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SUBJECT: Investigation of Effect of Seal Configuration on Mixing Flow
and Radiation Damage in HRT-Type Circulating Pumps

TO: I. Spiewak

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SUMMARY

To increase the life of the canned motor circulating pumps in aqueous homogeneous reactors, it is necessary to minimize the flow of solution or slurry from the loop into the motor section. To determine the effect of various configurations of the seal between the motor and the impeller sections, tests were conducted using one of the Westinghouse Model 400A pumps. It was found that flow rates of less than 0.02 liters per hour can be obtained by modifying the inlet to the lower suction port of the internal coolant pump.

With this modified configuration and a purge rate of 10 liters per hour, radiation damage to the stator insulation due to radioactive material in the motor cavity is minor. Life expectancies for the HRT pump motors based on radiation damage from each of various sources are as follows:

Failure Due to Electrical Breakdown of the Motor Insulation

Radiation from pump scroll	13.4 years
Background radiation	308 days
Radiation from solution in motor, with purge	38 years
Radiation from solution in motor, without purge	243 days

Failure Due to Hydrogen Pressure in the Stator Can

Radiation from pump scroll	12.3 years
Background radiation	284 days
Radiation from solution in motor, with purge	34 years
Radiation from solution in motor, without purge	218 days

INTRODUCTION

Due to the type of insulation used in the construction of the Westinghouse 400A pumps, the gamma flux densities in the various cavities in the pump and surrounding the pump greatly influence the life expectancy of the pump. Radiation can shorten the life of the pump either by causing electrical breakdown of the insulation or by causing hydrogen evolution from the insulating material and failure of the stator liner can.

Tests have shown that there is some mixing flow of uranyl sulfate into the motor section even though there is a steady flow of purge water through the pump. The mechanism causing this mixing flow is unknown but is considered to be the result of either poor seal design or eccentric operation of the shaft in the seal region. Whatever the cause, if the pump is to operate for several years, the flow into the rotor section must be reduced as much as possible.

Other sources which would also cause insulation deterioration should be considered. These are primarily background radiation from the reactor cell and radiation from uranyl sulfate in the pump impeller cavity.

TEST APPARATUS

To find the effect of seal configuration on the rate of mixing flow from the impeller cavity into the motor cavity, the 400A-2 loop was utilized. The loop contained a Westinghouse 400A canned motor pump having a wear-ring seal between the impeller and motor cavities.

The pump was equipped with an undersize impeller such that it produced a flow of approximately 230 gpm across a 55 ft. head. The loop proper was unchanged from that shown in ORNL Dwg. TD-D-2574. The small flow through the pressurizer caused some difficulty in sampling procedure. Satisfactory samples were finally obtained after installing a bypass from the high pressure side of the DP cell to the suction side of the pump.

The volume of the loop was 58 liters and the fluid volume of the pump motor section was 4 liters.

Potassium sulfate was used to determine the mixing flow rate. This was accomplished by finding the change in K^+ concentration in the motor cavity as a run progressed. Pump concentrations were determined to within 0.1 ppm and loop concentrations to within 1 ppm. Loop concentration was in the region of 2500 ppm at the start of each run.

Purge water for the motor section of the pump was measured by a rotameter. The purge water was removed from the system through the pressurizer. Since no provision was made to return the K_2SO_4 removed from the loop, the total quantity of potassium in the system was continuously decreasing. This proved to greatly complicate the processing of experimental data.

TESTING PROCEDURE

The loop was filled with distilled water and the pump was run for an hour to wash the loop in preparation for each run. During this time a purge of approximately 30 liters per hour was introduced to remove any residual potassium in the system. After this flush, 360 gms. of K_2SO_4 dissolved in 5 liters of distilled water were injected into the loop. The system was then run for 15 minutes before the first samples were taken. Samples were then taken every hour of both the loop fluid and the fluid in the motor cavity. To obtain the loop sample, the bypass, mentioned previously, was flushed for 15 minutes and the sample removed from the bypass. It was found that, in order to get representative samples from the motor cavity, the sampling rate should not exceed 10 cc per minute.

For the zero purge runs, the pump was stopped to remove the samples. Zero purge samples were taken at times of $1/4$, $3 1/4$, and $5 1/4$ hours after injection of the salt into the loop.

DATA PROCESSING EQUATIONS

The solution for finding the rate of mixing flow from the impeller section into the motor section using the experimental data is obtained from the following equations.

$$\frac{dm_P}{dt} = \frac{L^F P}{V_P} m_L - \frac{P^F L}{V_P} m_P \quad (1)$$

$$\frac{dm_L}{dt} = \frac{P^F L}{V_L} m_P - \frac{L^F P}{V_L} m_L - \frac{P}{V_L} m_L \quad (2)$$

$$P^F L = L^F P + P \quad (3)$$

where:

m_P = K^+ concentration in the motor section of the pump, ppm

m_L = K^+ concentration in the loop, ppm

V_P = fluid volume in the motor section of the pump, l

V_L = loop volume, l

$L^F P$ = flow rate from the loop to the motor section, l/hr

$P^F L$ = flow rate from the motor section to the loop, l/hr

P = purge rate, l/hr

t = time, hrs.

Equations 1, 2 and 3 have for their solution

$$m_P = A e^{\beta_1 t} + B e^{\beta_2 t} \quad (4)$$

where:

$$A = \left(\frac{V_L \beta_1}{P^F L} + 1 \right) \left(m_{Lo} - \alpha \right) \quad (4a)$$

$$B = \left(\frac{V_L \beta_2}{P^F L} + 1 \right) \alpha \quad (4b)$$

$$\alpha = \frac{m_{Po} - m_{Lo} \left(1 + \frac{V_L \beta_1}{P^F L} \right)}{\frac{V_L}{P^F L} (\beta_2 - \beta_1)} \quad (4c)$$

$$\beta_1 = \frac{-\left(V_P + V_L \right) + \sqrt{\left(V_P + V_L \right)^2 - 4 \left(\frac{V_P V_L}{P^F L} \right) P}}{2 \frac{V_P V_L}{P^F L}} \quad (4d)$$

$$\beta_2 = \frac{-\left(V_P + V_L \right) - \sqrt{\left(V_P + V_L \right)^2 - 4 \left(\frac{V_P V_L}{P^F L} \right) P}}{2 \frac{V_P V_L}{P^F L}} \quad (4e)$$

If the effect of $L^F P$ on m_L is neglected and the change of loop concentration is assumed to be represented by

$$m_L = m_{Lo} e^{-\gamma t} \quad (5)$$

then a solution may be obtained for m_p of

$$m_p = C (e^{-\gamma t} - e^{-\delta t}) + m_{p0} e^{-\delta t} \quad (6)$$

where:

$$C = \frac{L_P^F m_{L0}}{P_L^F - \gamma V_P} \quad (6a)$$

$$\delta = \frac{P_L^F}{V_P} \quad (6b)$$

γ = determined graphically.

The value of δ is such that after two or three hours the term $e^{-\delta t}$ becomes sufficiently small that it may be neglected. Equation 6 gives fair results for $t > 4$, but in the region of $0 < t < 4$ the results are questionable.

EXPERIMENTS AND RESULTS

The first data was taken with the seal essentially in the "as-received" condition. The seal consisted of a smooth shaft sleeve rotating in a labyrinth wear ring (Fig. 2). The data was obtained with questionable sampling procedures and are actually of dubious value. Values of L_P^F from 2.0 to 0.4 liters per hour were indicated with purge rates from zero to 30 liters per hour.

The pump was disassembled and the wear ring replaced by a smooth-bore cylinder. A spiral groove was cut in the shaft sleeve in an attempt to "screw" the fluid from the motor section into the impeller section. The sampling procedure was changed and runs with various purge rates were made. While these runs produced results that were still somewhat dubious, they did appear to have more consistency and a more general trend. It appeared that this change in seal construction did not reduce the mixing flow by any appreciable amount.

The next change made was in the circulating system in the motor section. The coolant circulating pump for the motor has two inlets, one of which is located at the top of the seal. This inlet consists of a 3/16 inch diameter hole drilled through the shaft. It was felt that the location of this hole might alter the pressure distribution immediately above the seal and influence the mixing flow rate. This hole was plugged and the results for the following runs were very enlightening. These runs indicated that the L_P^F was reduced to about 0.02 to 0.04 liters per hour.

If it were necessary to leave the lower inlet plugged, the possibility of overheating the lower radial bearing should be investigated. Several methods of cooling the lower bearing were considered but no tests were made.

The next series of runs were made with the suction hole open and a different type of suction inlet. In order to raise the inlet as far from the seal as possible, the top of the shaft sleeve was serrated (Fig. 1). The notches then served as the inlet while previously the inlet had consisted of holes drilled through the sleeve. This modification produced excellent results. Values of $L_P^{F_P}$ of less than .01 liter per hour with 10 liters per hour purge and 0.45 liter per hour with no purge were obtained.

The low $L_P^{F_P}$ values with the suction inlet open presented grounds for a new hypothesis - that the fluid coming into the motor was flowing through the annular area between the shaft and the sleeve while the purge flow was passing through the area between the sleeve and the stationary wear ring.

To determine whether the decreased flow rates were due to changes in seal configuration or to better sampling procedures, the inlet was returned to its original form of holes drilled through the sleeve. As an expediency, the serrated sleeve was inverted and used. A Teflon washer was installed at the lower end of the sleeve to block the serrations. The values of $L_P^{F_P}$ were somewhat lower than those determined in the second series of runs. However if the hypothesis deduced from the serrated sleeve run is correct, then the Teflon washer could have caused the change in results.

The pump was returned to its original condition and the first set of runs repeated. Purge flow during these runs was very unsteady but the results indicate that the purge flow does not greatly affect the mixing flow rate. The paralleling of this set of runs and the previous one adds emphasis to the hypothesis that some fluid is flowing from the loop through the area between the shaft and the sleeve into the motor section.

A set of runs was then made with the pump in its original condition except that a serrated sleeve which was sealed to the shaft with a Teflon washer was installed. The $L_P^{F_P}$ values obtained from this set of runs were the lowest obtained from any of the seal configurations. The mixing rate varied from approximately 0.48 liter per hour at zero purge to less than .002 liter per hour at purge rates from 10 to 20 liters per hour.

The data of many of the runs seemed to counter all logic and showed an increase in $L_P^{F_P}$ as the purge flow increased, although the zero purge runs showed $L_P^{F_P}$ rates some 10 times that for a 10 liters per hour purge. The only feasible explanation for this is that the potassium contamination in the purge water was sufficient to produce the apparent increase in $L_P^{F_P}$.

Almost all runs, regardless of test or sampling procedure showed the perplexing phenomenon of a significant rise in the potassium concentration in both the pump and the loop during the third hour of the run. No explanation is offered for this behavior.

Figure 3 shows the results of a typical run. The general trend of the results of each change in pump configuration is shown in Figure 4.

RADIATION DAMAGE

The effect of the uranyl sulfate in the motor section upon the insulation can be calculated if the fluid concentration and activity are known. After equilibrium conditions have been established, the concentration in the motor cavity will be

$$m_P = m_L \frac{L^F P}{P^F L}.$$

In order to determine the gamma flux density, the time each increment of fluid volume spends in the motor section must be known. This residence time is not the same for all increments because some will remain inside the cavity for an infinite length of time while others will remain for only a fraction of a second.

The average residence time, t_R , that a volume increment will be in the motor section is given by

$$t_R = \frac{V_P}{P}. \quad (8)$$

Although close, t_R is not the exact time for calculating the total activity in the motor section because an increment that is present for a very short time will contribute more to the source strength during this time than an increment which has been in the motor for several days will contribute during the same time interval. However, the error introduced by using the average residence time is minor in this investigation.

If τ is the time that an increment remains in the motor cavity and the number of increments that remain for any finite time τ is expressed by

$$N_\tau = C e^{-\beta \tau} \quad (9)$$

and if the increment has been out of the reactor core for some time T , then from the Wigner-Way equation the average activity, A_t , is expressed by

$$A_t = K_1 \int_0^\infty e^{-\beta \tau} (T + \tau)^{-1.2} d\tau \quad (10)$$

which has for a solution

$$A_t = K_2 T^{1.2} e^{-\beta T} \left(1 - \beta T + \frac{\beta^2 T^2}{2!} - \frac{\beta^3 T^3}{3!} + \dots \right).$$

By lowering the concentration to that produced by a 10 liter per hour purge and a mixing flow of 0.02 liters per hour, the life expectancy of the motor winding insulation, considering only the gamma flux produced by solution in the motor section, would be over 20 years. This is based on damage dose rates reported by Gift¹.

Using the gamma flux density as reported by Engel², the insulation deterioration due to radiation from the impeller section of the pump would probably result in pump failure after 13 years. Since very little can be done to reduce the strength or shield against this radiation source, it should be considered the primary factor and all other sources of radiation reduced to secondary values.

The greatest damage to the insulation could come from the reactor cell background radiation. Using the values given by Campbell³ and considering a narrow beam attenuation through the stainless steel of the pump, the insulation could fail after 308 days. Although this is extremely short compared to the 13 years mentioned previously as the primary factor, it is not a condition that must exist. It has been calculated that a 1 inch thick lead shield around the pump would raise the life expectancy based on background radiation to about 4.66 years.

One other potential cause of insulation failure is the possibility of loss of purge flow. In this condition, although the average residence time is relatively long, the motor section concentration will eventually reach reactor loop concentration. The calculated life of the motor with no purge is approximately 218 days.

CONCLUSIONS

Very little can be done to reduce the radiation from the impeller section of the pump but radiation from other sources can be reduced to allow this source to be the major factor in insulation deterioration.

By proper seal design, the concentration of uranyl sulfate in the motor section of the pump may be reduced sufficiently that it will not cause deterioration of the insulation during the expected life of the pump. It appears that this may be accomplished by using a serrated shaft sleeve which is shrunk on the rotor shaft to prevent flow between the sleeve and the shaft. This configuration proved the most successful of all those tested.

The pump should not be operated in the reactor without a dependable supply of purge water.

Without additional shielding, the reactor cell background radiation will drastically shorten the life of the pump. In view of the relatively simple task of installing shields around the motor sections of the pumps, it is recommended that this be accomplished before the reactor goes critical.

APPENDIX

- Section I. Sample of Data Processing
- Section II. Life Expectancy Considering Radiation from Pump Scroll
- Section III. Life Expectancy Considering Cell Background Radiation
- Section IV. Life Expectancy Considering Radiation From Solution in Motor Cavity During Normal Operation
- Section V. Life Expectancy Considering Hydrogen Generation From Insulation Material
- Section VI. Life Expectancy Considering Radiation From Solution in Pump With No Purge Flow

SECTION I. SAMPLE OF DATA PROCESSING

Data for Plugged Pump Inlet With 11.527 Liters Per Hour Purge

<u>Time</u>	<u>% Flow</u>	<u>ppm K⁺ concentration</u>	<u>Source</u>
1045	33	2150 1.0	Loop Pump
1145	33	1850 3.2	Loop Pump
1245	34	1650 1.9	Loop Pump
1345	34	1300 1.6	Loop Pump
1445	35	1040 2.0	Loop Pump
1545	34	840 1.8	Loop Pump

Average Flow = $33.833\% \times 9 \times 3785.43 = 11.527$ liters/hourAssume $L_{LP}^F = 0.02$

Then from equation (3)

$$P_L^F = 0.02 + 11.527$$

$$= 11.547 \text{ liters/hour}$$

$$\beta_1 = \frac{-62 + \sqrt{62^2 - \frac{4 \times 11.527 \times 4 \times 58}{11.547}}}{2 \left(\frac{4 \times 58}{11.547} \right)} \quad (4d)$$

$$\beta_1 = \frac{-62 + 54.0149}{40.1836}$$

$$\beta_1 = -0.198716$$

$$\beta_2 = \frac{-62 - \sqrt{62^2 - \frac{4 \times 11.527 \times 4 \times 58}{11.547}}}{2 \left(\frac{4 \times 58}{11.547} \right)} \quad (4e)$$

$$\beta_2 = \frac{-62 - 54.0149}{40.1836}$$

$$\beta_2 = -2.88712$$

$$\alpha = \frac{1.0 - 2150 \left[1 + \frac{58 (-0.198716)}{11.547} \right]}{\frac{58}{11.547} \left[-2.88712 - (-0.198716) \right]} \quad (4c)$$

$$= \frac{1.0 - 2150 (.00186)}{-13.50372}$$

$$= 0.222087$$

$$B = \frac{58 (-2.88712)}{11.547} + 1 \quad (0.222087) \quad (4b)$$

$$B = -2.999937$$

$$A = \left[\frac{58 (-0.198716)}{11.547} + 1 \right] (2150 - 0.222087) \quad (4a)$$

$$A = 3.999937$$

$$m_p = 3.999937 e^{-0.1987t} - 2.999937 e^{-2.887t} \quad (4)$$

t	m _p
0	1.00
1/2	2.9116
1	3.1110
1 1/2	2.9276
2	2.6788
3	2.2253
4	1.8247
5	1.4959
6	1.2263

These values are plotted on semi-log paper and a curve drawn through them. This is a theoretical curve for the assumed L_{Fp} . The experimental data is superimposed on a graph of a family of these curves and the actual flow rate found by inspection (See Figure 3).

SECTION II. LIFE EXPECTANCY CONSIDERING RADIATION FROM PUMP SCROLL

Dosage at lowest portion of motor windings²

$$= 6 \times 10^6 \frac{\text{mr}}{\text{hr}}$$

Since

$$1 \frac{\text{mr}}{\text{hr}} = \frac{.0188}{E_\gamma \mu_e} \frac{\text{Photons}}{(\text{cm}^2)(\text{sec})}$$

where μ_e = absorbtion coefficient in air

$$= 3.7 \times 10^{-5} \text{ cm}^{-1} \text{ for Er}$$

E_γ = average energy of gammas

$$= 0.7 \text{ Mev}$$

$$\begin{aligned} \text{Thus } \phi_{\text{flux}} &= \frac{.0188}{.7 \times 3.7 \times 10^{-5}} \times 6 \times 10^6 \frac{\text{photons}}{(\text{cm}^2)(\text{sec})} \\ &= 4.36 \times 10^9 \frac{\text{photons}}{(\text{cm}^2)(\text{sec})} \end{aligned}$$

Energy absorbed by insulation is given by:

$$E_{\text{ab.}} = \phi \mu'_e E_\gamma J \text{ rads/hr}$$

where, μ'_e = absorbtion coefficient for insulation = $.029 \frac{\text{cm}^2}{\text{gm}}$ for E_γ

$$J = 5.767 \times 10^{-5} \frac{\text{rad-gm-sec}}{\text{Mev-hr}}$$

$$\begin{aligned} E_{\text{ab.}} &= 4.36 \times 10^9 \times .7 \times .029 \times 5.767 \times 10^{-5} \text{ rads/hr} \\ &= 5.12 \times 10^3 \frac{\text{rads}}{\text{hr}} \end{aligned}$$

Gift found that a dose limit of 6.0×10^8 should be taken as the point at which the motor may fail.

Thus the life expectancy may be taken as:

$$\frac{6.0 \times 10^8 \text{ rads}}{5.12 \times 10^3 \text{ rads/hr}} = 117 \times 10^3 \text{ hrs} = 13.4 \text{ years}$$

The above calculation is for pump scroll filled with hot soup.

SECTION III. LIFE EXPECTANCY CONSIDERING CELL BACKGROUND RADIATION

The dose rate at the surface of pump has been estimated to be:³

$$3.4 \times 10^8 \frac{\text{mr}}{\text{hr}}$$

and corresponds to a gamma flux of:

$$\phi = 2.47 \times 10^{11} \frac{\text{photons}}{(\text{cm}^2)(\text{sec})}$$

The energy absorbed by the stator insulation assuming no attenuation would then be:

$$\begin{aligned} &= 2.47 \times 10^{11} \times 0.7 \times .029 \times 5.767 \times 10^{-5} \text{ rads/hr} \\ &= 2.89 \times 10^5 \text{ rads/hr} \end{aligned}$$

With a maximum allowable dose of:

$$6 \times 10^8 \text{ rads}$$

the life expectancy would be:

$$\frac{6 \times 10^8 \text{ rads}}{2.89 \times 10^5 \text{ rads/hr}} = 2080 \text{ hrs} = 86.6 \text{ days}$$

Assuming narrow beam attenuation through 1 inch of 304 stainless steel the reduced gamma flux at the stator would be given by:

$$\phi = \phi_0 e^{-\mu x}$$

where $\phi_0 = \text{initial flux} = 2.47 \times 10^{11} \frac{\text{photons}}{(\text{cm}^2)(\text{sec})}$

μ = absorption coefficient for stainless steel

$$\approx .50 \text{ cm}^{-1} \text{ (extrapolated from data given in Reactor Handbook - Physics, AECD-3646)}$$

x = thickness in cm.

$$\begin{aligned} \text{Therefore: } \phi &= 2.47 \times 10^{11} e^{-.50(2.54)} \\ &= 6.94 \times 10^{10} \frac{\text{photons}}{\text{cm}^2 \cdot \text{sec}} \end{aligned}$$

and the energy absorbed by insulation would be:

$$\begin{aligned} E_{\text{ab}} &= 6.94 \times 10^{10} \times 0.7 \times .029 \times 5.767 \times 10^{-5} \text{ rads/hr} \\ &= 8.11 \times 10^4 \text{ rads/hr.} \end{aligned}$$

The time before possible failure would be:

$$\frac{6.0 \times 10^8 \text{ rads}}{8.11 \times 10^4 \text{ rads/hr}} = 7400 \text{ hrs} = 308 \text{ days}$$

To protect the stator from the background radiation, a shield should be designed to give a life of 12.3 yrs. which is the life estimate from radiation in the scroll.

This gives a gas production of 0.0453 ml/hr, which is a factor of 15.8 less than the rate for background radiation with 1-in. of 347 stainless steel shielding (from Section V of Appendix).

The gamma flux must then be reduced to $\frac{6.94 \times 10^{10}}{15}$

$$\phi = 4.62 \times 10^9 \frac{\text{photons}}{\text{cm}^2 - \text{sec}}$$

$$\phi = \phi_0 e^{-\mu x}$$

$$\phi = \text{initial flux} = 2.47 \times 10^{11} \frac{\text{photons}}{\text{cm}^2 - \text{sec}}$$

$$\mu = \text{absorbition coefficient for stainless steel, } \approx .50 \text{ cm}^{-1}$$

$$x = \text{thickness in cm}$$

$$e^{\mu x} = \phi_0 / \phi = \frac{2.47 \times 10^{11}}{4.62 \times 10^9} = 0.535 \times 10^2 = 53.3$$

$$\mu x = 4.01$$

$$x = \frac{4.01}{0.5} = 8.02 \text{ cm of stainless steel}$$

Assuming 1-in. of stainless steel for the pressure vessel and cooling jacket,

additional thickness $t = 8.02 - 2.54 = 5.48$ cm of stainless steel

$$\text{Density of stainless steel} = 0.29 \text{ lb/in}^3$$

$$\text{Density of lead} = 0.4096 \text{ lb/in}^3$$

$$\text{Thickness of Lead Shield} = 5.48 \times \frac{0.29}{0.4096} = 3.88 \text{ cm} = 1.525 \text{ in.}$$

$$\approx 1.5$$

Assume 1-in. lead shielding in addition to stainless steel press. housing.

Correcting for density thickness of stainless steel would be $1 + \frac{.4096}{.29}$

$$X = 1 + 1.41 = 2.41 \text{ in. of stainless steel} = 6.13 \text{ cm}$$

$$\begin{aligned}\phi &= \phi_0 e^{-\mu x} \\ &= (2.47 \times 10^{11}) e^{-.5(6.13)} \\ &= \frac{2.47 \times 10^{11}}{e^{3.06}} = \frac{2.47 \times 10^{10}}{2.14} = 1.155 \times 10^{10} \frac{\text{photons}}{\text{cm}^2 \text{ sec}} \\ \frac{6.94}{1.155} &= 6\end{aligned}$$

With 1-in. lead shield, the life expectancy should be:

Electrical Failure = 5-6 yrs.

Hyd. Press. Failure = 4.66 yrs.

SECTION IV. LIFE EXPECTANCY CONSIDERING RADIATION FROM SOLUTION IN MOTOR CAVITY
DURING NORMAL OPERATION

The residence time of an increment of volume of hot soup in the backside has been estimated from a Gaussian distribution study to be ~ 25 min. Total time out of the reactor would then be:

$$25 \text{ min} \times \frac{60 \text{ sec}}{\text{min}} + 10 \text{ sec} = 1510 \text{ sec.}$$

This corresponds to:

$$1.510 \times 10^3 \text{ sec} \times \frac{1 \text{ hr}}{3.6 \times 10^3 \text{ sec}} \times \frac{1 \text{ day}}{24 \text{ hr}} = .01748 \text{ day}$$

The rate of gamma emission determined from the Wigner-Way equation would then be:

$$\begin{aligned} \text{Rate of gamma emission} &= 1.9 \times 10^{-6} (.0174)^{-1.2} \\ &= 1.9 \times 10^{-6} \times 1.3 \times 10^2 \\ &= 2.46 \times 10^{-4} \frac{\text{photons}}{(\text{sec})(\text{fission})} \end{aligned}$$

The gamma power density would then be:

$$\begin{aligned} S_d &= \frac{2.546 \times 10^{10} \times 5 \times 10^6}{5 \times 10^5} \times (.01748)^{-0.2} \frac{\text{photons}}{\text{cm}^3 \cdot \text{sec}} \\ &= 2.546 \times 10^{11} \times 2.25 \frac{\text{photons}}{\text{cm}^3 \cdot \text{sec}} \\ &= 5.73 \times 10^{11} \frac{\text{photons}}{\text{cm}^3 \cdot \text{sec}} \end{aligned}$$

Since the gamma power density above is for hot soup containing a maximum of fission products and occupying the total available volume of the backside, a dilution factor is necessary for this study since the maximum concentration in the backside at equilibrium due to mixing has been found to be only .003 times the loop concentration (.003 m_L). The case for total m_L has been computed up to now. Considering this development will yield a gamma power density of:

$$3 \times 10^{-3} \times 5.73 \times 10^{11} \frac{\text{photons}}{\text{cm}^3 \cdot \text{sec}} = 1.72 \times 10^9 \frac{\text{photons}}{\text{cm}^3 \cdot \text{sec}}$$

Utilizing the geometry employed by Gift¹ and:

$$\phi_r = \frac{B \text{ Sr } R_o^2}{2 (a + Z)} F(\theta, b_2)$$

where:

$$R_o = 2.5 \text{ in.} \quad \mu_s = .084$$

$$a = 0.03 \text{ in.} \quad \frac{\text{cm}^2}{\text{gm}}$$

$$h = 2.5 \text{ in.}$$

$$\frac{a}{R_o} = \frac{.03}{2.5} = .012$$

$$\begin{aligned} \mu_s (a + R_o) &= \frac{.084}{.9982323} (2.53 \times 2.54) \\ &= .0842 (6.47) = .545 \end{aligned}$$

$$m \sim .5$$

$$\frac{1}{m} \mu_s Z \sim 2.3$$

$$b \sim 0$$

$$Z = \frac{2.3 \times .5}{.0842} = 13.65 \text{ cm.}$$

$$\theta = \cos^{-1} .03/1.25 = 88^\circ 37'$$

$$F(\theta, b) \cong 1.4$$

A gamma flux was found to be:

$$\phi_r = \frac{2.7 \times 1.72 \times 10^9 \times 6.47 \times 1.4}{2(13.68)}$$

$$\phi_r = 1.54 \times 10^9 \frac{\text{photons}}{\text{cm}^2 \cdot \text{sec}}$$

The energy absorbed corresponding to this flux would be:

$$E_{ab} = 1.54 \times 10^9 \times .7 \times .029 \times 5.767 \times 10^{-5} \frac{\text{rads}}{\text{hour}}$$

$$= 1.80 \times 10^3 \text{ rads/hr}$$

Possible failure of the pump would then occur after:

$$t = \frac{6.0 \times 10^8 \text{ rads}}{1.80 \times 10^3 \frac{\text{rads}}{\text{hr}}} = 33.3 \times 10^4 \text{ hr}$$

$$= 38.0 \text{ years.}$$

SECTION V. LIFE EXPECTANCY BASED ON HYDROGEN GENERATION FROM INSULATION MATERIAL

Gift¹ found that the gas production rate may be represented by:

$$Pd = 1.17 \times 10^{-8} V Eabs.$$

where V = volume of silicone glass insulation, cm^3

$Eabs.$ = energy absorption rate

Considering the three independent cases of (1) pump scroll filled with hot soup, (2) cell background radiation (narrow beam attenuation) and (3) contamination due to mixing.

Gas production rates for each were found to be, respectively:

(1) .0453 ml/hr

(2) .716 ml/hr

(3) .0163 ml/hr

Using these gas production rates, and using $P = 1.6$ atmospheres which is 4 times the ASME code value for allowable working external pressure on the stator can, the life of the pump can be estimated from a hydrogen pressure standpoint by the equation:

$$t = \frac{PMV}{Pd \rho RT} \quad (\text{from perfect gas law})$$

where: Pd = gas production rate ml/hr

P = pressure (atmospheres) = 1.6

ρ = density of hydrogen at STP = 8.98×10^{-5} gm/cc

M = molecular weight = 2.016 gm/gm-mole

V = volume of gas space = 3.6×10^3 cm^3

R = gas constant = $82.057 \frac{cm^3 \cdot atm.}{gm \cdot mole \cdot ^\circ K}$

T = temperature = $50^\circ C = 323^\circ K$

t = hours exposure

$$t = \frac{PMV}{(P_a) \phi RT} = \frac{1.6 \times 2.016 \times 3.6 \times 10^3}{(P_d) 8.98 \times 10^{-5} \times 82.057 \times 3.23 \times 10^2}$$

$$= \frac{1}{P_d} (4.88 \times 10^3)$$

$$t_1 = \frac{1}{0.0453} (4880) = 107,500 \text{ hrs.} = 12.3 \text{ years}$$

$$t_2 = \frac{1}{0.716} (4880) = 6820 \text{ hrs.} = 284 \text{ days}$$

$$t_3 = \frac{1}{0.0163} (4880) = 299,000 \text{ hrs.} = 34 \text{ years}$$

SECTION VI. LIFE EXPECTANCY CONSIDERING RADIATION FROM SOLUTION IN PUMP WITH NO PURGE FLOW

$$\frac{dQ}{dt} = - \frac{P^F L}{V_P} Q_t = - \frac{.48}{4} Q_t$$

$$Q_t = Q_0 e^{-.12 t}$$

$$\bar{T} = \frac{\int_0^{\infty} t Q_0 e^{-.12 t} dt}{Q_0 e^{-.12 t} dt} = 8.33 \text{ hrs.} = \frac{V}{.48 \times 24} \text{ days}$$

$$S_D = 2.545 \times 10^{11} t^{-0.2} \text{ photons/sec-cm}^3 \quad (t \text{ in days})$$

$$\begin{aligned} \text{Total source strength} &= \int_0^{V_P} S_D (\bar{T} + 10) dV \\ &= \int_0^{4000} 2.545 \times 10^{11} \left[\frac{V}{.48 \times 24} + \frac{10}{86,400} \right]^{-0.2} dV \\ &= 3.921 \times 10^{14} \text{ photons/sec} = 9.803 \times 10^{10} \text{ photons/sec-cm}^3 \end{aligned}$$

From Sections IV and V,

Life Expectancy Based on Insulation Breakdown

$$= 3.33 \times 10^5 \times \frac{1.72 \times 10^9}{9.803 \times 10^{10}} = 5.84 \times 10^3 \text{ hrs.} = 243 \text{ days}$$

Life Expectancy Based on Hydrogen Evolution

$$= 2.99 \times 10^5 \times \frac{1.72 \times 10^9}{9.803 \times 10^{10}} = 5.24 \times 10^3 \text{ hrs.} = 218 \text{ days.}$$

Figure 1. Partial Section of Serrated Sleeve Used in Runs 5 and 7

Figure 2. Schematic of 400A Seal Assembly, Original Design

Fig. 3 Plot of Data for Plugged Pump Inlet with 12.8 Liter Per Hour Purge. Reference Line is Theoretical Values for Mixing Flow (LFp) of 0.02 Liters Per Hour

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