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SUBJECT: Estimates of Temperature Rise and Pressure Drop Effects of Sample
Holder in the HRT Core.

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SUMMARY:

A study has been made to determine the surface temperature of structural components of the sample holder which is to be placed in the core of the HRT and to see if boiling might occur around the holder. Three structural materials, titanium, zircaloy, and stainless steel, have been considered. Heat generation rates in these metals have been estimated for operation at 5 Mw and at 10 Mw and are listed in Table II. By estimating the surface to volume ratio of various components of the holder it is shown that the higher surface temperature will probably occur in the structural Y-beam. Assuming natural circulation it is possible to estimate the temperature drop between the Y-beam surface and the main bulk of the fuel solution. The temperature drop required to remove the heat generated in a titanium or zircaloy Y-beam is $\sim 25^{\circ}\text{F}$ (5 Mw) while that required for a stainless steel Y-beam is $\sim 35^{\circ}\text{F}$. The calculations indicate that if titanium or zircaloy is used the surface temperature will be $\sim 314^{\circ}\text{C}$ (max) and no boiling of the fuel solution will occur unless the total pressure falls below ~ 1540 psia. If stainless steel is used the fuel solution around the holder may boil if the pressure is lowered to 1650 psia. Either titanium or zircaloy is recommended as the structural material for the sample holder. Care should also be taken to remove any pockets or crevices in the holder where fuel might be trapped and become stagnant.

Several batteries of samples will be placed in the exit line from the core vessel. The greatest restriction to flow occurs at the ring holder assembly. An estimate of the pressure drop at this point for normal operation has been made and is ~ 0.7 psi. If four sample batteries are used in the exit line the additional pressure drop will be ~ 3 psi.

INTRODUCTION:

During operation of the HRT, sample specimens of zircaloy, stainless steel or other material will be placed in the core of the HRT and in the vertical exit pipe above the core vessel. The structural assembly (shown in drawings D-25624 & D-25625) designed to hold these samples will be made of titanium, stainless steel or zircaloy. Since this assembly is in an intense radiation field, there will be some heat generation in the metal itself. If the surface of the metal reaches a high enough temperature the fuel solution around it will boil. This is particularly undesirable as boiling will probably cause phase separation of the fuel solution and deposits of uranium on the metal surfaces. This in turn will cause more heat generation in the metal and consequently more boiling. The purpose of this paper is to estimate the heat generation rates in the metal and the surface temperatures that can be expected during normal operation. Since the intensity of radiation is greatest at the center of the core conditions at this point were assumed for the heat generation estimations.

Estimation of Heat Generation in Sample Holder Assembly

Three heat sources were considered in estimating the heat generation in the metal of the sample holder. They are:

1. Absorption of fission-gamma energy.
2. Energy from distributed secondary-gamma sources.
3. Energy from secondary-gammas emitted in the sample itself.

Equations used (1)

For absorption of fission-gamma energy

$$H_1 = P(r) \frac{\mu_{\text{sample}}}{\mu_{\text{core}}} \left[\omega_{\gamma(\text{prompt})} + \omega_{\gamma(\text{delayed})} \right], \quad \frac{\text{watts}}{\text{cc}} \quad (1)$$

For energy from distributed secondary-gamma sources

$$H_2 = \kappa \phi_s(r) \frac{\mu_{\text{sample}}}{\mu_{\text{core}}} \sum_i \Sigma_i E_{\gamma i}, \quad \frac{\text{watts}}{\text{cc}} \quad (2)$$

For energy from secondary-gammas emitted in sample

$$H_3 = \kappa \phi_s(r) \Sigma_{\text{sample}} E_{\gamma}, \quad \frac{\text{watts}}{\text{cc}} \quad (3)$$

Total heat generation

$$H_T = H_1 + H_2 + H_3 \quad (4)$$

where H_T = total heat generation rate, watts/cc

$P(r)$ = power density of fuel solution at the sample (assumed equal to the maximum power density of HRT or 22.3 watts/cc for 5 Mw operation) (2)

$\phi_s(r)$ = thermal neutron flux at the sample (assumed equal to the maximum flux of the HRT of 1.07×10^{14} neut/cm²-sec at 5 Mw.) (2)

μ = energy absorption coefficients for gammas (μ is evaluated for gamma energies of 1-2 Mev for H_1 and 5-8 Mev for H_2).

(1) The Reactor Handbook - Vol. 2 - Engineering.

(2) M. C. Edlund and P. M. Wood, "Physics of the Homogeneous Reactor Test Statics", ORNL-1780.

α = conversion factor ($= 1.6 \times 10^{-13} \frac{\text{watt-sec}}{\text{Mev}}$)

β = probability that a gamma ray emitted inside the sample will be absorbed inside the sample (values of β for various geometries are given in the Reactor Handbook)⁽¹⁾.

$\omega_{\gamma}(\text{prompt})$ = Fraction of total available energy per fission emitted as prompt gamma energy (≈ 0.027)⁽¹⁾

$\omega_{\gamma}(\text{delayed})$ = Fraction of total available energy per fission emitted as delayed γ -energy (≈ 0.032)⁽¹⁾

E_{γ} = average energy of emitted gammas, Mev/neutron capture.

Σ = macroscopic cross section, cm^{-1} .

The samples and sample holder assembly will probably be made from either titanium, stainless steel, zircaloy or some combination of these metals. Heat generation rates were considered for all three materials. Some properties of materials used in the calculation are given in Table I:

TABLE I

Properties Used in Estimation of Heat Generation Rates

Material	Density ρ , gms/cc	Neutron Cross Section σ_a (280°C), barns	Capture Gamma Energy E , Mev	Gamma Energy Absorption Coefficient, cm^{-1}	
				$\mu(1\text{-}3\text{Mev})$	$\mu(5\text{-}8\text{Mev})$
Titanium	4.5	4.1	8.8	0.113	0.104
Zircaloy	6.4	0.13	8.6	0.160	0.149
Stainless Steel	7.86	1.77	7.6	0.197	0.182
Fuel Sol'n.	0.83			0.0236	0.0137
Sulfur		0.36	8.6		
Copper		2.61	7.9		
U-235		73.5 (radiative capture)	5		

(1) The Reactor Handbook - Vol. 2 - Engineering.

Resulting heat generation rates as calculated from equations 1 - 4 are listed in Table II. From the standpoint of heat generation stainless steel appears to be more undesirable than either titanium or zircaloy.

TABLE II

Heat Generation Rates in Sample Holder
watts/cc

Power of HRT, Mw	Titanium		Zircaloy		Stainless Steel	
	5	10	5	10	5	10
H_1	6.10	12.2	8.92	17.84	10.95	21.9
H_2	1.08	2.16	1.54	3.08	1.89	3.78
H_3	3.85	7.7	0.13	0.26	3.63	7.26
H_T	11.0	22.1	10.6	21.2	16.5	32.9

Heat Removal From Sample Holder Assembly

In order to calculate the heat removal rates needed from the surface of the assembly, the surface area to volume ratio was estimated for each component. Estimates were made using drawings D-25624 and D-25625. They are:

$$\frac{S}{V} = (\text{structural Y-beam}) = 12 \text{ in}^2/\text{in}^3$$

$$\frac{S}{V} = (\text{sample specimen}) = 18 \text{ in}^2/\text{in}^3$$

$$\frac{S}{V} = (\text{hollow screw holding sample}) = 13 \text{ in}^2/\text{in}^3$$

$$\frac{S}{V} = (\text{ring assembly to house battery of sample}) = 38 \text{ in}^2/\text{in}^3$$

That portion of the surface of the Y-beam covered by the ring assembly may not be fully available to transfer heat. If this area is neglected the surface to volume ratio for the structural Y-beam is $\sim 9.2 \text{ in}^2/\text{in}^3$.

Necessary heat removal rates from various components of the sample holder are listed in Table III.

TABLE III
Heat Removal Rates From Surface of Sample Holder

Component	q/A, Btu/hr-ft ²			
	5 Mw		10 Mw	
	Titanium or Zircaloy	Stainless Steel	Titanium or Zircaloy	Stainless Steel
Sample	4930	7390	9850	14,700
Hollow Screw	6820	10,200	13,600	20,400
Ring Assembly	2330	3500	4670	6980
Structural Y-beam (for S/V = 12)	7390	11,100	14,800	22,100
(for S/V = 9.2)	9640	14,500	19,300	28,800

From Table III it appears that the structural Y-beam surface will become hotter than any other component. This component then should be made from either zircaloy or titanium rather than stainless steel.

Since the flow of fuel solution is relatively slow in the center of the HRT core, it will be assumed that the heat transfer coefficient will depend on natural convection only. An expression was derived in CF 55-7-64 (3), from the Nusselt equation for free convection, relating the heat transfer coefficient and temperature drop across the liquid film

$$h_c = 130 (\Delta t)_f^{1/3} \quad (5)$$

where h_c = heat transfer coefficient, $\frac{\text{Btu}}{\text{hr ft}^2 \cdot ^\circ\text{F}}$

$(\Delta t)_f$ = temperature drop across the liquid film, $^\circ\text{F}$

Since the physical properties of the fuel solution are essentially the same as those considered in CF 55-7-64, it will be assumed that equation (5) applies here.

Since the hottest surface temperature will probably be that of the structural Y-beam component, this will be the only case considered. The heat transfer equation can be written

$$\frac{q}{A} = h_c (\Delta t)_f = 130 (\Delta t)_f^{2/3}$$

(3) Aven, R. E., "Some Heat Removal Considerations of the HRT Pressure Vessel During Operation", CF 55-7-64.

Solving for $(\Delta t)_f$

$$(\Delta t)_f = \left[\frac{q/A}{130} \right]^{3/4} \quad (6)$$

In this case $(\Delta t)_f$ will represent the temperature difference between the surface of the Y-beam and the average temperature of the fuel solution at the point in question.

Some values of $(\Delta t)_f$ for the Y-beam are (for $S/v = 12$):

Material	At 5 Mw	At 10 Mw
Titanium or Zircaloy	$(\Delta t)_f = 21^\circ\text{F}$	$(\Delta t)_f = 35^\circ\text{F}$
Stainless Steel	$(\Delta t)_f = 28^\circ\text{F}$	$(\Delta t)_f = 47^\circ\text{F}$

If the surface area of the Y-beam that is covered by the ring assembly is assumed unavailable to transfer heat (i.e., $S/v \approx 9.2$) then the values for $(\Delta t)_f$ become:

Material	At 5 Mw	At 10 Mw
Titanium or Zircaloy	$(\Delta t)_f = 25^\circ\text{F}$	$(\Delta t)_f = 43^\circ\text{F}$
Stainless Steel	$= 34.5^\circ\text{F}$	$= 57^\circ\text{F}$

As presently designed the sample holder and samples which are inside the core vessel will have the following approximate metal volume:

Volume of Y-beam (36 in. in core)	=	16.2 in ³
Volume of 4 batteries of samples (24 samples)	=	6.48
Volume of 4 ring assemblies	=	2.75 in ³
Total Volume		25.4 in ³

The total heat generation in the core vessel due to the sample holder is (for 5 Mw)

$$\begin{aligned} q_{\text{Ti or Zr}} &= 15,700 \text{ Btu/hr} \\ q_{\text{Fe}} &= 23,700 \text{ Btu/hr} \end{aligned}$$

This corresponds to a total average temperature rise in the fuel solution of $\leq 0.1^\circ\text{F}$.

Pressure Drop Across Battery of Samples in Exit Line From Core Vessel

To get an estimate of pressure drop across a battery of samples in the exit line the following assumptions were made:

- 1) All pressure drop occurs at the ring assembly of the holder.
- 2) Pressure drop consists of an expansion loss and a contraction loss.
- 3) All flow is forced around the ring assembly; i.e., there is no flow through the small openings in the center of the ring holder.

Expansion and contraction losses are given by ⁽⁴⁾

$$(\Delta P)_{\text{expansion}} = \frac{(v_0 - v_1)^2 \rho}{2 g_c} \quad (7)$$

$$(\Delta P)_{\text{contraction}} = \frac{K \rho v_1^2}{2 g_c} \quad (8)$$

where v_0 = normal velocity in core exit pipe = 14.8 ft/sec

v_1 = average velocity through restricted cross section = 21.0 ft/sec

ρ = density of fuel solution = 50.6 #/ft³ at 300°C

g_c = conversion factor = 32.2 $\frac{\text{lbs mass-ft}}{\text{lb force-sec}^2}$

$K = 0.4 \left(1.25 - \frac{S_2}{S_1} \right)$

S_2 = cross sectional area available to flow at the ring = 0.0471 ft²

S_1 = cross sectional area of exit line = 0.0668 ft²

The total pressure drop using equations (7) and (8) is ~ 0.7 psi/battery of samples. For four batteries (24 samples) the total pressure drop is ~ 2.8 psi in addition to the normal (unobstructed) pressure drop in the exit line from the HRT core vessel.

⁽⁴⁾ J. H. Perry, ed, "Chemical Engineers' Handbook" 3rd Edition, p. 388, McGraw-Hill (1950).

Conclusions:

From the standpoint of heat generation in the structural material of the sample holder either titanium or zircaloy would be better than stainless steel. Since the neutron cross section of titanium is relatively high while that for zircaloy is low it would appear that the best material of the three considered is zircaloy. The neutron poisoning effect is less of a problem, however, than is boiling of the fuel solution, so if zircaloy is unavailable as a structural material for the holder then titanium should be used.

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