE DIMENSIONAL PARAMETERS ARE (SEE FIGURE 1),

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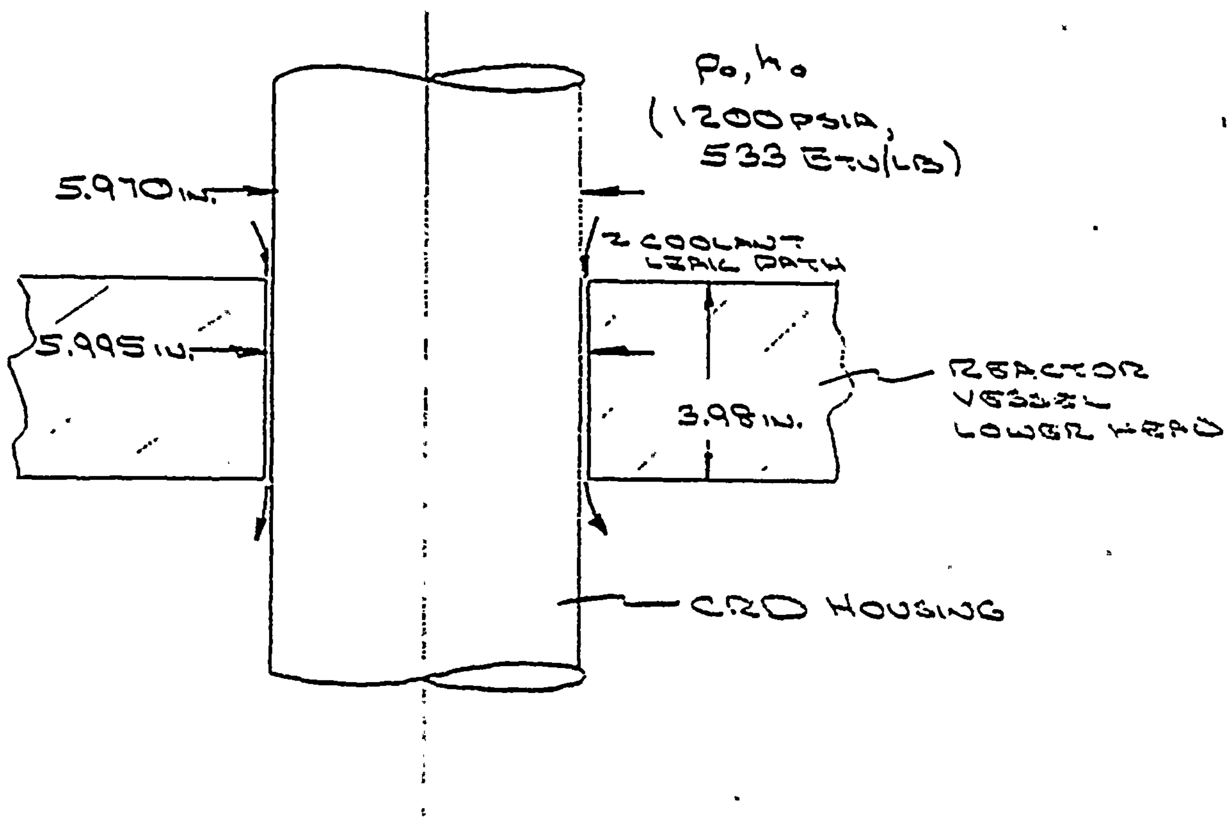
FIGURE 1

SIMPLIFIED SKETCH OF CRD PENETRATION LEAK PATH



$D_H = 2 \times$ (CRD HOUSING TO VESSEL RADIAL GAP)

$$D_H = 2 \cdot \left(\frac{5.995 - 5.970}{2} \right) = .025 \text{ IN}$$

$L = 3.98$ IN (MINIMUM LENGTH – OUTER PENETRATIONS)

$$A_F = \frac{\pi}{4}(5.995^2 - 5.970^2) = 0.235 \text{ IN}^2 \text{ OR } 1.63 \cdot 10^{-3} \text{ FT}^2$$

FROM REFERENCE 4 (p. A-23), THE ABSOLUTE ROUGHNESS FOR DRAWN TUBING IS $5 \cdot 10^{-6}$ FT. THE RELATIVE ROUGHNESS IS,

$$\frac{\varepsilon}{D_H} = \frac{5 \cdot 10^{-6}}{.025/12} = 2.40 \cdot 10^{-3}$$

FROM REFERENCE 4 (p. A-24),

$$f = .024$$

ASSUME AN ENTRANCE LOSS COEFFICIENT OF 0.5. THE PRESSURE LOSS COEFFICIENT IS,

$$\left(K + \frac{fL}{D}\right) = 0.5 + \frac{.024 \times 3.98}{.025}$$

$$= 4.32$$

THE ASSUMED FLUID PARAMETERS ARE,

$P = 1200$ PSIA

$h = 533 \frac{BTU}{LB}$ (ASSUMES 30°F SUBCOOLING)

$\rho = 48\ LB/FT^3$.

C. RESULTS

THE PRESSURE AT THE END OF THE LEAK PATH (P_{ox}) IS PLOTTED AS A FUNCTION OF FLOW RATE ($\mathring{G}_c$) IN FIGURE 2 FROM EQUATION (A) ABOVE. IT IS GIVEN BY,

$$P_{ox} = 1200 - 4.32 \cdot \frac{\mathring{G}_c^2}{2 \cdot 32.2 \cdot 48 \cdot 144}$$

$$P_{ox} = 1200 - 9.70 \cdot 10^{-6} \cdot \mathring{G}_c^2.$$

NOTE THAT THIS EQUATION IS BASED ON THE DENSITY OF THE LIQUID PHASE. IF THE PRESSURE DROPS BELOW SATURATION, FLASHING WILL OCCUR AND THE DENSITY

OF THE FLUID WILL BE REDUCED. THIS WILL RESULT IN AN INCREASED PRESSURE DROP, A REDUCED PRESSURE AT THE END OF THE LEAK PATH AND A REDUCED CRITICAL FLOW RATE.

THE CRITICAL FLOW RATE AT AN ENTHALPY OF 533 BTU/LB IS ALSO PLOTTED IN FIGURE 2 AS A FUNCTION OF PRESSURE BASED ON THE CRITICAL FLOW RATE CORRELATION FROM REFERENCE 1.

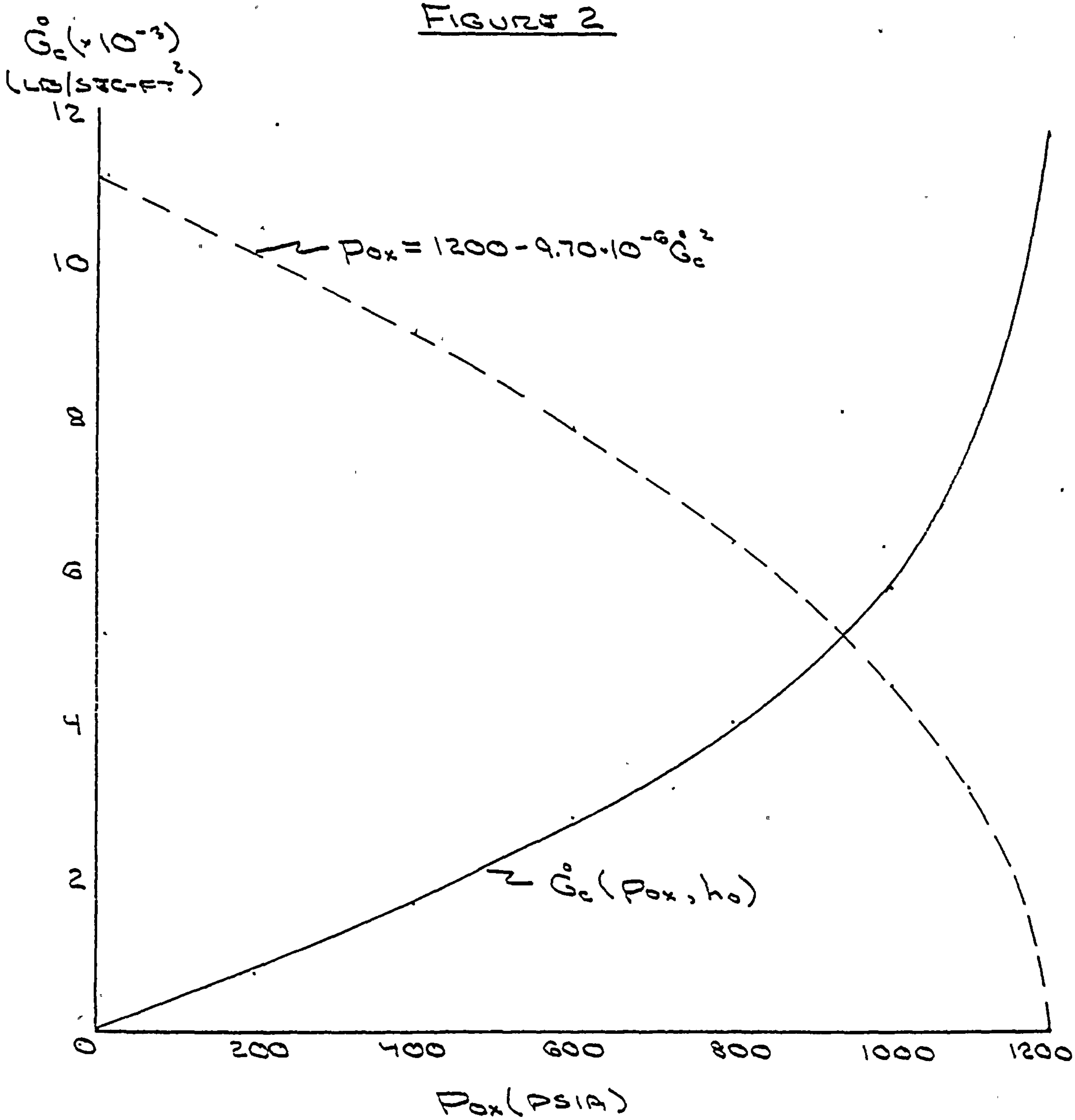
AT THE INTERSECTION OF THE TWO CURVES,

P_{ox} = 940 PSIA (EQUALS SATURATION PRESSURE)

$\dot{G}_c$ = 5200 LB/SEC-FT^2

THE FLOW RATE THROUGH THE ASSUMED LEAKING CRD PENETRATION IS,

FIGURE 2



$\mathring{G}_c (\times 10^{-3})$
(LB/SEC-FT^2)
12
10
8
6
4
2
0
$P_{ox} = 1200 - 9.70 \times 10^{-6} \mathring{G}_c^2$
$\mathring{G}_c (P_{ox}, h_o)$
200
400
600
800
1000
1200
P_{ox} (PSIA)

$$\mathring{M}_L = \mathring{G}_c A_F$$

$$\mathring{M}_L = 5200 \frac{LB}{SEC\text{-}FT^2} \cdot 1.63 \cdot 10^{-3} FT^2$$

$$\mathring{M}_L = 8.48 \frac{LB}{SEC}$$

OR,

$$\mathring{V}_L = 8.48 \frac{LB}{SEC} \cdot \frac{1}{62.4 \frac{LB}{FT^3}} \cdot 7.48 \frac{GALLONS}{FT^3} \cdot 60 \frac{SEC}{MIN}$$

$$\mathring{V}_L = 61.0 \text{ GPM}$$

THIS LEAK RATE SHOULD BE CONSIDERED A "BEST-ESTIMATE" VALUE. BASED ON THE UNCERTAINTIES IN THE PARAMETERS (E.G. CRITICAL FLOW RATE, FRICTION COEFFICIENT, FLOW PATH GAP AND LENGTH), IT IS ESTIMATED THAT THE ACTUAL LEAK RATE WOULD BE IN THE RANGE FROM 30 GPM TO 120 GPM.

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D. REFERENCES

(1) NEDO-21052, "MAXIMUM DISCHARGE RATE OF LIQUID-VAPOR MIXTURES FROM VESSELS," SEPT. 1975.

(2) MPR ASSOC. DRAWING SK-1085-43-500, "CRD HOUSING + STUB TUBE CONFIGURATION AT PEN. NO'S. U1 THRU U8.

(3) COMBUSTION ENG. DRAWING E-231-595 (SHEET 2) "AS-BUILT DIMENSIONS".

(4) CRANE CO. TECHNICAL PAPER NO. 410, "FLOW OF FLUIDS THROUGH VALVES, FITTINGS AND PIPE," 1980.