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REACTORS — POWER

OAK RIDGE NATIONAL LABORATORY

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DATE: July 3, 1956
SUBJECT: Preliminary Design of an Iodine Removal
System for a 460-MW Thorium Breeder Reactor
TO: R. B. Briggs
FROM: D. E. Ferguson

CLASSIFICATION CANCELLED

DATE MAR 12 1957

For The Atomic Energy Commission

H. F. Caneel
Chief, Declassification Branch TC

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TO: R. B. Briggs
FROM: D. E. Ferguson

Weinrich and Cox have revised their preliminary design of an iodine removal system for the core of a 450 MW, two-region thorium breeder reactor. This revised design,¹ see Figure 1, is a modification of the material given in Section 3.0 and Appendix 1 of ORNL-CF-56-2-81. Only one significant change has been made. In their original study the calculated amount of oxygen removed from the system was 34 lb/day. Based on more reliable vapor pressure data, the oxygen removal rate is now calculated to be 230 lb/day.

A calculation of the predicted Xe-135 poison level has been added. They arrived at a value of 0.58%, assuming an independent yield of .003 for Xe-135.

D. E. Ferguson

DEF/jr

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1. Weinrich, W. W., and Nixon, W. A., private communication, May 1956.

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3

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Notes

Critical valves in hot areas should be equipped with by-passes.

Valves A, B and C should be remote controlled block valves.

Vessel drains, vents and decontamination connections are not shown.

Dashed squares indicate equipment in cold areas.

indicates remote controlled block valves.

Cox and Weirich Chemical Engineers 3316 E St. N.W. Washington, D.C.	
Fig. 1. I_2 Separation System	
Eng. V.A.N. 5/2/56	

023 003

I₂ REMOVAL SYSTEM

Discussion of Calculations

The iodine removal system described in these calculations was designed to continuously remove iodine from the circulating stream of homogeneous reactors. The method of removal is to continuously strip the iodine from a part of the reactor fuel stream with a mixture of oxygen and heavy water vapor. The iodine in the vapor stream is subsequently absorbed in heavy water, concentrated by evaporation and stored until the iodine has decayed. Iodine is removed from the fuel stream as fast as it is produced, thereby maintaining the iodine content of the fuel stream at a low concentration and limiting the production of iodine decay products in the reactor fuel loop.

In previous calculations (ORNL-CF-56-2-81) two systems were considered: one in which final concentration was done at the system pressure of 2000 psi and another in which final concentration was done at atmospheric pressure. Since that time, interest has centered mainly on the atmospheric pressure concentration system. The calculations included in this report include the previous calculations for the atmospheric pressure concentration system, and, in addition, calculations of the Xe-135 poison level and stripping rate.

A. Stripping Column

The removal rate of iodine assumed for this design is given on page 8. The total power produced by the reactor was assumed to be 360 megawatts, equivalent to the fission of 400 grams per day of U-235. Total iodine production on this basis is 0.27×10^{-6} pound moles per minute.

The allowable I₂ concentration was taken as 15 mg/kg of D₂O

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The reactor was assumed to operate at 2000 psia and 310°C.

The design of the stripping column and related equipment is given on pages 12 and 13.

Assumptions made to calculate the vapor circulation rate are as follows:

1. $K_g = 7$ moles I_2 per mole vapor / moles I_2 per mole soup.
2. Vapor leaving the top of the stripping column is at 90% of saturation with I_2 .
3. Vapor entering the jet contains 10% of the exit vapor I_2 content.

The vapor circulation rate was determined to be 4.2 moles per minute.

The design of the jet to circulate the vapor stream is based on Vitro Report V-87-50-0. Assumptions made for this design are as follows:

1. Liquid pressure drop across jet = 20 psi.
2. Jet efficiency = 5%.
3. Vapor pressure drop through system = 1 psi.

The soup required for jet operation is 175 gpm.

To insure adequate contact between the vapor stream and soup, the jet liquid-vapor mixture is discharged into the base of the stripping column, and the vapor passes upward countercurrent to a stream of soup introduced into the top of the column. Approximately 3 theoretical stages are required in the column to bring the vapor to 90% of equilibrium with the circulating fuel.

The stripping column size is based on correlations given in Perry, p. 684-685. Reduced temperatures and pressures were used to determine vapor specific volume. Correlations were used which included

corrections for the liquid density, gas density and liquid viscosity at the high temperature and pressure existing in the stripping column.

The pressure drop through this column was estimated from correlations in Perry, p. 681.

No information was found which could be used to determine the height of a theoretical stage. For the purpose of this design, the height was estimated at 3 feet per stage.

B. Absorption Column

The absorption column design was based on the following assumptions:

1. Gas feed rate of 4.2 pound moles/min.
2. I_2 in feed: 7.1×10^{-8} moles/mole vapor.
3. I_2 in exit vapor = 0.7×10^{-8} moles/mole vapor.
4. Exit liquor 50% of equilibrium in I_2 .
5. $K_W = 0.2$ moles I_2 per mole vapor/mole I_2 per mole D_2O .

The column diameter was calculated using the same liquid loading as was used for the stripping column.

The heavy water-iodine stream from the bottom of the absorption column contains oxygen which is lost in the concentration column. The amount of oxygen lost was estimated from Henry's Law constants taken from Industrial and Engineering Chemistry, 44, 1146 (1952). The estimated loss is 230 pounds per day.

C. Concentration Column

The heavy water- I_2 stream from the absorber is concentrated by evaporation in a reboiled atmospheric pressure column. The recovered D_2O is recycled to the absorber; the concentrated D_2O - I_2 stream is sent to storage. The following assumptions were made in this

calculation.

1. Final concentrate volume equals 100 gallons/day.
2. Reflux ratio of 1:1.
3. Volatility of the I_2 is reduced to zero by adding NaOD to the top of the column.

A column approximately 2.1 feet in diameter is required. Sufficient packed height should be included to limit entrainment and insure contact between the NaOD solution and I_2 .

Vent gas from the reflux accumulator will contain any xenon formed during I_2 removal and all of the oxygen contained in the feed to the concentrator. This vapor stream can be sent through carbon beds to a disposal stack.

D. Xe-135 Poison Level

The Xe-135 poison level was estimated by modifying equations given in Appendix II of ORNL-CF-56-2-81 to apply to the I_2 removal system considered for this design. The calculations are shown on pages 18-23. The estimated Xe-135 poison level is 0.575%, based on the values of constants given in the reference report.

E. I-135 Decay

An approximate calculation was made to estimate the amount of Xe-135 formed in the stripper and concentrator by I-135 decay. The total hold-up time in these vessels was estimated to be 10,200 seconds. Based on this hold-up time, 0.07×10^{-6} lb moles/minute of Xe-135 would be produced and removed from the overhead vapor of the concentrator. This value may vary greatly depending on the actual capacities of the vessels and piping.

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F. Xe-135 Stripping

The amount of Xe-135 which is stripped from the circulating fuel stream and absorbed in the heavy water is estimated on pages 22-23. The maximum amount which could be removed by this method is approximately 2% of the total Xe-135 production. This reduction in the Xe-135 poison level has been ignored in previous calculations.

Design of Iodine Removal System

1. Use an I_2 removal rate of 33.0 mg/min
 $= 0.27 \times 10^{-6}$ lb moles/min.

2. Concentration of I_2 in soup.

Use 0.15 mg/kg D_2O or 1.13×10^{-8} moles I_2 /mole D_2O .

3. Stripping column design.

a. Assume vapor reaches 90% of saturation at the exit of the column.

$$\begin{aligned}\text{Vapor } I_2 \text{ content at exit} &= 0.9 \times 7 \times 1.13 \times 10^{-8} \\ &= 7.1 \times 10^{-8} \text{ moles } I_2/\text{mole vapor.}\end{aligned}$$

b. Assume vapor is stripped of 90% of its I_2 content in the absorption column.

$$\begin{aligned}\text{Vapor } I_2 \text{ content at exit of absorption column} &= 0.1 \times 7.1 \times 10^{-8} \\ &= 0.7 \times 10^{-8} \text{ moles } I_2/\text{mole vapor.}\end{aligned}$$

$$\text{Vapor circulation rate} = \frac{27 \times 10^{-8}}{6.4 \times 10^{-8}} = 4.2 \text{ lb moles/min} = G.$$

c. Liquid circulation rate.

$$M\bar{V} (P_1 - P_2) = \frac{G}{E} (RT \ln P_4/P_3)$$

(jet formula V-87-50-0)

M = lb moles/min of soup
 $\bar{V}$ = molal liquid volume
 P_1 = entering liquid pressure
 P_2 = discharge liquid pressure
 P_3 = entering gas pressure
 P_4 = discharge gas pressure
 E = efficiency of jet = 5%

$$\bar{V} = 0.0225 \text{ ft}^3/\text{lb} = 0.45 \text{ ft}^3/\text{lb mole}$$

$$\text{Let } P_1 - P_2 = 20$$

$$\text{Let } P_4 = 1980$$

$$\text{Let } P_3 = 1979$$

$$M (0.45)(20) = \frac{4.2}{0.05} (10.75 \times 1032 \ln \frac{1980}{1979})$$

$$M = 51.9 \text{ lb moles/min}$$

$$= 175 \text{ gpm}$$

Minimum liquid which must be stripped

$$M'(x_1 - x_2) = 0.27 \times 10^{-6}$$

$$M' = \frac{0.27 \times 10^{-6}}{1.13 \times 10^{-8}} = 23.9 \text{ lb moles/min}$$

$$= 80.5 \text{ gpm}$$

Use 175 gpm to jet and 100 gpm to top of stripper.

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023 009

I_2 content of soup discharged from the stripper

$$\frac{275}{0.45 \times 7.48} (1.13 \times 10^{-8} - x_2) = 0.27 \times 10^{-6}$$

$$x_2 = 0.80 \times 10^{-8} \text{ lb moles } I_2/\text{mole soup.}$$

d. Column operation.

Assume liquid and vapor at jet discharge are at 90% of equilibrium.

$$M_2(x_2) + G_2(y_2) = M_1(x_1) + G_1(y_1)$$

$$51.9(x_2) + 4.2(7)(x_2) = 51.9(1.13 \times 10^{-8}) + 4.2(0.7 \times 10^{-8})$$

$$x_2 = 0.78 \times 10^{-8} \text{ lb moles } I_2/\text{mole soup}$$

$$y_2 = 6.3(x_2) = 4.94 \times 10^{-8} \text{ lb moles } I_2/\text{mole vapor}$$

I_2 removed by contact in jet

$$G\Delta y = 4.2 (4.94 \times 10^{-8} - 0.7 \times 10^{-8})$$

$$= 17.8 \times 10^{-8} \text{ lb moles/min.}$$

$$I_2 \text{ pickup in column} = 27 \times 10^{-8} - 18 \times 10^{-8} = 9 \times 10^{-8} \text{ lb moles/min.}$$

Soup I_2 concentration at the exit of the contact column

$$\frac{100}{0.45 \times 7.48} (1.13 \times 10^{-8} - x_2) = 9 \times 10^{-8}$$

$$x_2 = 0.83 \times 10^{-8}$$

$$\text{equilibrium } y_2 = 7 \times 0.83 \times 10^{-8}$$

$$= 5.81 \times 10^{-8} \text{ lb moles } I_2/\text{mole vapor.}$$

From an x-y diagram of the column operation the height requirement is found to correspond to about three theoretical stages (see Figure 2).

Figure 2. Stripping Column Operation

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023 011

e. Column size.

System pressure	2000
P.P. D ₂ O at 310°C	1430
P.P. O ₂	570

$$\text{Vapor composition} = \frac{1430}{2000} \times 100 = 71.5\% \text{ D}_2\text{O} = y_{\text{D}_2\text{O}}$$

$$28.5\% \text{ O}_2 = y_{\text{O}_2}$$

$$(T_c)_{\text{mix}} = (T_c)_a y_a + (T_c)_b y_b, \text{ etc.}$$

$$(P_c)_{\text{mix}} = (P_c)_a y_a + (P_c)_b y_b, \text{ etc.}$$

$$(T_c)_{\text{H}_2\text{O}} = 647.3^\circ\text{K}$$

$$(P_c)_{\text{H}_2\text{O}} = 218.53$$

$$(T_c)_{\text{O}_2} = 154^\circ\text{K}$$

$$(P_c)_{\text{O}_2} = 49.7$$

$$(T_c)_{\text{mix}} = 506^\circ\text{K}$$

$$(P_c)_{\text{mix}} = 170.2 \text{ atm}$$

$$T_R = T/T_c = 583/506 = 1.15$$

$$P_R = P/P_c = \frac{2000}{14.7 \times 170.2} = 0.8$$

$$\mu = 0.8 = PV/nRT$$

$$\frac{y}{n} = \frac{0.8 RT}{P} = \frac{0.8 \times 10.73 \times 1030}{2000} = 4.5 \text{ ft}^3/\text{lb mole}$$

$$G = (4.2 \times 0.715 \times 20 + 4.2 \times 0.285 \times 32) 60 = 5,900 \text{ lb/hr}$$

$$L = \frac{100}{7.48 \times 0.0225} \times 60 = 35,600 \text{ lb/hr in column}$$

89,000 lb/hr including jet liquid

$$\text{Gas MW} = 0.715 \times 20 + 0.285(32) = 23.4$$

$$\text{Gas density} = \frac{23.4}{4.5} = 5.2 \text{ lb/ft}^3$$

From Perry, p. 681

$$\phi = \sqrt{5.2/0.075} = (69.4)^{1/2} = 8.3$$

$$\left(\frac{62.3}{\rho_L}\right)^{1/2} = \left(\frac{62.3}{44.5}\right)^{1/2} = 1.18$$

$$\frac{G}{\phi} \left(\frac{62.3}{\rho_L}\right)^{1/2} = \frac{5900}{8.3} \times 1.18 = 800$$

Viscosity correction:

$$\mu = 0.05 \text{ centipoise}$$

$$V = \frac{0.05 \times 0.672 \times 10^{-3}}{44.5} = 0.75 \times 10^{-6} \text{ ft}^2/\text{sec}$$

$$V = 0.75 \times 10^{-6} \times 928 = 0.07 \text{ centipoise}$$

$$\text{Corrected } \frac{G}{\phi} = \frac{800}{(0.07)^{-0.15}} = 800 \times 0.67 = 535$$

$$L \text{ at flooding} = 15,000 \text{ lb/hr-ft}^2 \text{ for 1 in. Raschig rings}$$

$$\text{Area} = \frac{35,600}{15,000 \times 0.7} = 3.4 \text{ ft}^2$$

$$\text{Diameter} = \left(\frac{3.4 \times 4}{\pi}\right)^{1/2} = 2.08 \text{ ft}$$

Pressure drop

$$G/\phi = 535$$

$$L = 10,500$$

$$P = 2 \text{ in./ft packed depth}$$

Column height - There is no data available. Assume 3 ft per theoretical transfer unit = 9 ft packing.

4. Absorption column. $\frac{\text{mole } I_2/\text{mole vapor}}{\text{mole } I_2/\text{mole } D_2O}$
 a. Assume $K_v = 0.2$

Gas feed = 4.2 lb moles/min

I_2 feed = 7.1×10^{-8} moles I_2 /mole vapor

I_2 exit = 0.7×10^{-8} moles I_2 /mole vapor

b. Assume liquid at the bottom of the column is at 50% of saturation

$$\frac{7.1 \times 10^{-8}}{x} = 0.2$$

$$x = 35.5 \times 10^{-8} \text{ moles } I_2/\text{mole } D_2O \text{ at equilibrium}$$

At 50% of equilibrium

$$\text{moles } D_2O/\text{min} = \frac{27 \times 10^{-8}}{35.5 \times 10^{-8} \times 0.5} = 1.52$$

$$\text{lb/min } D_2O = 30.4 \text{ lb/min}$$

From Figure 3 number of theoretical stages = 3.

c. Column size. Same loading as the absorption column.

$$A = 0.174 \text{ ft}^2$$

$$D = 6 \text{ in.}$$

5. O_2 loss from absorption column.

$$O_2 \text{ FP} = 570 \text{ psi}$$

Henry's Law constant = 1.74×10^5 psi/mole fraction (see Industrial and Engineering Chemistry, Vol. 44, p. 1146, 1952.)

$$x_{O_2} = \frac{570}{174000} = 0.00328 \text{ mole fraction } O_2 \text{ in } D_2O$$

$$\frac{x_{O_2}}{1 - x_{O_2}} \frac{M_{O_2}}{M_{D_2O}} (100) = \frac{0.00328 \times 32 \times 100}{0.99672 \times 20} = 0.526 \text{ lb } O_2/100 \text{ lb } D_2O$$

Figure 3. Absorption Column Operation

023 015

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$$\text{Loss of } O_2/\text{day} = \frac{30.4 \times 1440 \times 0.526}{100} = 230 \text{ lb/day}$$

6. Concentration column.

$$\text{Feed} = 30.4 \times 1440 = 43,800 \text{ lb/day } D_2O$$

$$0.27 \times 10^{-6} \times 1440 = 0.39 \times 10^{-3} \text{ lb moles } I_2/\text{day}$$

Assume the following reaction:

$$NaOH = 0.78 \times 10^{-3} \text{ lb moles/day}$$

$$\text{Product} = 100 \text{ gal/day} = 830 \text{ lb/day}$$

Product volume can be varied widely to correspond to the best storage system.

$$\text{Overhead } D_2O \text{ product} = 42,970 \text{ lb/day}$$

$$\text{Assume reflux} = 42,970 \text{ lb/day}$$

$$\text{Heat balance - base temperature} = 100^\circ F$$

Heat In

$$\text{Feed} = 43,800 (605-68) = 23.5 \text{ MM}$$

$$\text{Reflux at } 100^\circ F = 0$$

$$\text{Reboiler} = x$$

Heat Out

$$\text{Vapor } 2 \times 42,970 (1150-68) = 92 \text{ MM}$$

$$\text{Btms. } 830 (180-68) = 0.09 \text{ MM}$$

Reboiler duty = $92 - 23.5 = 68.5$ MM BTU/day

Add 10% for heat loss

$$\text{Reboiler duty} = \frac{1.1 \times 68.5}{24} = 3.1 \text{ MM BTU/hr}$$

Column diameter:

Base diameter on top of column conditions

Vapor = 85,940 lb/day

Liquid = 42,570 lb/day

Gas density = $\frac{1}{26.8} = 0.039$ lb/cu. ft

$$\phi = 0.039/0.075 = 0.72$$

$$\frac{L\phi}{G} = \frac{42,970 \times 0.72}{85,940} = 0.36$$

$L = 600$ lb/hr/ft² at loading

Use $L = 500$ for design

$$\text{Area} = \frac{42,970}{500 \times 24} = 3.6 \text{ ft}^2$$

$$\text{Diameter} = \left(\frac{3.6 \times 4}{\pi} \right)^{1/2} = 2.1 \text{ ft}$$

CALCULATION OF Xe-135 POISON LEVEL
(Additions to Calculations Made on February 7, 1956)

I-135 and Xe-135 Material Balance

Based on the work by Aven, the following calculations were made to determine the amount of solution to be stripped to maintain the Xe-135 poison level at 0.5%.

I-135 Material Balance at Equilibrium

$$\text{I-135 production rate} = Y_1 \alpha P$$

$$\text{I-135 decay rate} = N_1 V \lambda_1$$

$$\text{I-135 stripping rate} = N_1 S_1 F$$

$$Y_1 \alpha P = N_1 V \lambda_1 + N_1 S_1 F \quad (1)$$

Xe-135 Material Balance at Equilibrium

$$\text{Xe-135 production rate} = Y_2 \alpha P + N_1 V$$

$$\text{Xe-135 decay rate} = N_2 V \lambda_2$$

$$\text{Xe-135 neutron absorption rate} = N_2 V \sigma_a (\text{Xe}) \phi$$

$$\text{Xe-135 stripping rate} = N_2 S_2 F$$

$$Y_2 \alpha P + N_1 V \lambda_1 = N_2 V [\lambda_2 + \sigma_a (\text{Xe}) \phi] + N_2 S_2 F \quad (2)$$

Xe-135 poison level

$$\frac{\sum_a (\text{Xe})}{\sum_a U} = \beta \quad (3)$$

From equation (1)

$$N_1 = \frac{Y_1 \alpha P}{V \lambda_1 + S_1 F}$$

From equation (3)

$$\beta \sum_a (U) = \sum_a XE = N_2 \sigma_a(Xe)$$

$$N_2 = \frac{\beta \sum_a (U)}{\sigma_a(Xe)}$$

Equation (2) becomes

$$Y_2 \alpha^P + \frac{Y_1 \alpha^P V \lambda_1}{V \lambda_1 + S_1 F} = \frac{\beta \sum_a (U) V}{\sigma_a(Xe)} \left[\lambda_2 + \sigma_a(Xe) \phi + \frac{S_2 F}{V} \right] \quad (4)$$

$Y_1 = 0.059$ atoms I-135/fission

$Y_2 = 0.003$ atoms Xe-135/fission

$\alpha = 3.38 \times 10^{16}$ fissions/sec/MW

$P = 360$ MW

$V = 10^7$ ml

$\lambda_1 = 2.88 \times 10^{-5}$ sec⁻¹

$\lambda_2 = 2.1 \times 10^{-5}$ sec⁻¹

$S_1 = 0.29$ (fraction of I₂ stripped from feed to column)

$S_2 = 0.00$ (fraction of Xe stripped from feed to column, estimated)

$\sum_a (U) = 2.0 \times 10^{-3}$ cm²/ml

$\phi = 6.5 \times 10^{14}$ n/cm²/sec

$\sigma_a(Xe) = 3 \times 10^{-18}$ cm²/atom

N = atoms per ml in main loop

F = feed to stripping column

Subscript 1 refers to I-135

Subscript 2 refers to Xe-135

Solving equation (4) and using 275 gpm as F

$$F = \frac{275 \times 3785}{60} = 17,300 \text{ ml/sec}$$

$$Y_2 \alpha F = 0.003 \times 3.38 \times 10^{16} \times 360 = 3.66 \times 10^{16} \text{ atoms Xe/sec}$$

$$\frac{Y_1 \alpha F V \lambda_1}{V \lambda_1 + S_1 F} = \frac{0.059 \times 3.38 \times 10^{16} \times 360 \times 10^7 \times 2.88 \times 10^{-5}}{10^7 \times 2.88 \times 10^{-5} + 0.29 \times 17,300}$$

$$= 3.8 \times 10^{16} \text{ atoms Xe/sec}$$

$$\lambda_2 + \sigma_a(\text{Xe})\phi + \frac{S_2 F}{V} = 2.1 \times 10^{-5} + 3 \times 10^{-18} \times 6.5 \times 10^{14} + 0$$

$$= 1.971 \times 10^{-3}$$

$$\frac{\beta \sum_a(u) v}{\sigma_a(\text{Xe})} = \frac{\beta \times 2.0 \times 10^{-3} \times 10^7}{3 \times 10^{-18}} = 0.666 \times 10^{22} \beta$$

$$3.66 \times 10^{16} + 3.8 \times 10^{16} = \beta \times 0.666 \times 10^{22} \times 1.97 \times 10^{-3}$$

$$\beta = 0.00575 = 0.575\%$$

Xe-135 Production in Concentrating Column

System volume.

Absorption column. Assume liquid level is 2 ft.

$$\text{Volume} = \frac{\pi(0.5)^2 \times 2 \times 7.48}{4} = 2.94 \text{ gallons.}$$

Concentration column. Assume liquid level is 2 ft and column diameter is 1 ft in the liquid hold-up section.

$$\text{Volume} = 11.76 \text{ gallons.}$$

Add 10% for pipe capacities

$$\text{Total volume} = 1.1 \times 14.70 = 16.2 \text{ gallons.}$$

Hold-up time in absorber column

$$\frac{2.94}{223} \times 3600 = 45.5 \text{ seconds}$$

Hold-up time in piping

$$\frac{1.47}{2.23} \times 3600 = 24.8 \text{ seconds}$$

$$\text{when flow} = \frac{43,800 \text{ lbs/day}}{24 \times 8.33 \times 0.9} = 223 \text{ gallons/hr}$$

Hold-up time in concentrator

$$\text{flow out of concentrator} = 100 \text{ gallons/day}$$

$$\frac{11.76 \times 24 \times 3600}{100} = 10,200 \text{ seconds}$$

Total delay time is then about 10,300 seconds.

$$\ln \frac{P_1}{P} = t\lambda = 10,300 \times 2.88 \times 10^{-5}$$

$$\ln \frac{P_1}{P} = 0.292$$

P_1 = initial amount of I

$$\frac{P_1}{P} = 1.34$$

P = final amount of I

$$P = \frac{P_1}{1.34}$$

$$P = \frac{0.27 \times 10^{-6}}{1.34} = 0.202 \times 10^{-6} \text{ lb moles/min}$$

$$\text{Xe-135 produced} = 0.07 \times 10^{-6} \text{ lb moles/min.}$$

023 021

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Xe-135 Removal by Stripping

From page 19, the concentration of Xe-135 in the main stream is

$$N_2 = \frac{\beta \sum_a (U)}{Q_a(Xe)}$$

$$\text{Approximately } N_2 = \frac{0.00575 \times 2 \times 10^{-3}}{3 \times 10^{-18}} = 3.84 \times 10^{12} \text{ atoms/ml.}$$

From ORNL-CF-56-2-81, the distribution coefficient between vapor and liquid for Xe-135 is

$$\frac{7 \text{ atoms per ml vapor}}{\text{atoms per ml liquid}}$$

At equilibrium, vapor will contain

$$7 \times 3.84 \times 10^{12} = 26.9 \times 10^{12} \text{ atoms/ml vapor}$$

Vapor density from page 12 is 4.5 ft³/lb mole.

$$\frac{26.9 \times 10^{12}}{6.23 \times 10^{23}} \times \frac{4.5 \times 28316}{454} = 1.210 \times 10^{-8} \text{ moles Xe-135/mole vapor}$$

$$\text{Partial pressure of Xe-135} = 1.210 \times 10^{-8} \times 2000 = 2.42 \times 10^{-5} \text{ psi.}$$

Henry's Law constant for Xe-135 in D₂O is 100,000 psi/MF

$$\text{Mole fraction Xe-135 in D}_2\text{O} = 2.42 \times 10^{-10}$$

$$\text{Liquid circulation} = 1.52 \text{ lb moles D}_2\text{O/minute}$$

Therefore maximum Xe-135 that can be removed by stripping and absorption in D₂O is

$$1.52 \times 2.42 \times 10^{-10} = 3.6 \times 10^{-10} \text{ lb moles/minute}$$

Total Xe-135 production (from page 20) is

$$Y_{2OP} = 3.66 \times 10^{16} \text{ atoms Xe/sec}$$

$$\frac{Y_{1OP} V \lambda_1}{V \lambda_1 + S_1 F} = \frac{3.8 \times 10^{16} \text{ atoms Xe/sec}}{7.46 \times 10^{16} \text{ atoms Xe/sec}}$$

$$\frac{7.46 \times 10^{16} \times 60}{6.23 \times 10^{23} \times 454} = 159 \times 10^{-10} \text{ lb moles Xe-135/minute}$$

Therefore the maximum amount of Xe-135 that can be removed by stripping and absorption is approximately 2% of the total Xe-135 production. This amount has been neglected in previous calculations.

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