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LOADING, OPERATING CONDITIONS, AND WATER
SHUTOFF TIMES FOR A CHARGE OF TWELVE ENRICHED
SINGLE TUBE ELEMENTS, PT-IP-501A

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M. J. Wise

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January 21, 1963

LOADING, OPERATING CONDITIONS, AND WATER SHUTOFF TIMES FOR A CHARGE OF TWELVE ENRICHED SINGLE TUBE ELEMENTS, PT-IP-544-A

Production Test IP-544-A⁽¹⁾ authorized the irradiation of 1.6% enriched single tube elements in KER-1 and 2 and specified certain limitations on the operating conditions for the elements. The test required that specific operating conditions and trip settings for particular loadings would be approved by the managers of the Process and Reactor Development Subsection and the Process Technology Subsection prior to charging.

(1) Kratzer, W.K. and M. J. Wise, Production Test IP-544-A, Irradiation of 1.6% Enriched Thick Walled Single Tube Elements in KER-1 and 2, HW-75456, December 12, 1962 (SECRET)

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The purpose of this document is to provide the process tube loading, operating limits, and water shutoff times for a charge of twelve 12-inch 1.6% enriched single tube elements in KER-1 and 2.

Process Tube Loading

The tube loading shall consist of ³three 8-inch triangular perfs downstream, ²⁷twenty-three 8-inch spacers, ²³one modified 8-inch triangular perf, twelve 12-inch elements, and one modified 8-inch triangular perf upstream.

Operating Limits

The maximum operating outlet temperature and high outlet temperature trip are given in Figure 1 as a function of the observed tube ΔT . The low pressure trip and boiling point suppression trip will be set according to Process Standards, HW-46000-K.

If low pressure recirculation is required, the low pressure trip will be set at 500 psig, the high outlet temperature trip set at 200°C, the low flow trip set at 32,000 lbs/hr, and the boiling point suppression trip set according to Process Standards.

Water Shutoff Times

Water shutoff times with the reactor down are given in Figure 2 as a guide for determining how long flow can be interrupted to a loop containing irradiated fuel elements without jeopardizing the results of the fuel test. Water shutoff times related to reactor safety, such as infinite water shutoff times to avoid fuel meltdown, are not within the scope of this document.

Allowable water shutoff times expressed as a function of time after shutdown are given in Figure 2 for the following three cases:

Case A

With the loop recirculating at a system pressure of 500 psi or greater, the coolant temperature at 20 C or less, and the reactor down at least four hours, flow is stopped and then started again without reducing pressure below 500 psi. The limiting condition that restricts the water shutoff time is the maximum fuel temperature, which should not exceed 250 C to avoid temperature induced changes in the fuel elements that would affect test results.

Case B

With the loop operating on single-pass at atmospheric pressure with 20 C water, and the reactor down at least four hours, flow is interrupted and started again without draining the tube; that is, the tube remains completely full of water. The limit in this case is 100 C coolant temperature to avoid large quantities of steam in the tube.

Case C

With the loop operating on single-pass at atmospheric pressure with 20 C water and the reactor down at least four hours, flow is interrupted. The tube is drained, leaving the elements in air and flow is then restored to the tube.

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Case C (continued)

The limit in this case is 100 C surface temperature of the fuel elements, imposed to prevent dried radioactive film particles sloughing from the fuel and getting out of the open tube.

The above three cases cover most of the types of flow interruption during shut-down in KER-1 or KER-2 while loaded with irradiated single tube fuel elements. The times given in Figure 1 are conservative and can be amended by the author if warranted by special circumstances. Assumptions, sources of data, and tabular presentations of the data are given in the appendix.

W. K. Kratzer
Chemistry and Metallurgy Subsection
N-REACTOR DEPARTMENT

M. J. Wise
Testing Subsection
IRRADIATION PROCESSING DEPARTMENT

Approvals:

T. W. Ambrose, Manager
Process & Reactor Development Sub-
section
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

R. W. Reid, Manager
Process Technology Subsection
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

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FIGURE 2

Allowable water shutoff times for single tube elements in KER-1 and 2.

APPENDIX

1. Assumptions

- a. All calculations are based on the maximum powered fuel element in the loading. The normal equilibrium operating power of this element is 170 KW/ft, or 9670 B/min-ft. The heat generation rate of the element at any time after shutdown is based on the fission product decay heat given by S. S. Jones in Figure 1, HW-33870. The fuel element is assumed to be the only source of heat in the system.
- b. The allowable time is that required to heat the system from its initial state to the limiting temperature with no loss of heat from the system. The system in Case C, dry tube, is defined as the fuel element. The system in Cases A and B, water-filled tube, is defined as everything inside the outer surface of the process tube. Although the process tube is at an initial temperature of 20 C, it is assumed, to be conservative, that it absorbs only enough heat to raise its temperature from the temperature of the adjacent graphite to the limiting temperature.
- c. The graphite temperature is assumed to decay by the expression $f = e^{-.75t}$ where f is the proportion of the total temperature drop between the initial temperature, 800 C, and the final temperature, 20 C, and t is the time in hours after shutdown.

2. Sources

The fission product decay heat was taken from Figure 1, HW-33870, by S. S. Jones. The heat capacities for the materials in the process tube were taken from HW-73217, by Jones and Hickman. The graphite temperature relationship was provided by L. L. Grumme, KE Reactor Physicist.

3. Tabular Data

Table 1 gives the heat capacities of the materials in the process tube, fuel element, water system in B/lb-°F. Table 2 gives the volume, mass, and heat capacity expressed as B/ft-°F for the components in the system. Table 3 gives the heat generation rate, heat capacity, and time to reach the limiting temperature for each of the three cases. Figure 2 was plotted from the data given in Table 3.

TABLE 1

	<u>Heat Capacity, B/lb-°F</u>	
	<u>100° C</u>	<u>200° C</u>
Zr-2	0.073	0.078
U	0.030	0.033
Water	1.0	1.1

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TABLE 2

Volume, Mass, and Heat Capacity of Material
In a Section of Process Tube Containing a Fuel Element

<u>Component</u>	<u>Material</u>	<u>OD, In.</u>	<u>ID, In.</u>	<u>Vol.</u> <u>In³/ft</u>	<u>Mass</u> <u>Lbs/ft</u>	<u>Heat Capacity</u> <u>B/ft-°F</u>	
						<u>100°C</u>	<u>250°C</u>
Process Tube	Zr-2	2.400	2.028	15.52	3.63	0.27	0.28
Outer Water Annulus	Water	2.028	1.791	8.53	0.31	0.31	0.34
Outer Jacket	Zr-2	1.791	1.731	1.99	0.47	0.03	0.04
Fuel	U	1.731	1.016	18.51	12.70	0.38	0.42
Inner Jacket	Zr-2	1.016	0.972	0.82	0.19	0.01	0.02
Inner Water Annulus	Water	0.972	0.592	5.60	0.20	0.20	0.22
Center Rod	Zr-2	0.592	--	3.30	0.77	0.06	0.06

Total Heat CapacityCase A

Process Tube	0.28
Fuel-Water-Rod	1.10

Case B

Process Tube	0.27
Fuel-Water-Rod	0.99

Case C

Fuel	0.42
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TABLE 3

Hours After Shut- down	F, frac- tion of Equili- brium Power	Heat Genera- tion Rate B/min-ft	Process Tube Initial Temp. °C	Case A, 250°C Limit				Case B, 100°C Limit				Case C 100°C Limit, Dry	
				Heat Cap. Proc. Tube B/ft	Heat Cap. Fuel- Water B/ft	Total Heat Cap. B/ft	Time to Reach Limit Min.	Heat Cap. Proc. Tube B/ft	Heat Cap. Fuel- Water B/ft	Total Heat Cap. B/ft	Time To Reach Limit Min.	Heat Cap. Fuel B/ft	To Reach Limit Min.
4	.0170	164	59	96	455	551	3.4	20	143	163	1.0	60	0.4
6	.0105	102	29	111	455	566	5.5	35	143	178	1.7	60	0.6
10	.0092	89	24	114	455	569	6.4	37	143	180	2.0	60	0.7
15	.0081	78	20	116	455	571	7.3	39	143	182	2.3	60	0.8
20	.0076	73	20	116	455	571	7.8	39	143	182	2.5	60	0.8
30	.0066	64	20	116	455	571	8.9	39	143	182	2.8	60	0.9
40	.0060	58	20	116	455	571	9.8	39	143	182	3.1	60	1.0

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