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SUBJECT: EFFECTS OF LEEDOWN RATES AND OXYGEN INJECTION RATES
ON XENON POISON LEVEL AND EXCESS OXYGEN CONCENTRATION
IN THE HRT

TO: S. E. Beall

FROM: P. N. Haubenreich

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ABSTRACT

Calculations indicate that it is impossible, even at high oxygen injection rates, to insure an excess of oxygen in the HRT fuel solution if the bubble letdown rate is more than one or two liters per minute. If, on the other hand, no bubbles are allowed to form, a reasonable excess oxygen concentration can be maintained with an oxygen injection rate which would not tax the capacity of the off-gas system. The xenon poison will be reduced to less than two per cent by liquid letdown alone, and if an iodine adsorption bed is installed below the catalytic recombiner, the xenon poison should be less than one per cent without any bubble letdown. Therefore, it is recommended that sufficient copper be added to prevent the formation of gas bubbles, and that the oxygen injection rate be limited to a value which would permit adequate holdup times in the present charcoal adsorption beds, assuming this quantity is sufficient to meet corrosion requirements.

INTRODUCTION

In order to reduce corrosion and prevent uranium precipitation in stagnant lines, it appears necessary to maintain a concentration of oxygen in the fuel high-pressure circulating stream considerably in excess of that which would be present due to the radiolytic decomposition of the water.

One of the features of the aqueous homogeneous reactor system which has been planned for demonstration in the HRT is the reduction in xenon poisoning which can be attained by continuously stripping gases from the fuel solution.

Unfortunately, there exists a conflict in the desire to have a high concentration of oxygen and a low concentration of xenon. The same mechanism which so effectively removes xenon, namely, the letdown of radiolytic gas, also operates to strip oxygen and reduce the excess concentration which can be attained. Thus a compromise is necessary in establishing the rate at which radiolytic gas should be let down.

It is the purpose of the calculations reported here to explore the relations between letdown rates, oxygen injection rates, and the xenon and excess oxygen concentrations in the main circulating stream, and thus to provide the information necessary for a decision on the rate of gas letdown.

SUMMARY

The calculated effects of gas letdown and oxygen injection rates on the concentration of dissolved oxygen in the high-pressure circulating stream of the HRT are shown in Figs. 1 and 2. The bubble letdown rate referred to in these figures is the volume flow rate of wet gas leaving the stream at the gas separator. The excess oxygen is the total oxygen less that which would be required to combine with all the dissolved hydrogen. As the bubble letdown rate increases, the total dissolved oxygen drops below the stoichiometric concentration due to the greater solubility of the hydrogen (lower Henry's Law constant for hydrogen.) Solubility data are reviewed in Appendix A, and the equations by which the hydrogen and oxygen concentrations were calculated are described in Appendix B.

Figure 3 shows the effect of gas letdown and oxygen injection rates on the xenon poison level. The method of calculation is described in Appendix C.

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Xenon Poison, percent

FIG. 3
EFFECT OF GAS LETDOWN
ON XENON POISON LEVEL
0.75 GPM Feed
0.20 GPM Purge
300°C Core Outlet
8 MW Core Power
1700-2600 psia

Oxygen Injection
Rate:

100 cc/min.

500 cc/min.

1000 cc/min.

Bubble Letdown Rate, liters/minute

KEUFFEL & ESSER CO., N. Y. NO. 233-61
Semi-Logarithmic, 8 Cycles X 10 to the Inch, 5th Lines Accented
MADE IN U.S.A.

DISCUSSION

The rate of gas letdown for the HRT was originally specified at a value calculated to reduce the xenon poison level to 0.2 per cent. The original calculations, which neglected the xenon letdown in the liquid and assumed that all I^{135} decayed to Xe^{135} in the high-pressure system, indicated that the xenon level was fixed by the volume flow rate of gas letdown.^{1*} The required rate, which was independent of total pressure, was calculated to be 12.3 liters/min.^{**} More recently, Ferguson, Leuze, and McNees predicted the distribution of fission products in the HRT, taking into account the effects of iodine letdown on the xenon concentration.² These calculations were for 2000-psia operation and a set of system flow rates which are different from those under which the HRT will probably operate.

The calculations reported here extend Ferguson's work to cover a range of operating conditions including those now proposed as standard. Since the time of the original calculations, more data on solubilities, xenon cross-section and fission yields have become available, and these are incorporated in the present calculations. The results are shown in

*Numbers in superscript refer to similarly numbered references in the bibliography at the end of paper.

**The mass flow rate of gas at this volume rate depended, of course, upon the total pressure. At 2000 psia the required volume rate happened to correspond closely to the gas which would be generated at 1 Mw without internal catalyst. Unfortunately, the figure of 1 megawatt's equivalent gas became regarded as the standard rather than the volume flow rate, and calculations of operating conditions at total pressures other than 2000 psia usually assume that one megawatt's gas would be let down.

Fig. 3. The marked effect of the oxygen injection rate illustrated in this figure is due mainly to the dilution of the iodine vapor in the recombiner condenser by the oxygen leaving in the off-gas stream. The proposed iodine adsorption bed preceding the recombiner should serve to reduce the xenon level still further, so that it appears likely that the xenon poison level in the HRT will be one per cent or less with no bubble letdown at all.*

Experience on the HRT mockup has demonstrated the necessity of a large excess oxygen concentration in the circulating stream under non-radioactive conditions. Calculations by Gift indicate that the radiolytic production of oxygen in stagnant lines cannot be relied upon to furnish protection, so that it will be desirable to have a positive excess of oxygen in the HRT circulating stream.³ It is obvious from Figs. 1 and 2 that an excess of oxygen in solution can be maintained only if the bubble letdown rate is very low.

Although it appears from Figs. 1 and 2 that excess oxygen would be present if the bubble letdown rate is, say, 1 liter/min and the oxygen injection rate 1000 cc (STP)/min, the calculations and the data are not exact enough to say with certainty that this is true.** Also, to operate at a steady bubble letdown rate this small would be practically impossible, since to do so it would be necessary to put in enough copper to recombine 4.95 megawatt's gas but not 5.00 megawatt's.

*A preliminary estimate is that an iodine adsorption bed will reduce the xenon poison to about 0.5 per cent for no gas letdown and an oxygen injection rate of 500 cc/min. This assumes that the bed traps all the iodine entering it and holds it up until it decays to xenon. Further calculations on this subject are in progress.

**See Appendix II for a discussion of observed vs calculated oxygen concentrations during oxygenated water and depleted uranium runs in the HRT.

Another factor which must be considered is the off-gas problem; in particular, the effect of the oxygen diluent on the capacity of the charcoal adsorption beds. Recent calculations indicate that the beds will be adequate under the expected temperature conditions only if the oxygen flow does not exceed 500 cc/min with two beds in service.* If the oxygen injection rate is so high that this off-gas flow is exceeded, the fission gas activity leaving the beds may be too high to be safely released to the stack, unless steps are taken to improve the capacity of the beds. Such steps might be to increase the size of the beds (increase in bed size would have to be in proportion to the increase in diluent flow rate) or to provide means of cooling the present beds to a much lower temperature.

*D. E. Ferguson, personal communication.

CONCLUSIONS

It appears that the most desirable course is to operate the HRT with sufficient copper to prevent bubble formation, and that the oxygen injection rate be limited to a value which will satisfy corrosion requirements with the minimum load on the charcoal beds.

APPENDIX A
REVIEW OF SOLUBILITY DATA

Oxygen

Recent work at Battelle Memorial Institute has explored the solubility of oxygen in H_2O and uranyl salt solutions up to very high partial pressures.⁴ In the range of partial pressures of interest in the HRT, Henry's Law is applicable. The solubilities, expressed as Henry's Law constants, are shown in Fig. 4. The latest BMI data are shown as circles, earlier BMI data as triangles, and Critical Table values for lower temperatures are shown as squares.* Although data on the solubility of O_2 in D_2O is unavailable, it can be assumed that the Henry's Law constants are the same as for O_2 in H_2O . Solubility is decreased in uranyl sulfate solutions as shown in Fig. A-30, reference 4.

Hydrogen

Hydrogen solubilities are shown in Fig. 5. The Battelle points (circles and triangles) are the slopes obtained from a number of observations of solubility at different partial pressures.^{4,5} BMI data show that hydrogen in water obeys Henry's Law to at least 1300-1500 psi partial pressure, which is as high as the measurements went. A Canadian, T. W. Barry, made some careful measurements at 217°C and partial pressures from 0 to 1370 psi which also followed Henry's Law

*See bibliography for references.

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FIG. 5
HENRY'S LAW CONSTANTS
FOR HYDROGEN IN H_2O

- Steiner (1936)
- △ Prins (1950)
- △ Ipatieff (1934)
- I.C.T. (1949)
- + Sauer (1905-1910) (1951)
- x Sauer (1905-1910) (1951)
- Barry (1952)

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and checked the BMI data.⁷ Suciu and Sibbitt at Purdue measured the amounts of hydrogen dissolved in water at total pressures of 1000 and 2000 psia and a number of temperatures.⁸ Henry's Law constants calculated from their data are based on one observation each and thus do not have the statistical weight of the BMI or Canadian points which represent the average slope of a number of points.

The black triangles in Fig. 5 represent some work by Ipatieff and Teodorovich.⁹ The values shown are tabulated by Pray et al. as Henry's Law constants obtained from the Russian work.⁵ Actually, as pointed out by Barry, the data of Ipatieff and Teodorovich do not follow Henry's Law, and thus to calculate Henry's Law constants from their data is misleading. The points are included here only to show what has sometimes been used as a basis of a curve of Henry's Law constant vs temperature. The conclusion reached by Barry, after attempting to duplicate their results, was that the data of Ipatieff and Teodorovich were erroneous and should be ignored.

The effect of uranyl sulfate on decreasing the solubility appears somewhat more pronounced for hydrogen than for oxygen.⁴

Deuterium

Battelle measurements indicate that deuterium in D_2O follows Henry's Law, and their D_2 - D_2O constants agree with H_2 - H_2O constants as shown in Fig. 6, where the D_2 - D_2O points are shown to fit the H_2 - H_2O curve. Barry found some evidence that D_2 solubility in H_2O may be somewhat greater than the solubility of H_2 in H_2O .⁷

Xenon

BMI data on xenon in H_2O and D_2O produce Henry's Law constants which fit the same curve.

APPENDIX B

OXYGEN CONCENTRATION CALCULATIONS

Equations are derived below which can be used to predict the deuterium and oxygen concentrations in the fuel high-pressure circulating stream. It is assumed in the derivation that equilibrium is reached between gases in the bubbles and the gas dissolved in the liquid at the gas separator. Because the feed line enters only a short distance upstream of the gas separator, this assumption may not be realized. During oxygenated water and depleted uranium runs in the HRT, the calculated oxygen concentration was greater than the observed concentration in 42 out of 49 observations, the calculated concentration running 20 to 70 per cent greater than the observed. This difference could be explained by the loss of undissolved oxygen from the high-pressure system as a result of the method of injection and the proximity of the feed line and the gas separator. Modifications in the oxygen injection point may increase the fraction of the injected oxygen which dissolves in the feed and thus make the equations a more accurate representation of the actual conditions.¹⁰

Deuterium and Oxygen Concentrations

A deuterium balance on the high-pressure system gives

$$\text{PEG} = k C_c C_d V_l + LC_d + BH_d C_d \quad (1)$$

The individual terms represent production, internal recombination, and liquid and gas letdown. (See table of nomenclature.) The oxygen balance on the high-pressure system is

$$\frac{I}{22.414} + 0.5 \text{PEG} = 0.5 k C_c C_d V_l + LC_o + BH_o C_o \quad (2)$$

which includes injection as well as the radiolytic production, recombination and letdown.

The total concentration of gases in the bubbles is fixed by the temperature and total pressure. At 300°C

$$C_g = \frac{1}{22.414} \left(\frac{P_t - 1250}{14.7} \right) \left(\frac{273}{573} \right)$$

$$C_g = \frac{P_t - 1250}{692} \quad (3)$$

Since the volume of fission product gases is negligibly small compared to that of deuterium and oxygen, if there are any bubbles

$$H_d C_d + H_o C_o = C_g \quad (4)$$

From this

$$C_d = \frac{C_g}{H_d} - \left(\frac{H_o}{H_d} \right) C_o \quad (5)$$

From (1) and (2)

$$\frac{I}{11.207} = 2(L + BH_o)C_o - (L + BH_d)C_d \quad (5)$$

Substituting (5) in (6)

$$\frac{I}{11.207} = [2(L + BH_o) + (L + BH_d)\frac{H_o}{H_d}]C_o - (L + BH_d)\frac{C_g}{H_d} \quad (7)$$

Solving for C_o

$$C_o = \frac{\frac{I}{11.207} + (L + BH_d)\frac{C_g}{H_d}}{2(L + BH_o) + (L + BH_d)\frac{H_o}{H_d}} \quad (8)$$

The excess oxygen is equal to $C_o - 0.5 C_d$.

If the purge and feed rates are fixed, I, L and B are interrelated as shown in Appendix C.

Distribution Coefficients

The distribution coefficient may be obtained from the Henry's Law constant as follows: The concentration of a perfect gas in the bubbles is

$$C_G = \left(\frac{1}{22.414} \right) \left(\frac{p}{14.7} \right) \left(\frac{273}{T} \right) = 0.8286 \left(\frac{p}{T} \right)$$

The concentration dissolved in the liquid is

$$C_L = \left(\frac{\rho}{M} \right) F$$

The distribution coefficient is

$$H = \frac{C_G}{C_L} = \frac{0.8286 \, p/T}{\rho F/M} = 0.8286 \left(\frac{M}{\rho} \right) \left(\frac{1}{T} \right) \left(\frac{p}{F} \right)$$

Since $K = p/F$,

$$H = 0.8286 \left(\frac{M}{\rho} \right) \left(\frac{K}{T} \right)$$

Since ρ/M is about the same for D_2O as for H_2O in the temperature range of interest, and since K for D_2 in D_2O is the same as K for H_2 in H_2O , it will be assumed that H for D_2O is the same as for H_2O .

For H_2O at $300^\circ C$,

$$M = 18 \text{ g/mol}$$

$$\rho = 712 \text{ g/liter}$$

$$T = 573 \text{ } ^\circ K$$

$$H = 3.655 \times 10^{-5} \text{ K}$$

For O_2 in H_2O at $300^\circ C$, $K = 2.05 \times 10^5 \text{ psi/mol fr.}$ For UO_2SO_4 solution containing about 10 g U/liter, the solubility of O_2 is about 0.96 of that in pure water. So for 10 g/liter solution, $K = 2.05 \times 10^5 / 0.96 = 2.13 \times 10^5$; $H_0 = 7.80$.

For H_2 in 10 g/liter solution at $300^\circ C$, $K = 1.70 \times 10^5 / 0.86 = 1.98 \times 10^5 \text{ psi/mol fr.}$ and $H = 7.23$.

APPENDIX C

IODINE AND XENON CONCENTRATION CALCULATIONS

The method of calculation described below is essentially the same as that used by Ferguson et al.² Iodine decay in the high-pressure circulating system, the dump-tank liquid and the dump-tank vapor is taken into account. Iodine and xenon held up in the pressurizer is considered negligible. Figure 7 helps to clarify the significance of the equations.

Fig. 7. Distribution and Flows of I^{135} and Xe^{135} in the HRT

Iodine Equations

At steady state the following equation applies to the I^{135} in the fuel high-pressure system.

$$Y_i \alpha P/N = V_i C_{i1} \lambda_i + (L + B H_{i1}) C_{i1} - f C_{i2} - p C_{i3} \quad (1)$$

The various terms describe the production rate, the decay rate, the letdown rate (in both liquid and gas) and the rates of introduction via the feed and purge streams, respectively. (See Fig. 8.)

The ratios of concentrations in the dump tanks and in the condensate to that in the high-pressure system can be found by writing similar equations for material balances around parts of the low-pressure system. Around the low-pressure system as a whole:

$$(L + B H_{i1}) C_{i1} = f C_{i2} + p C_{i3} + q H_{i3} C_{i3} + (V_2 + V_v H_{i2}) C_{i2} \lambda_i \quad (2)$$

Around the dump tanks

$$m C_{i4} + r C_{i3} = s H_{i2} C_{i2} + (V_2 + V_v H_{i2}) C_{i2} \lambda_i + f C_{i2} \quad (3)$$

Around the recombiner and condenser

$$q H_{i2} C_{i4} = (r + p + q H_{i3}) C_{i3} \quad (4)$$

From equations (2), (3), and (4), it follows that

$$C_{i3} = \mu_i C_{i2} \quad (5)$$

$$C_{i2} = \nu_i C_{i1} \quad (6)$$

Where

$$\mu_i = \frac{q H_{i2} [f + (V_2 + V_v H_{i2}) \lambda_i + s H_{i2}]}{r q H_{i2} + (r + p + q H_{i3}) m} \quad (7)$$

$$\nu_i = \frac{L + BH_{i1}}{f + (\nu_2 + \nu_v H_{i2}) \lambda_i + (p + q H_{i3}) \mu_i} \quad (8)$$

Substituting (5) and (6) in (1) and solving for C_{i1}

$$C_{i1} = \frac{\gamma_i \alpha P/N}{\nu_i \lambda_i + L + BH_{i1} - (f + p \mu_i) \nu_i} \quad (9)$$

Xenon Equations

Xenon-135 is produced both directly in fission and by decay of I^{135} . Also, there is significant destruction by neutron burnup in the high-pressure system. Otherwise the equations are similar to those for I^{135} . The equations for Xe^{135} corresponding to equations (1) through (4) are:

$$\gamma_x \alpha P/N + \nu_i C_{i1} \lambda_i = \nu_i (\lambda_x + \phi \sigma_x) C_{x1} + (L + BH_{x1}) C_{x1} - f C_{x2} - p C_{x3} \quad (10)$$

$$(L + BH_{x1}) C_{x1} = f C_{x2} + p C_{x3} + q H_{x3} C_{x3} + (\nu_2 + \nu_v H_{x2}) C_{x2} \lambda_x - (\nu_2 + \nu_v H_{i2}) C_{i2} \lambda_i \quad (11)$$

$$m C_{x4} + r C_{x3} = s H_{x2} C_{x2} + (\nu_2 + \nu_v H_{x2}) C_{x2} \lambda_x - (\nu_2 + \nu_v H_{i2}) C_{i2} \lambda_i + f C_{x2} \quad (12)$$

$$q H_{x2} C_{x4} = (r + p + q H_{x3}) C_{x3} \quad (13)$$

From equations (11), (12), and (13)

$$C_{x3} = \mu_x C_{x2} + \eta C_{i2} \quad (14)$$

$$C_{x2} = \nu_x C_{x1} + \theta C_{i2} \quad (15)$$

Where

$$\mu_x = \frac{q H_{x2} [f + (V_2 + V_v H_{x2}) \lambda_x + s H_{x2}]}{r q H_{x2} + (r + p + q H_{x3}) m} \quad (16)$$

$$v_x = \frac{L + B H_{x1}}{f + (V_2 + V_v H_{x2}) \lambda_x + (p + q H_{x3}) \mu_x} \quad (17)$$

$$\eta = \frac{q H_{x2} (V_2 + V_v H_{x2}) \lambda_i}{r q H_{x2} + (r + p + q H_{x3}) m} \quad (18)$$

$$\theta = \frac{(V_2 + V_v H_{x2}) \lambda_i - (p + q H_{x3}) \eta}{f + (V_2 + V_v H_{x2}) \lambda_x + (p + q H_{x3}) \mu_x} \quad (19)$$

Substituting (14) and (15) in (10) and solving for C_{x1}

$$C_{x1} = \frac{Y_x \alpha P / N + \{v_i \lambda_i + [(f + p \mu_x) \theta + p \eta] v_i\} C_{i1}}{V_i (\lambda_x + \phi \sigma_x) + L + B H_{x1} - (f + p \mu_x) v_x} \quad (20)$$

The xenon poison level, defined as the ratio of the xenon cross section to the U^{235} cross section is given by

$$\frac{C_{x1} \sigma_x}{C_{25} \sigma_{25}}$$

The average flux in the high-pressure circulating stream, used in computing xenon burnup is

$$\Phi = \frac{10^3 \alpha P}{N C_{25} \sigma_f V_i}$$

Effect of Iodine Adsorption Bed

An iodine adsorption bed which does not hold up xenon serves essentially as a converter which traps iodine and releases xenon. The equations given above can be modified rather simply to take into account the effects of the bed. Assume the bed traps the fraction ϵ of the iodine entering it. The rate at which I^{135} enters the bed is $qH_{12}C_{14}$, the rate leaving is $(1 - \epsilon)qH_{12}C_{14}$. The difference, $\epsilon qH_{12}C_{14}$, decays on the bed and the stream passing through the bed gains xenon at this rate. Add a term $\epsilon qH_{12}C_{14}$ to the right side of equation (2), change the left side of (4) to $(1 - \epsilon)qH_{12}C_{14}$ and solve as before. Add $\epsilon qH_{12}C_{14}$ to the left side of (11) and the left side of (13) and solve for the xenon concentrations.

Iodine and Xenon Constants

Numbers used in the xenon calculations are as follows:

$$\begin{aligned}
 P &= 5 \text{ Mw} \\
 \alpha &= 60 \times 3.38 \times 10^{16} \text{ fissions/Mw-min} \\
 C_{25} &= 0.0286 \text{ mol/l} \\
 \sigma_{25} &= 443 \times 10^{-24} \text{ cm}^2 \\
 \sigma_F &= 374 \times 10^{-24} \text{ cm}^2 \\
 \sigma_X &= 3.2 \times 10^{-18} \text{ cm}^2 \\
 V_1 &= 460 \text{ liters} \\
 V_2 &= 120 \text{ liters} \\
 V_V &= 770 \text{ liters} \\
 \gamma_i &= 0.059 \text{ atoms/fission} \\
 \lambda_i &= 1.73 \times 10^{-3} \text{ min}^{-1} \\
 H_{11} &= 0.5
 \end{aligned}$$

$$H_{i2} = 0.06$$

$$H_{i3} = 0.11$$

$$y_x = 0.003 \text{ atoms/fission}$$

$$\lambda_x = 1.27 \times 10^{-3} \text{ min}^{-1}$$

$$H_{x1} = 4.0$$

$$H_{x2} = 14$$

$$H_{x3} = 18$$

The distribution coefficients were taken from reference (2) with the exception of H_{x1} which was calculated from Fig. 6 in Appendix A. The U^{235} concentration is the equivalent of 8 g 25/kg D_2O at $280^\circ C$, which is the predicted critical concentration.

Flow Rate Relations

Many of the flow rates are interrelated. For example, for a given feed and purge rate, if the gas letdown increases, the liquid letdown must decrease. The normal values and relations between volume flow rates are set forth below. The volume flow rate relations are applicable to either H_2O or D_2O . Masses are for H_2O ; D_2O masses will be 1.1 times as great.

Feed, f.--The feed rate is controlled by the operator. Normal rate is $0.75 \times 8.3 = 6.2 \text{ lb/min}$, which corresponds to $f = 2.94 \text{ liter/min}$ at $100^\circ C$.

Purge, p.--The purge rate is fixed at about $0.2 \times 8.3 = 1.66 \text{ lb/min}$ or $p = 0.76 \text{ liter/min}$ at $65^\circ C$.

Oxygen Injection, I.--This rate can be varied at will up to about 1.1 liter (STP)/min.

Off-Gas, g.--The off-gas rate is essentially I corrected to the off-gas temperature of 65°C

$$g = \left(\frac{338}{273} \right) I = 1.24 I$$

Steam Boilup, ρ .--The dump tank evaporation rate, controlled by evaporator steam pressure, will normally be 9 lb/min or $\rho = 6830$ liter/min at 100°C.

Bubble Letdown, B.--This can be controlled by the copper concentration. At the 300°C outlet, the mass flow rate of vapor is 0.0463 B kg/min. The flow rate of noncondensibles depends also upon the total pressure. Expressed in standard liters/min, the noncondensable flow rate, B' , is

$$B' = \left(\frac{273}{573} \right) \left(\frac{p_t - 1250}{14.7} \right) B = \frac{(p_t - 1250) B}{30.85}$$

$$B' = 14.6 B \quad \text{at } p_t = 1700 \text{ psia}$$

$$B' = 24.3 B \quad \text{at } p_t = 2000 \text{ psia}$$

Because the fission gases are negligible, the radiolytic gas flow rate is $(B' - I)$ liter (STP)/min. The mass flow rate of radiolytic gas is $(B' - I)/1868$ kg/min.

Liquid Letdown, L.--The liquid letdown rate is the difference between the purge and feed rates and the letdown rate in the gas phase. The mass flow rate in the liquid letdown, ρ_L , is

$$\rho_L = 2.82 + 0.75 - 0.0463B - (B' - I)/1868, \quad \text{kg/min}$$

I is negligible in this equation; the liquid density at 300°C is 0.712 kg/liter, giving the following expressions for L

$$L = 5.01 - 0.0760B \quad \text{at } p_t = 1700 \text{ psia}$$

$$L = 5.01 - 0.0833B \quad \text{at } p_t = 2000 \text{ psia}$$

Entrainment Separator Drain, m.--About 1.0 lb/min of the diluent is condensed in the entrainment separator. The liquid drain consists of this condensate, the liquid letdown and the water condensed in the let-down heat exchanger.

$$m = 0.45 + 0.712 L + 0.0463 B \text{ kg/min}$$

$$m = 4.19 - 0.0081 B \text{ for } p_t = 1700 \text{ psia}$$

$$m = 4.19 - 0.0135 B \text{ for } p_t = 2000 \text{ psia}$$

Condensate Return, r.--The total rate of condensation in the condenser is 3.6 kg/min of diluent and $(B' - I)/1868$ kg/min of recombined water. All except the purge is returned to the dump tanks.

$$r = 3.6 - 0.76 + (B' - I)/1868$$

Again $I/1868$ is negligible.

$$r = 2.90 + 0.0551 B \text{ for } p_t = 1700 \text{ psia}$$

$$r = 2.90 + 0.0604 B \text{ for } p_t = 2000 \text{ psia}$$

Steam-Gas Mixture to Recombiner, q.--The volume flow rate is given approximately by

$$q = 8.0 \times 26.80 \times 28.317 + \left(\frac{373}{273} \right) B'$$

$$q = 6070 + 20.0 B \text{ for } p_t = 1700 \text{ psia}$$

$$q = 6070 + 33.3 B \text{ for } p_t = 2000 \text{ psia}$$

NOMENCLATURE

B	bubble letdown rate, liter/min of wet gas at gas separator
B'	gas letdown rate, liter/min at standard conditions
C	concentration, mol/liter
C _g	concentration of all non-condensibles in wet gas at gas separator
C ₂₅	concentration of U ²³⁵ in high-pressure circulating fuel solution
E	conversion factor, ev/min per Mw
f	fuel feed rate leaving dump tank, liter/min
G	mols of water dissociated per ev of energy absorbed
g	off-gas rate leaving condenser, liter/min
H	distribution coefficient, (mol/liter gas)/(mol/liter liquid)
I	oxygen injection rate (less consumption due to corrosion), liter/min
K	Henry's Law constant, psi/mol fraction
k	specific recombination rate constant, liter/mol Cu - min
L	liquid letdown rate at gas separator, liter/min
M	molecular weight, g/mol
m	liquid drain from entrainment separator, liter/min
N	Avogadro's number, atom/mol
p	purge rate, liter/min
p _t	total pressure, psia
P	reactor core power, Mw
q	steam-gas flow to recombiner, liter/min
r	condensate return to dump tanks, liter/min
s	steam flow leaving dump tanks, liter/min

T	absolute temperature, °K
V	volume, liters
y	direct fission yield, atom/fission
α	fission rate/power, fissions/Mw-min
η	defined by Equation 18, Appendix C
θ	defined by Equation 19, Appendix C
λ	radioactive decay constant, min ⁻¹
μ	defined by Equation 7 or Equation 16, Appendix C
ν	defined by Equation 8 or Equation 17, Appendix C
ρ	density
σ_x	xenon-135 absorption cross section, cm ²
σ_{25}	uranium-235 absorption cross section, cm ²
σ_f	uranium-235 fission cross section, cm ²
Φ	average thermal neutron flux in high-pressure system, n/cm ² -min

Subscripts

c	copper in high-pressure system
d	deuterium in high-pressure system
i	iodine-135
o	oxygen in high-pressure system
v	dump-tank vapor
x	xenon-135
1	high-pressure circulating system
2	dump-tank liquid
3	condensate in recombiner condenser
4	entrainment separator

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Dear Miss Pflueger:

Subject: CF 57-4-128 and CF 57-5-100 (Unclassified)

Enclosed are seven copies of each of the subject documents which we feel are of interest to the Pennsylvania Advanced Reactor Project. We will appreciate your making them available to them. These documents may also be used for the Civilian Application Program if considered applicable.

Very truly yours,

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