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SUBJECT: Pressure Rise in the Reversed Flow HRT Following
a Cold Fluid Accident During Startup

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Abstract

The maximum pressure rise in the core of the HRT following a cold water accident during startup has been calculated for upward flow of core fluid and for reversed flow. With the reactor initially critical at 260°C and a power level of 0.04 watts, fuel solution at 100°C was considered to enter the core at a flow rate of 150 gpm. With reversed flow this added reactivity at an average rate of 1.7% Δk_e /sec, while with upward flow the rate was 0.67% Δk_e /sec. The core pressure increased rapidly to a maximum of 550 psi above normal operating pressure with reversed flow and 400 psi with upward flow when only the core pressurizer was available for fluid expansion. With the core and blanket pressurizers connected, the excess pressures were 375 psi and 210 psi, respectively.

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INTRODUCTION

The Homogeneous Reactor Test (HRT) is a two-region reactor with a $U^{235}O_2SO_4-D_2O$ solution in the core and D_2O in the blanket. With upward flow operation the fuel solution enters at the bottom of the core through flow-diffusing screens and exits at the top.

Modifications to the HRT core have been suggested¹ and are presently being made to reverse the direction of flow through the core. With reversed flow the HRT will have a flow distribution described ideally as a free jet passing through a sphere along its polar axis from north to south.² Core fluid is entrained into and mixes with the jet during its passage. In order to satisfy continuity in the jet, fluid is shed from the jet at the bottom of the sphere and flows back up along the walls of the vessel.

This flow pattern causes the incoming fluid to pass more rapidly into the important central region of the reactor than does the slug flow existing in upward flow. Therefore, with reverse flow, a cold-water accident would add reactivity at a higher rate initially than with upward flow. It would be expected that this greater rate of reactivity addition would cause a more rapid rise in reactor power and a larger increase in core pressure.

SUMMARY OF RESULTS

The results of the reactor power and pressure rise calculations are summarized in Table 1. Some calculations were made with only the core pressurizer available for fluid expansion ($V_p = 2.5 \text{ ft}^3$) while others considered the core and blanket pressurizers to be connected ($V_p = 5 \text{ ft}^3$). Two different values for the temperature coefficient of reactivity were

Table 1. Results of Power and Pressure Rise Calculation

Case No.	Flow Direction	m, sec^{-1}	ℓ (sec)	ξ^* (sec^{-2})	$\frac{\partial k_e}{\partial T} \times 10^3$ $^{\circ}\text{C}^{-1}$	V_p, ft^3	$x_{\max}$	$t(x_{\max})$ sec	$P_{\max}$ psi	$t(P_{\max})$ sec
90	UP	-8.8	5.7×10^{-4}	15.2	- 1.85	2.5	3.0×10^9	2.25	425	2.45
3	UP	-8.3818	6×10^{-4}	11.2	- 1.85	2.5	2.9×10^9	2.94	400	3.15
12	UP	-8.3818	6×10^{-4}	11.2	- 1.7	2.5	3.2×10^9	2.94	400	3.15
13	UP	-8.3818	6×10^{-4}	11.2	- 1.7	5.0	3.2×10^9	2.94	210	3.20
14	UP	-8.3818	6×10^{-4}	11.2	- 1.85	5.0	2.9×10^9	2.94	210	3.20
8	Reverse	-8.6868	6×10^{-4}	28.4	- 1.85	2.5	5.9×10^9	1.48	545	1.60
9	Reverse	-8.6868	6×10^{-4}	28.4	- 1.7	2.5	6.4×10^9	1.48	545	1.60
10	Reverse	-8.6868	6×10^{-4}	28.4	- 1.7	5.0	6.4×10^9	1.48	380	1.47
11	Reverse	-8.6868	6×10^{-4}	28.4	- 1.85	5.0	5.9×10^9	1.48	375	1.47

* The value for ξ represents an average from time zero to time of $x_{\max}$.

considered in order to determine what effect this would have on the core pressure rise. As shown in the table, the change in temperature coefficient had a negligible effect, while the pressurizer volume available for core fluid expansion was very important.

Case 90, a special case using the same parameter values as a previous study³ of HRT safety, was run to compare results with that study. The pressure rise calculated in the previous study was 400 psi; case 90 predicted a 425 psi pressure rise, so the comparison is quite good.

DISCUSSION OF RESULTS

The rate of reactivity addition during the cold-water accident was calculated assuming no nuclear heating of the fluid. This reactivity addition rate was then used as input data for the pressure rise calculation in which the effects of nuclear heating were included. However, by doing the calculation in two parts, the temperature effects lag the input value k_e by one time step. Thus, the value of k_e at any time is slightly higher than it would be if the temperature effects were not lagging. This difference should be small and on the conservative side.

With the core and blanket pressurizers directly connected, the maximum calculated pressure rise with reversed flow was about 375 psi. This is slightly below the value calculated for upward flow with only one pressurizer. Therefore, the pressure rise in the reversed-flow HRT with connected pressurizers would be no greater than with upward flow and only one pressurizer available.

METHOD OF CALCULATION

In order to estimate the maximum pressure rise in the core, it was first necessary to calculate the rate of reactivity addition associated with the entrance of cold fluid into the core. This calculation was made using a two-group, two-dimensional reactor code, EQUIPOISE.⁴ The HRT was approximated in cylindrical geometry as shown in Fig. 1.

A series of calculations was made with various fuel concentrations and a uniform temperature of 260°C to establish the critical concentration. It was then considered that fuel solution of this critical concentration was cooled to 100°C and introduced into the core at 150 gpm (one-third normal flow rate). With upward flow it was assumed that the cold fluid rose through the core without mixing and with no nuclear heating of the fluid. In reversed flow the cold fluid passed down through the core in the central jet (regions 1-5 in Figure 1). Hot fluid was entrained in the jet² and increased the average temperature of fluid in the jet by about 30°C per foot traveled. Again it was considered that no nuclear heating took place.

Time increments were chosen such that individual regions of the core were successively filled with the cold fluid and the corresponding values of k_e were calculated. The values of k_e are plotted as a function of time in Figure 2. Time zero was taken when cold fluid entered the top of region 1 in reversed flow and the bottom of region 5 in upward flow.

The curve of k_e versus time was approximated by a series of ramp additions of reactivity in a kinetics code, PET-I.⁵ This code was modified to include a calculation of the core pressure rise as a function of time using Equation (1).⁶

Fig. 1. Approximation of HRT shape used for EQUIPOISE calculation. (Dashed lines represent actual outline.)

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$$p = \frac{\omega_n^2}{\gamma_2 \omega_n^2} \left\{ x + \gamma_1 (x-1) \left[1 + \frac{\omega_n^2 (x-1)}{2\gamma_3} \right] + \omega_n^2 c_2 y \right\} \quad (1)$$

where p = core pressure rise, psi
 x = relative reactor power, dimensionless
 y = normalized temperature rise of core fluid. The remaining terms are constants which are defined in Reference 6.

A typical plot of x , y , and p as functions of time is shown in Figure 3. Equation (1) was evaluated as a function of time, and the maximum value was taken as $P_{\max}$.

In most of the cases calculated, the pressure did not show a definite maximum value, so the value chosen was somewhat arbitrary. For example, in Figure 3 with a pressurizer volume of 2.5 ft^3 , the pressure has a small peak, but subsequently rises to a value higher than that at the peak. It was decided to use the higher value when the peak did not correspond to the maximum value of the pressure. In this case, the value chosen was 550 psi at 1.6 seconds rather than the peak value which was 500 psi at 1.48 seconds. However, in Figure 3 with a pressurizer volume of 5 ft^3 the pressure reaches a very definite maximum value of 375 psi at 1.47 seconds, and this was the value used.

REFERENCES

1. C. G. Lawson, Proposed Revisions to the HRT Core, ORNL CF-60-1-20, Jan. 12, 1960.
2. C. G. Lawson, Fuel Transport Lag Time and Temperature Distribution for Reversed Flow HRE-2 Core, HRP-60-41, April 4, 1960.
3. P. R. Kasten, Dynamics of the Homogeneous Reactor Test, ORNL-2072, June 7, 1956.
4. M. L. Tobias and T. B. Fowler, EQUIPOISE, an IBM-704 Code for the Solution of Two-Group, Two-Dimensional Neutron Diffusion Equations in Cylindrical Geometry, ORNL-2967, 1960.
5. S. Jaye and M. P. Lietzke, Power Response Following Reactivity Additions to the HRT, ORNL CF-58-12-106, Dec. 30, 1958.
6. P. R. Kasten, Homogeneous Reactor Safety, ORNL CF-55-5-51, May 9, 1955.

APPENDIX A

Calculation of Delayed Neutron Precursor Constants

The delayed neutron precursor constants were calculated from effective yield relationships given by Kasten.¹ The flow models chosen were slug flow for the upward flow case and complete mixing in reverse flow.

Table 2

Delayed Neutron Precursor Constants Reversed Flow

Group, i	Decay Constant, λ_i sec ⁻¹	β_i (static)	β_i (effective)	$C_i(0)$
1	0.0124	0.0002112	0.000128	17.203
2	0.0305	0.001402	0.000902	49.279
3	0.1114	0.001254	0.000962	14.392
4	0.3013	0.002528	0.00224	12.405
5	1.364	<u>0.001005</u>	<u>0.000978</u>	1.194
	Totals	0.00640	0.00521	

Upward Flow

Group, i	λ_i	β_i (static)	β_i (effective)	$C_i(0)$
1	0.0124	0.0002112	0.000122	16.47
2	0.0305	0.001402	0.000831	45.42
3	0.1114	0.001254	0.000892	13.34
4	0.3013	0.002528	0.00221	12.21
5	1.364	<u>0.001005</u>	<u>0.000977</u>	1.193
	Totals	0.00640	0.00503	

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