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TEMPERATURE EFFECT ON REACTIVITY OF
THE C R & D WATER BOILER

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ABSTRACT

The temperature coefficient of reactivity of the California Research and Development Company Water Boiler reactor has been measured as minus 0.026 per cent Δk per degree centigrade between 10.8 and 37.7 degrees centigrade. As an extension of this measurement the boiler was allowed to rise, being limited only by temperature, on three successively shorter periods and the peak power attained was noted. For excess k 's of 0.126, 0.177 and 0.269 per cent maximum powers attained were 3.1, 5.8 and 15.8 kilowatts respectively. In addition, a power-temperature oscillation experiment was performed.

TEMPERATURE EFFECT ON REACTIVITY OF THE CR&D WATER BOILER

1. INTRODUCTION

The California Research and Development Company Water Boiler reactor is similar in general characteristics to its predecessors - Hypo (1) and Supo (2) at Los Alamos and the NAA, Inc., WBNS (3) at Downey, California. The general characteristics are: spherical core, graphite reflector, and aqueous uranium fuel solution. All such reactors exhibit a relatively large negative temperature coefficient of reactivity. This coefficient is negative primarily because of the decreasing density and subsequently increasing neutron leakage which accompany an increase in fuel temperature. This characteristic, coupled with the negative power coefficient resulting from gas bubble production, has placed the water boiler-type reactor in the "inherently safe" category, with respect to operational hazards.

2. REACTOR DESCRIPTION

A detailed description of the CR&D Water Boiler has been issued as a separate report (4). A brief description of those components of interest in this experiment is as follows:

A. Core - The core consists of two steel hemispheres which were spun from 3/32 inch thick sheet and welded together. Included inside the sphere is a six turn helical cooling coil, 5/16 inch ID by 1/32 inch wall, with approximately 160 inches length immersed in fuel solution. This coil is filled with circulating distilled water in normal operation; however, in this series of experiments the water was not circulated other than as needed to adjust the solution temperature prior to measurement of reactivity. Also included in the core is a 1.1 inch ID by 0.063 inch wall thickness tube mounted on a horizontal diameter of the sphere (referred to as the "glory hole"). This tube is open at the ends for sample insertion and, therefore, air-filled.

Attached to the top of the sphere is a 2 inch ID by 1/8 inch wall thickness pipe which conducts the cooling and sweep gas lines out of the reflector graphite surrounding the core.

Attached to the bottom of the sphere is a small line for filling and draining the fuel solution. This line is approximately 1/4 inch in outer diameter and has a 1/16 inch wall thickness. It is always full of fuel solution.

Three thermocouples are welded to the outside of the sphere in approximately the same location. These thermocouples were used to indicate solution temperature during the experiments. Figures 1 and 2 show the core assembly. All material used in the construction is stainless steel.

FIG. 1 - SPHERE ASSEMBLY - DISASSEMBLED

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FIG. 2 - SPHERE ASSEMBLY

B. Reflector - The reflector which surrounds the sphere is a five foot diameter right circular cylinder formed from machined slabs. It is high purity graphite and has a density of 1.7. The graphite in the vicinity of the sphere is machined to fit the contour of the sphere and its appendages. Figure 3 shows the sphere during its installation in the reflector tank. A contact fit does not exist at the major portion of the sphere surface. The sphere is considered to be essentially insulated from the graphite with regard to short term temperature fluctuations since, with no cooling other than radiation and conduction to the surroundings, the temperature rise has been observed at constant power, to increase linearly with time over a period of approximately 40 minutes.

There are four rectangular horizontal voids in the graphite reflector which pass the sphere tangentially. These voids allow the control and safety rods to pass within approximately 1/2 inch of the sphere. The voids extend to the far side of the sphere with respect to their point of entrance into the reflector cylinder. Figure 4 shows their geometric relation to the sphere.

C. Fuel Solution - The volume of the fuel solution in the sphere is 14.524 liters. This volume leaves an unoccupied portion of the sphere 2.5 cm in height and 290 cm³ in volume. There is contained in the fuel solution 694.2 grams of U-235. The remainder of the volume is primarily water with some sulphur, hydrogen and oxygen which accompanied the uranium and sulphuric acid added to the core during the loading of the reactor. A molecular breakdown of the solution is given below.

Hydrogen - 798 mols
Oxygen - 420 mols
Sulphur - 5.64 mols
Uranium - 2.95 mols

The heat capacity of the sphere and those parts of its appendages which might be of importance in heat transfer (e. g., 6 inches to top pipe), the cooling coil, central exposure tube, and fuel solution has been calculated as 16.6 kilocalories per degree Centigrade distributed as follows:

<u>Item</u>	<u>Weight</u>	<u>Heat Capacity</u>
Solution (assume equiv. weight of water)	15.60 kg	15.60 kilocalories/°C
Stainless Steel	6.68 "	.97 kilocalories/°C
Top Pipe	.72 "	16.57 kilocalories/°C
Sphere	4.95 "	
Cooling Coil	.63 "	
Glory Hole	.38 "

FIG. 3 - SPHERE IN PLACE

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FIG. 4 - CONTROL AND SAFETY ROD GEOMETRY

3. EXPERIMENTS

Three individual experiments were conducted on the reactor to
(1) gain information on the actual temperature coefficient of reactivity, and
(2) observe the effect of the temperature coefficient during power transients.

3.1 Temperature Coefficient

The temperature coefficient has been measured between 10.8 and 37.6 degrees Centigrade. All measurements were made using the following procedure:

(a) The fuel solution temperature was adjusted to the desired value. This was done by using the cooling system to heat or cool the core by passing the circulating water through a heater or refrigeration unit.

(b) The temperature was allowed to equalize throughout the sphere by waiting for several minutes before the reactivity measurement. No detectable temperature change in a period of five minutes was considered sufficient evidence of temperature stability. Cooling or heating water circulation was normally discontinued ten minutes before the reactivity measurement. The temperature, as reported by a multipoint recorder, could be read with an accuracy estimated at ± 0.1 degrees Centigrade.

(c) Safety and control rods were withdrawn.

(d) The power level was allowed to rise a minimum of one decade after the rods were completely removed from the reactor before period measurements began.

(e) A set of three "standard" periods was taken for each temperature. The three periods were determined at different ranges of power during the same power rise. A logarithmic amplifier and recorder, operated by a gamma compensated ionization chamber, were used to indicate power level. The "standard" periods were measured between 1-50, 5-100, and 10-100 watts.

(f) The period measurements were converted to Δk values by using the water boiler inhour formula (1):

$$\Delta k = \left(\frac{135}{T} + \frac{626}{T+0.62} + \frac{6287}{T+2.19} + \frac{16,538}{T+6.51} + \frac{62,604}{T+31.7} + \frac{24,421}{T+80.2} \right) \times 10^{-4}\%$$

If the first period measured (1-50 watts) departed significantly from the later two measurements it was discarded on the basis that equilibrium of the delayed neutrons had not been achieved by the time the measurement began.

* This function is presented graphically in Appendix D, pages 33-35.

(g) Periods to be measured were restricted, to a minimum of about 13 seconds, with two exceptions necessitated by data normalization. It was felt that restriction to the longer periods was necessary, if equilibrium was to be attained because of the relatively long time required to withdraw the control rods.

In the range of fuel temperatures between 10.9 and 16.7 degrees Centigrade a boron absorber was introduced in the central exposure facility to decrease the available reactivity. Similarly, a solid rod of Lucite and a D₂O filled aluminum tube were used successively for temperatures above 27.2 degrees Centigrade in order to increase the available reactivity. It was found that this method of adjusting the reactivity was acceptable since the slope of the reactivity-temperature curve was not affected. Figure 5 demonstrates this point graphically and also presents the total data gathered. The detailed data for the experiment are tabulated in Appendix A.

3.2 Power - Temperature Oscillations

In the second experiment performed the reactor was allowed to rise in power to a level of 500 watts. No cooling water was circulated through the core. The power level of 500 watts was maintained for approximately one hour by the automatic control system, until the reactor was no longer capable of remaining critical with all control rods removed because of the fuel temperature rise from power dissipation in the core. At this time, with all rods removed, the reactor power was allowed to begin oscillating as the core was alternately cooled by conduction and heated by power dissipation. The power and core temperature were noted as a function of time. Figure 6 is a graphical presentation of the data. Temperature data in this experiment were taken from the thermocouples mentioned previously and shown in Figure 1.

3.3 Power Transients

Having determined the temperature coefficient it was of interest to see if one could predict, in the simplest case, the peak power attainable in an unperturbed, except for temperature increase, rise in the boiler power. This point is of particular interest in regard to reactor hazards calculations. Although the CR&D Water Boiler facility, most particularly the biological shielding, is not designed for prolonged operation at power levels in excess of two kilowatts, it was determined that a series of low excess reactivity excursions was entirely practicable. Consideration was given to the possibilities of physical abuse to the reactor and its auxiliaries, and to personnel exposure to radiation. The regurgitator assembly which is attached to the core, and acts as a reservoir for expelled fuel solution assured no ultimate change in the core loading. Adjusting the reactor sweep gas static pressure to a sufficiently low value before each transient, the large

FIG. 5 - REACTIVITY vs. TEMPERATURE

FIG. 6 - POWER-TEMPERATURE vs. TIME-OSCILLATION EXPERIMENT

volume of the gas system, and the presence of the catalytic recombiner in the gas system avoided the possibility of positive pressures greater than a few inches of water gauge being developed in the closed cycle gas system. The experiments were performed without operation of the sweep gas system since it had been previously observed that this affected the rate of heat loss from the sphere. Gas flow to the recombiner, caused by unequal pressure distribution in the sweep gas system, assured partial recombination of the hydrogen and oxygen evolved. Explosion traps and the absence of any ignition source negated the possibility of damage from inflammation or detonation hazard in the localized regions where hydrogen concentration could conceivably reach the required concentrations. In addition, the sphere assembly and gas system were designed and fabricated to withstand a pressure of 300 psi, which is in excess of the maximum pressure developed in any hydrogen-oxygen detonation. Personnel exposure was predicted (5) and found to be less in all cases than that received by the operating personnel during one hour of normal operation at 500 watts.

After the analysis of potential hazards it was concluded that a series of three transients, in order of increasing reactivity should be studied. Estimates had been made of the peak power to be expected from transients, resulting from excess reactivities of 0.1, 0.2 and 0.3 per cent. The results were found to be 1.96, 10.3 and 31.1 kilowatts respectively. The calculations were based on the assumptions that the sphere was isolated from the graphite reflector, that the heat capacity of the core includes the fuel solution, that part of the cooling coil immersed in the fuel solution, glory hole tube, and approximately six inches of the two-inch diameter pipe fastened to the top of the sphere. The heat capacity of these components is, as mentioned previously, 16.6 kilocalories/ $^{\circ}$ C.

It was not possible to precisely adjust the excess reactivity of the reactor by initial core temperature because of an anomalous characteristic the boiler had adopted a few days before the experiment was performed. Due to what is suspected to be a slight shift in one of the smaller graphite pieces surrounding the core, possibly from control and/or safety rod passage, a small amount of reactivity disappeared and later re-appeared at unpredictable intervals. Graphite movement around the core had been observed upon one occasion with the withdrawal of an exposure stringer passing tangential to the core. The phenomenon did not serve as a source of possible hazard since the effect was small and, when present, consistently throughout some 75 period measurements, resulted in a loss of reactivity.

The transients measured and recorded involved excess k 's of 0.126, 0.177 and 0.269 per cent. The first case involved a slightly greater excess reactivity than desired due to imperfect temperature adjustment of the fuel solution. The latter two cases exhibited the presence of the phenomenon described above. Beforehand knowledge of the exact excess k was not important, as long as it was reasonably close to the desired value, since it

could be determined from the data taken. Peak powers attained were 3.1, 5.8 and 15.8 kilowatts in order of greater excess k's. Peak power predictions of transients involving these exact excess k's, made with the assumptions mentioned previously, yield values of 3.19, 7.8 and 20.8 kilowatts.

Data taken during the transients are tabulated in Appendix C.

Figure 7 is a plot of the three transients based on a common time scale.

From mechanical integration of the power transient curves the following has been established:

	Transient		
	No. 1	No. 2	No. 3
Total Energy (Watt-Hrs)	261	335	517
Energy to Turn-Around (Watt-Hrs)	109	108	128
Energy to Departure From Initial Period (Watt-Hrs)	6.8	13.6	27.7
<u>Miscellaneous Information</u>			
Δk (%)	0.126	0.177	0.269
Period (Sec)	57	34	16
Peak Power Attained (kw)	3.1	5.8	15.8
Temperature Rise of Core ($^{\circ}\text{C}$)	5.3	8.1	13.0

Figure 8 shows the temperature rise as a function of time during the transients as based on a common time scale. Turn-around points for each transient are indicated.

Static pressure in the gas system was measured before and after each transient. It was thought that a measure of gas production as a function of pressure under transient conditions might be obtained depending upon the action of the recombiner. As evidenced by the inconsistency of the data, the catalytic recombiner interfered with the measurement by recombining significant portions of the hydrogen and oxygen.

4. DISCUSSION AND CONCLUSIONS

The authors regret there is not sufficient time available under the circumstances to analyze the transient experiment. The data gathered are presented in detail and include Fig. 9, the neutron distribution in the core, in the hope that others might be able to pursue the analysis further. It appears that certain qualitative conclusions can be drawn from the data,

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FIG. 7 - POWER vs. TIME-TRANSIENT EXPERIMENT

FIG. 8 - TEMPERATURE vs. TIME-TRANSIENT EXPERIMENT

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FIG. 9 - NEUTRON DISTRIBUTION IN CENTRAL EXPOSURE TUBE

however, and they are as follows:

(1) Knowledge of the temperature coefficient and heat capacity of a water boiler type reactor permits simplified, reasonably accurate predictions of the magnitude of "long" term power transients.

(2) The power coefficient, or gas evolution coefficient, presents itself, to a measurable degree, in transients of the magnitude studied.

(3) The sharp turn-around observed in the third transient is possibly due to either (a) unequal heat and/or bubble distribution in the core, resulting in a more subcritical region, comparatively speaking, in the center of the core, or (b) the short time accumulation of a large amount of gas within the fuel solution.

(4) Unless there is a significant time delay in the thermocouple due to its own heat capacity, and this is not believed to be the case, there is comparatively little heat loss to the outer regions of the sphere shell during transients such as were measured.

(5) During "long" transients of this nature personnel finding themselves without benefit of biological shielding would receive less than 35 per cent of the possible radiation dose if evacuation from the vicinity were accomplished at the time of peak power.

(6) The inflections reached just prior to the plateaus illustrated in the temperature vs time graph (Fig. 7) may possibly be ascribed to density changes in the fuel solution from bubble formation and consequent poorer heat transfer.

Conclusions that are obvious from the data gathered in the course of the first two phases of the experiments are:

(1) The temperature coefficient for this type of reactor is a linear function, as has been shown by others, in the range measured.

(2) Reactivity of a water boiler may be adjusted with foreign materials in the core without changing the slope of the temperature-reactivity curve.

(3) A reactor of this character will undergo, as expected, damped power oscillations if left unperturbed.

The power values quoted in this report are believed to be within ± 10 per cent of actual thermal values (6).

5. ACKNOWLEDGMENTS

The authors wish to express their appreciation to North American Aviation, Inc., for the reactor photographs used in this report. The photographs were made during the construction of the reactor.

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APPENDIX A

Temperature Coefficient Data

Core Temp(°C)	Periods (Seconds)				$\Delta k(\%)$	Adjust- ment	Cor- rected* $\Delta k(\%)$
	1-50 watts	5-100 watts	10-100 watts	Avg.			
10.8		17.19	17.37	17.28	0.259	Boron	0.573
12.8		26.35	26.45	26.40	0.206	Boron	0.520
16.7		65.15	65.23	65.19	0.115	Boron	0.429
17.1		5.83	5.87	5.85	0.419	None	0.419
21.6	12.89	12.92	13.05	12.95	0.299	None	0.299
25.4	28.13	28.30	28.14	28.19	0.199	None	0.199
27.2		14.69	14.77	14.73	0.280	Lucite	0.153
27.4	46.17	45.86		46.52	0.145	None	0.145
29.4	23.70		23.76	23.73	0.219	Lucite	0.092
29.4		87.98	88.55	88.26	0.092	None	0.092
30.2	7.52	7.48	7.60	7.53	0.379	D ₂ O	0.069
32.1	46.17	46.70	46.14	46.34	0.146	Lucite	0.019
37.6	30.52	30.44	30.62	30.53	0.189	D ₂ O	-0.121

*Corrections, as determined graphically from Fig. 4, are:

Boron = + 0.314 per cent Δk
 Lucite = - 0.127 per cent Δk
 D₂O = - 0.310 per cent Δk

APPENDIX BPrediction of Peak Powers

To calculate the peak power to be reached in a rise from zero power when the reactor has a known excess reactivity one may compute the change in Δk , or period, at fixed intervals during the rise. When Δk equals zero the peak has been reached. This stepwise calculation method is not rigorous in that a broken line function results. The answer obtained will be slightly, although not significantly, higher than actually is the case, providing a reasonable number of steps are considered. The method is laborious and an explicit expression probably exists. However, the progressive calculation yields an expected power curve as well as the peak power and it is of interest to compare the nature of the expected curve to that actually measured.

Sample Calculation

Assume the boiler to be rising from zero power with 0.1 percent excess reactivity.

It is known from the temperature coefficient that an increase in core temperature of 3.85 degrees Centigrade will compensate for the excess reactivity. Divide this temperature increase into three, one-degree steps and consider the remaining 0.85 degree in the last increment of power rise. The heat capacity of the core is 15.6 kilocalories or 6.96×10^4 watt-seconds per degree centigrade. Since the energy to be dissipated in the first increment of the rise and the original period are known, ΔT may be solved for in the following equation:

$$6.96 \times 10^4 = \int_0^{T_1} P_0 e^{\frac{t}{\tau_0}} dt = P_0 \tau_0 \left[e^{\frac{T_1}{\tau_0}} - e^0 \right]$$

$$= P_0 \tau_0 \left(e^{\frac{T_1}{\tau_0}} - 1 \right)$$

Where

T_1 = ending time of increment

P_0 = original power level

P_1 = final power level

τ_0 = period during rise

t = measured time of increment

Disregarding the minus one value as insignificant we find that

$$T_1 = \tau_0 \ln \frac{6.96 \times 10^4}{P_0 \tau_0}$$

Setting P_0 equal to 0.1 watt for convenience and substituting, we find that the time required for the boiler to dissipate the energy required to raise its temperature one degree Centigrade is

$$T_1 = 78.5 (\ln 8.86 \times 10^3) = 713 \text{ seconds.}$$

To determine the power the boiler is at after a 713 second rise we substitute in the equation

$$P_1 = P_0 e^{\frac{T_1}{\tau_0}}$$

and find that

$$P_1 = 0.1 (8.86 \times 10^3) = 886 \text{ watts}$$

By repetition of the above process it is determined that the peak power is 1,957 watts.

Tabulated below are the cases that were calculated.

<u>0.1% Δk</u>		<u>0.126% Δk</u>	
<u>Time (Seconds)</u>	<u>Power (Watts)</u>	<u>Time (Seconds)</u>	<u>Power (Watts)</u>
713	886	540	1,210
773	1,483	583	2,100
815	1,824	612	2,700
846	1,957	636.3	3,040
		658	3,190
<u>0.2% Δk</u>		<u>0.177% Δk</u>	
300	5,025	361	4,090
322	8,090	387.8	6,500
337.6	9,770	407.5	7,670
350.3	10,300	414.9	7,790
<u>0.3% Δk</u>		<u>0.272% Δk</u>	
153	16,440	237	10,130
163	25,430	266.7	17,260
170.6	29,840	277.6	20,440
176.4	31,150	282.4	20,830

APPENDIX CTransient DataTRANSIENT No. 1

<u>Time (Minutes)</u>	<u>Power (Watts)</u>	<u>Temperature (°F)</u>
0.	0.	81.9
1.0		81.9
1.5	0.042	81.9
2.0	0.075	81.8
2.5	0.125	81.8
3.0	0.22	81.6
3.5	0.36	81.5
4.0	0.62	81.4
4.5	1.00	81.3
5.0	1.70	81.2
5.5	2.75	81.1
6.0	4.6	81.0
6.5	7.6	81.0
7.0	12.5	81.0
7.5	21.0	81.1
8.0	35.0	81.2
8.5	59.0	81.2
9.0	96.0	81.2
9.5	170.0	81.2
10.5	405.0	81.2
11.0	650.0	81.2
11.5	1,000.0	81.2
12.0	1,500.0	81.6
12.5	2,100.0	82.0
13.0	2,600.0	82.9
13.7	3,100.0	84.0
14.0	3,150.0	84.5
14.5	3,000.0	86.0
15.0	2,600.0	87.0
15.5	2,150.0	88.0
16.0	1,700.0	88.5
16.5	1,500.0	89.1
17.0	1,150.0	89.3
17.6	900.0	89.5
18.0	760.0	89.9
18.5	620.0	90.1
19.0	500.0	90.3
19.5	410.0	90.5

<u>Time (Minutes)</u>	<u>Power (Watts)</u>	<u>Temperature (°F)</u>
20.0	330.0	90.7
20.5	262.0	91.0
21.0	220.0	91.0
21.5	175.0	91.0
22.0	150.0	91.0
22.5	120.0	91.0
23.0	98.6	91.0
23.5	80.0	91.0
24.0	64.8	91.0
24.5	52.0	91.0
25.0	44.0	91.0
25.5	36.0	91.0
26.0	30.0	91.0
26.5	24.0	91.0
27.0	20.0	91.0
28.0	15.0	91.0
29.0	9.0	91.0
30.0	6.3	91.0
31.0	4.5	91.0
32.0	3.1	91.0
33.0	2.2	91.0
34.0	1.55	91.0
35.0	1.1	91.0
36.0	0.77	91.0
39.0	0.31	91.0
42.0	0.125	91.0
46.0	0.05	90.5
50.0	0.026	90.0
55.0	0.019	89.8
60.0	0.0194	89.4
64.5	0.02	89.2
69.0	0.021	89.1
79.0	0.026	89.0
84.0	0.30	88.4

<u>Time (Minutes)</u>	<u>Power (Watts)</u>	<u>Temperature (°F)</u>
TRANSIENT No. 2		
0.	0.0	76.1
1.0		76.1
1.25	0.075	
1.5	0.12	76.2
2.0	0.305	76.2
2.5	0.78	76.2
3.0	1.92	76.2
3.5	4.7	76.1
4.0	11.5	76.0
4.6	34.0	76.0
5.0	70.0	76.0
5.5	170.0	76.0
6.0	400.0	76.0
6.5	880.0	76.0
7.0	2,050.0	76.0
7.5	3,800.0	76.0
8.0	5,500.0	77.0
8.5	5,600.0	78.6
9.1	4,750.0	81.4
9.5	3,700.0	83.5
10.0	3,100.0	84.5
10.5	2,450.0	85.6
11.0	2,000.0	87.0
11.5	1,530.0	87.5
12.0	1,200.0	88.6
12.5	950.0	89.0
13.0	730.0	89.0
13.5	560.0	89.1
14.0	440.0	89.4
14.5	342.0	89.9
15.0	270.0	90.2
15.5	218.0	90.6
16.0	169.0	90.6
16.5	133.0	90.6
17.0	104.0	90.6
17.6	78.0	90.6
18.0	67.0	90.6
18.5	53.0	90.6
19.0	41.0	90.6
19.5	32.5	90.6
20.0	27.5	90.6
21.3	15.0	90.6
22.0	10.7	90.6

<u>Time (Minutes)</u>	<u>Power (Watts)</u>	<u>Temperature (°F)</u>
TRANSIENT No. 2		
23.5	5.4	90.6
25.0	2.92	90.6
27.0	1.17	90.6
29.0	0.5	90.5
31.0	0.23	90.3
33.0	0.11	89.9
36.0	0.043	89.8
38.0	0.026	89.8
41.0	0.0175	89.8
TRANSIENT No. 3		
0.	0.	70.1
0.5		70.2
0.75	0.11	70.2
1.0	0.285	70.2
1.25	0.75	70.2
1.5	1.82	70.2
1.75	4.8	70.2
2.0	12.2	70.2
2.25	29.0	70.2
2.5	75.0	70.2
2.75	185.0	70.2
3.0	480.0	70.2
3.35	1,550.0	70.2
3.5	2,750.0	70.2
3.75	5,950.0	70.2
4.0	11,200.0	70.2
4.25	15,800.0	71.0
4.44	15,000.0	74.8
4.75	11,000.0	77.2
5.00	9,550.0	79.5
5.25	8,500.0	81.0
5.50	7,300.0	83.5
5.75	6,100.0	85.0
6.10	4,950.0	87.0
6.30	4,200.0	88.0
6.75	3,100.0	89.5
7.00	2,600.0	90.0
7.30	2,150.0	91.0
7.75	1,570.0	91.2
8.25	1,140.0	92.0
8.50	970.0	92.8

<u>Time (Minutes)</u>	<u>Power (Watts)</u>	<u>Temperature (°F)</u>
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TRANSIENT No. 3 Cont'd.

8.75	820.0	93.0
9.00	703.0	93.0
9.25	587.0	93.0
9.50	510.0	93.0
10.0	380.0	93.2
10.5	280.0	93.3
11.0	205.0	93.5
11.5	155.0	93.5
12.0	115.0	93.5
12.5	88.5	93.5
13.0	66.3	93.5
13.5	37.0	93.5
15.0	21.3	93.6
16.0	12.0	93.6
17.0	7.15	93.6
18.0	4.10	93.6
22.0	0.48	93.6
25.0	0.11	93.6
28.0	0.032	93.0
31.0		92.6

APPENDIX D-1 - EXCESS REACTIVITY vs. PERIOD

APPENDIX D-2 - EXCESS REACTIVITY vs. PERIOD

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APPENDIX D-3 - EXCESS REACTIVITY vs. PERIOD

0-32