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POST OFFICE BOX P
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SUBJECT: Calculations Applicable to HRT-BP
Development Loop P-1

TO: T. A. Arehart

FROM: P. G. Lafyatis

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810-1

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Preliminary calculations have been made for the operation of P-1 loop. Various characteristics of the loop have been calculated and are presented. The major problem seems to be that of handling hydrogen and oxygen to minimize the detonation hazards. Hydrogen is necessary in this loop for the precipitation of the plutonium, while oxygen is necessary to reduce the corrosion. The problem is complicated by the presence of the UO_2SO_4 which acts as a catalyst for the recombination of these two gases. As a result, amounts of the two must be periodically injected to maintain the required conditions.

Hydrogen and oxygen form explosive mixtures for a broad range of compositions. In the presence of steam, the explosive limits are somewhat narrowed. The lower limit is of major interest for the P-1 loop and has been reported to have different values by different sources. B.M.I.-705 lists the limit to be about 19% while Y-731 gives a minimum of 22% in their listings.

A suggested set of operating conditions which would give less than explosive concentrations are as follows:

Steam Pressure (500°F- UO_2SO_4 soln)	660 psig
H ₂	100
O ₂	150
Total	910

Excess oxygen above the stoichiometric requirement is considered as an inert diluent.¹ On this basis

$$\frac{150}{910} = 16.5\% \text{ stoichiometric H}_2\text{-O}_2 \text{ mixture}$$

which is below the explosive limit. If this excess oxygen should be consumed, then the composition might become

Steam	660
H ₂	100
O ₂	50
Total	810

$$\frac{150}{810} = 18.5\% \text{ stoichiometric H}_2\text{-O}_2 \text{ mixture, which is still in the safe range.}$$

McDuffie² et al. reports the kinetics of the $\text{H}_2\text{-O}_2$ recombinations under conditions close to those required in this work as:

$$-\frac{dP}{dt} = k_1(\text{UO}_2^{++})P \frac{\frac{V_l}{V_g}}{\frac{V_l}{V_g} + \frac{\alpha}{RT}}$$

Where $\frac{dP}{dt}$ = Change in H₂ partial pressure

(UO_2^{++}) = Concentration of (UO_2^{++}) ion

P = Hydrogen pressure

V_l = Volume of liquid

V_g = Volume of gas

UNCLASSIFIED

810

2

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$$\alpha = \frac{P_{H_2}}{[H_2]} \text{ psia/moles/liter}$$

$$R = 1.206 \text{ l} \cdot \text{psig} / \cdot \text{K mole}$$

$$T = \text{Absolute Temperature } ^\circ \text{K}$$

Using data from Figure 25 of the above report for 1.25 M UO_2SO_4 at 500°F ; $k = 0.4$. Data for the solubility of hydrogen in the uranyl sulfate solutions were not available, however, available data was extrapolated to give a value for $\alpha = \frac{1.38 \times 10^4 \text{ psia}}{\text{moles/liter}}$. It was apparent, however, that in deriving the

value for k in the above equation, the value for the solubility of hydrogen in pure water was used. In a later report McDuffie³ does give a value in pure water of $\alpha = \frac{6720 \text{ psi liter}}{\text{moles}}$, and points out that data concerning the

solubility of H_2 in the solutions is not available.

Evaluation of V_g and V_l required calculation of volumes in the loop. Table I presents the calculated values.

Table I

LOOP P-1 VOLUMES

#1 Restrictor	19.8 in. ³
#2 Restrictor	48.0
3-3" 90° LR Elbows @ 38.1	114.3
Spool Piece	10.8
Pressurizer	283.
Pump	370.
Hydroclone and Underflow Pot	2.1
Miscellaneous Tubing and Welds	19.1
Total Volume of System	867.1 in. ³

The gas volume was taken as 15% of the pressurizer volume (42 in.³). Values used in the calculation, corrected to gallons, were

$$V_l = 3.58 \text{ gal}$$

$$V_g = 0.18 \text{ gal}$$

Integration and evaluation of the equation indicates that the half life of the hydrogen pressure is 2.12 hours. Using the extrapolated value for α to evaluate H_2 used, about 0.0809 ft³ STP was consumed. Cylinders for adding H_2 have a volume of about 0.054 ft³. Replenishing the H_2 would then require simply allowing a 22 lb/in² change in pressure for the additions. Oxygen addition is not so straight forward since oxygen is also consumed in the corrosion process.

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Capacity of the heat exchanger for the loop was calculated from the data reported in the May UNOP Progress Report, page 56. U was assumed constant and the area converted to the area involved in the loop itself. The results are reported in Table II. A graph of heat removed vs pressure drop was prepared (see Figure 1) and indicates that under operating conditions a 27 psi drop should handle the heat in the loop.

Table III and Figure 2 report the calculation of final volume of gas and liquid in the loop vs the initial charging of the material. This is based on the dimensions given in Table I modified for expansion caused by heating the loop. External heat is not applied to the loop, except to the pressurizer shield to prevent excessive losses from the pressurizer. Start up heat will come from the pump work. During start up, the pressurizer temperature will lag behind the temperature of the rest of the loop. To keep this lag less than 10°C will require that the main loop be cooled. Assuming that the pump is the only source of heat in the loop and that there are no losses, calculations allowing a 10°C (18°F) lag indicates that the heat input should be about 183 BTU/min. The pump put in about 260 BTU/min, so that cooling must remove about 82 BTU/min. Under these conditions, the loop should reach operating temperature in 2.6 hours. Heat transferred from the shield to the pressurizer would serve to shorten this time.

The pressurizer shield if held at 572°F (300°C) will require about 5 KW heaters. Most of the heat will be lost to the walls of the surrounding can which was assumed to be at ambient conditions of 80°F. Under operating conditions, the shield should add about 2,000 BTU/hr to the pressurizer which should actually allow the pressurizer to operate at a slightly higher temperature than the loop. From the gas solubility data, however, it would appear that the solubility of the gas increases with temperature. Under these conditions, it would seem more logical to allow the temperature in the pressurizer to drop below the loop temperature.

P. G. Lafyatis
P. G. Lafyatis

PGL:mea

REFERENCES:

1. Lenis, B., and von Elbe, G., "Combustion Flames and Explosions of Gases," Academic Press, Inc., New York (1951).
2. ORNL 1153, p. 94.
3. Reactor Science and Technology, June, 1954.

UNCLASSIFIED

810

4

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- 5 -

Table II

HEAT EXCHANGER CHARACTERISTICS (P-1 LOOP)

Air Flow Rate, SCFM	U BTU hr °F ft ²	Total Heat Removed BTU/hr	Δ P psi
6.1	7.0	5684	6.7
10.9	11.5	10100	14.8
20.4	21.4	18100	31.2
28.8	24.3	25100	46.0
33.8	25.2	28200	54.4
39.7	26.7	32400	62.4
44.2	28.1	35200	68.0

1. Input air assumed at 80°F with $C_p = \frac{7.0 \text{ BTU}}{\text{lb mole } ^\circ\text{F}}$

Table III

INITIAL VS FINAL VOLUMES (P-1 LOOP)

Liquid Volume at 70°F (gallons)	Liquid Volume at 500°F (gallons)	Gas Volume at 500°F (gallons)
3.23	3.81	0
3.00	3.53	0.28
2.50	2.94	0.87
2.00	2.34	1.47
1.00	1.14	2.67

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810

5

- 7 -

FIGURE 2
INITIAL VS FINAL VOLUMES
PI LOOP

1-7

1-7