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DEFICIENT COOLING
12th QUARTERLY PROGRESS REPORT
APRIL 1-JUNE 30, 1972

U. S. ATOMIC ENERGY COMMISSION
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DEFICIENT COOLING

12th QUARTERLY PROGRESS REPORT

April 1—June 30, 1972

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ABSTRACT

Steady-state critical heat flux (CHF) data at 800 and 1000 psi for various mass fluxes were taken in a 16-rod assembly, with a 12-foot-long axial cosine variation. Excellent correlation of the data was obtained and no serious reductions of critical power were experienced for a bowed corner rod or a reduced corner clearance of 0.060 inch between spacers on 19-1/2-inch centers.

Transient data were also obtained for five typical reactor transients. No unexpected CHF was noted for operating transients at representative power levels. In most cases power levels were increased above normal reactor operating values to find the CHF thresholds.

CHF and heat transfer data were obtained for a bulged heater simulating a swollen fuel rod. Incident CHF was identical to that in the same assembly with a uniform heater.

SUMMARY

Steady-state CHF data and transient flow data, with and without typical reactor power decays, were taken in three different 16-rod, 12-foot-heated-length test sections with a cosine axial heat flux. Rod diameters were 0.562 inch and the hydraulic diameter was 0.522 inch. The test assembly geometry was typical of that for boiling water reactor fuel bundles, and spacers—closely resembling reactor construction—were used on 19-1/2-inch centers for test heater spacing and support in the flow channel.

Steady-state data were taken at pressures of 800 and 1000 psi, with mass fluxes in the range $G/10^6 = 0.25-1.00$ lb/h-ft² in all three test sections. The first test section was constructed with symmetrical radial clearances closely simulating those in a reactor, the second with a corner rod bowed to within 0.060 inch of the unheated wall, and the third with a corner rod having a reduced rod-wall clearance of 0.060 inch (compared with nominal 0.135) between two spacers in the region where CHF was most likely to occur. Excellent steady-state data were obtained with scatter of only about $\pm 3\%$. The critical power, at subcoolings of 25 to 30 Btu/lb typical of reactor operation, was the same for all three assemblies within the data scatter. Some CHF enhancement was indicated by the bowed rod.

Correlation of the 16-rod steady-state data was accomplished, using local quality—boiling length coordinates, for use in analysis of the 16-rod transient data. The correlation also represents the nine-rod data, previously reported in the 10th Quarterly Report (GEAP-10221-10), very well, and this is attributed to the two widely different test sections having the same ratio of heated perimeter/flow area, or thermal diameter.

The 16-rod transient runs accomplished in the ATLAS test facility are the first extensive test investigation of simulated reactor transients. Plots of transients and complete tabulations are shown for all the runs, which included flow decay at constant power, flow and power decay, flow ON/OFF/ON, flow and power decay representing a LOCA(DBA), and flow and power ramp up. Results of transients made at representative reactor power levels showed no unexpected CHF conditions. In most cases, power levels were increased above nominal operating values to find CHF thresholds.

Steady-state CHF tests and single-phase heat transfer tests were performed on a single-rod heater which had a bulged diameter along 3 inches of its length, representing a swollen fuel element. Incidence of CHF was found to coincide almost exactly at the same conditions as in a previous identical assembly without the swollen rod. Heat transfer coefficients along the axis of the swollen portion were calculated and compared with correlations.

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1. INTRODUCTION

1.1 GENERAL

The work on the Deficient Cooling Program is directed toward extension of out-of-pile heat transfer data in support of current nuclear-powered, water-cooled plants. A brief review of current technology reveals that the large bulk of data is of the steady- or quasi-steady-state class. Thus, a need exists for data taken under transient conditions of power, flow, and pressure in combination with different geometries. Analysis and study of such data are expected to contribute to the following overall objectives:

- a. A firmer understanding and establishment of heat transfer safety limitations, and
- b. Extension of safe operating limits to higher power densities.

Deficient cooling conditions are considered to be those which result in inadequate cooling of the fuel. They may result in potentially excessive cladding temperature which, in combination with the internal gas pressure of the fuel, may cause some type of fuel damage. Resultant temperatures depend on the mode or modes of heat transfer that arise during deficient cooling conditions. A brief description of these modes of heat transfer follows.

Three different modes of heat transfer can generally occur when heat is removed, during high quality conditions, from a surface such as a fuel rod: nucleate boiling, with a liquid film on the heated surface; transition boiling; and the liquid deficient region. Nucleate boiling occurs at very high surface heat transfer coefficients, usually in excess of 10,000 Btu/h-ft²-°F, with steady surface temperatures. Increase of heat flux eventually results in "film dryout" and a change of mode to transition boiling, which is usually characterized by temperature oscillations of varying amplitude on the heated surface. The transition mode of heat transfer exhibits relatively low heat transfer coefficients, on the order of 500 Btu/h-ft²-°F. Continued increase of heat flux eventually results in the liquid deficient regions, with some liquid droplets impinging on the heated surface which is mostly steam cooled.

The heat flux at which transition is made from the nucleate to transition mode of boiling, as evidenced by onset of surface temperature oscillations, is usually termed the critical heat flux (CHF). For low qualities, it is also known as the departure from nucleate boiling (DNB), or burnout point. Considerable effort has been made on parametric definition of the CHF with pressure, coolant flow, vapor quality, and the geometry of the system. These parametric studies serve as design data and indicate the operating conditions beyond which fuel surface temperatures increase substantially, with greater risk to fuel cladding integrity.

Most of the work defining limits of CHF has been done with small incremental heat flux increases which would allow it to be classified as quasi-steady-state data. However, the actual modes of heat transfer become more complex in some cases involving transients, when the dynamic characteristics of the fuel-coolant system come into play. Therefore, practical cases of transient conditions which are considered worthwhile for study and test under this Deficient Cooling Program are those involving:

- a. Transient reduction of flow,
- b. Transient increase of power, and
- c. Transient decrease of pressure which causes flashing and potentially deficient cooling conditions due to increased void content.

Furthermore, it is proposed to study typical geometry changes such as those due to fuel spacer components and those caused by rod bowing and swelling. Such studies are expected to define more clearly heat transfer safety limitations, and will eventually result in extension of safe operation to higher limits.

1.2 PROGRAM OBJECTIVES

The objectives expected to be accomplished under this program are as follows:

- a. Determine experimentally the CHF and temperature regimes which may occur in water reactor fuel assemblies due to nonstandard cooling conditions that result from power, flow, or pressure transients, and determine these values relative to steady-state data.
- b. Evaluate temperature regimes likely to be experienced by water reactor fuel assemblies in loss-of-coolant accidents, and determine areas of similarity or relationship between these regimes and those found in transient critical conditions.
- c. Evaluate consequences of fuel rod geometry changes on heat transfer performance from simulated tests on single and nine-rod electrically-heated bundles.
- d. Provide a plan for further in- and out-of-pile work necessary for more complete performance and definition of the performance of water reactor fuel under deficient cooling conditions.

1.3 ORGANIZATION OF PROGRAM

The work in this program was organized into tasks, an outline of which, together with the tasks' work content, is shown in Table 1-1. These task designations have been preserved throughout the program to provide systematic documentation and execution of the program.

Tasks 3, 4, 5, and 8 involve the experimental work. All of these tasks have been concluded, and the results of Tasks 4 (16-rod) and 5 are included in this report.

Table 1-1
TASK DESIGNATION AND CONTENT

Number	Title	Content
1	Planning and Analysis	<ul style="list-style-type: none"> a. Review current technology and plan appropriate tests to integrate with required safety programs b. Analysis as necessary to determine test parameters
2a	Design	<ul style="list-style-type: none"> a. Design new equipment or modifications of existing equipment to carry out test plans
2b	Manufacture	<ul style="list-style-type: none"> a. Manufacture or purchase new equipment required
3	One-Rod Exploratory Transient CHF Tests	<p>Exploratory tests involving</p> <ul style="list-style-type: none"> a. Steady-state and transient flow and pressure b. Modifications of heaters for nonuniform axial heat flux
4	Multirod Transient Tests 9- and 16-Rod	<p>Tests involving:</p> <ul style="list-style-type: none"> a. Steady-state and transient CHF conditions. Power transients with 16-rod tests only. b. Combinations of intra-bundle clearance, power distribution, and spacer components
5	One-Rod Tests with Geometry Changes	<ul style="list-style-type: none"> a. Steady-state CHF with simulated swelling
6	Data Reduction and Analysis	<ul style="list-style-type: none"> a. As required for test Tasks 1, 3, 4, 5, and 8
7	Project Administration, Reporting, and Recommendations	<ul style="list-style-type: none"> a. Administration of entire program b. Regular and topical reporting c. Future recommendations for continued efforts
8	Multirod Geometry Changes 9-Rod	<ul style="list-style-type: none"> a. Steady-state CHF data with spacer components and simulated fuel rod bowing and reduced clearances b. Subchannel flow and enthalpy measurements

2. MAGNETIC TAPE RECORDS FOR 16-ROD TESTS (D. W. Radcliffe, E. E. Polomik)

2.1 BASIC GEOMETRIES TESTED

Three different geometries were tested. These involved uniform radial clearance and radial heat flux, a bowed corner rod, and a corner rod with reduced rod-wall clearance.

The assembly designations, a brief description, and the types of data taken with each are listed in Table 2-1. Details of each test assembly are shown, and are discussed in Section 3.

The different types of transient flow and power runs made are shown schematically in Figure 2-1. A discussion of these transients and their similarity to reactor transients was included in the previous quarterly report, GEAP-10221-11.

Table 2-2 shows the original magnetic tapes used to store the steady-state CHF data. These have been combined onto one tape for storage, No. P55SS.

Table 2-1
DETAILS OF TEST ASSEMBLIES 16R-2, 16R-3, AND 16R-4

Test Assembly No.	Description		Types of Runs Made	
	Common to All	Geometry Variations	Steady State CHF	Transient
16R-2	Vertical flow. 12 ft heated length. Cosine axial heat flux, 1.387 peak/average. 0.562 in. o.d. heaters. 0.523 in. hydraulic diam. Spacers on 19-1/2 in. centers. First spacer 3 in. upstream from end of heated length.	Uniform radial Clearances and heat flux, nominal 0.135 in. corner clearances.	•	• (Most of runs with this assembly.)
16R-3		As 16R-2 except corner rod bowed to within 0.058 in. of wall between 2nd and 3rd spacers upstream of end of heated length.	•	—
16R-4		As 16R-2 except corner rod moved to within 0.060 in. of the wall between 2nd and 3rd spacers upstream of end of heated length.	•	• (A few typical runs.)

2.2 LIST OF TRANSIENT MAGNETIC TAPES WITH CONTENTS BY TYPES OF RUNS

The magnetic tapes used for storage of transient data are listed in Table 2-3, showing the types of runs on each. They have been combined, as noted, with four record tapes remaining: Nos. 4968, 8009, 10184, and 10183.

2.3 INDEX TO TRANSIENT MAGNETIC TAPES BY TYPES OF RUNS

Table 2-4 is a recapitulation of the transient runs listed by types of runs, showing the appropriate tape and run numbers.

Table 2-2
STEADY-STATE MAGNETIC TAPE RECORDS

Date	Assembly Number	Magnetic ^(a) Tape Number	Run Numbers ^(b)
5/12/72	16R-2	6115	6-58
5/15/72	16R-2	2580	162-170
5/16/72	16R-2	9842	259-267
5/24/72	16R-3	6189	2-10, 278-320
6/1 & 6/2/72	16R-4	7321	24-25, 323-362

(a) The five magnetic tape records shown have been combined for storage onto one tape number P55SS.

(b) Runs are not necessarily in consecutive sequence in the ranges shown.

Table 2-3
INDEX TO TRANSIENT MAGNETIC TAPE RECORDS BY TEST ASSEMBLIES AND TYPES OF RUNS

Date	Test Assembly Number	Magnetic Tape Number	Computer Run Number Range	Transient Types of Runs ^(a)					
				1	2	3	4	5	6
5/12/72	16R-2	4968 (Copy of original 6066)	100-114	X					
5/13/72	16R-2	8009 (Copy of original 6098)	116-150			X			
5/15/72	16R-2	9065 } Combined onto	171-222		X	X	X		X
5/16/72	16R-2	8368 } 10184	223-258	X			X	X	
5/23/72	16R-3	8279 } Combined onto	268-272						X
6/2/72	16R-4	1657 } 10183	364-379	X		X		X	

(a) Types of Runs.

- 1—Flow Decay Constant Power
- 2—Flow and Power Decay
- 3—Flow ON/OFF/ON Constant Power
- 4—Flow ON/DECAY/OFF/ON with Power Decay
- 5—Flow and Power Ramp Up
- 6—Power Step-Down for Thermocouple Response

Figure 2-1. Types of Transient Runs

3. TEST EQUIPMENT AND OPERATION (E. E. Polomik)

A general description of the ATLAS test facility in which the 16-rod data reported here were obtained, is contained in the previous quarterly report, GEAP-10221-11. The latter also contains schematic drawings, photos, and test section and instrumentation details for the first assembly, No. 16R-1, which was made in the previous quarter. Three assemblies, Nos. 16R-2, 16R-3, and 16R-4, described generally in Subsection 2.1, were tested during this quarter, and they are the source of the data reported here. The assemblies were generally the same as No. 16R-1 except for geometry changes, such as a bowed rod, reduced clearances, and changes in location of CHF thermocouples—

- Assembly No. 16R-2: uniform radial flux and clearances,
- Assembly No. 16R-3: uniform radial flux with a bowed corner rod, and
- Assembly No. 16R-4: uniform radial flux with reduced corner clearance.

Details for each of these assemblies are presented in Subsection 3.1.

3.1 TEST SECTION DETAILS

3.1.1 Assembly No. 16R-2

The most important details of assembly 16R-2 are shown in Figure 3-1. This test section, with uniform radial clearances and essentially uniform radial heat flux (within about 3% as noted on the inset of Figure 3-1), was used to determine steady-state CHF data and for the bulk of the transient flow and power tests. A truncated cosine axial heat flux, with a peak-to-average value of 1.387 which is typical of reactor values, was provided in all the heaters over their 12-foot heated length. The heaters were stainless steel, 0.562-inch o.d., with heat generated directly in the wall due to the passage of direct current. Nine spacers, typical of reactor construction and spacing, were used to support the heaters at 19-1/2-inch intervals axially. These were shimmed snugly into the channel to prevent variations in corner clearances.

Thermocouples for CHF detection were attached to the inside wall of the heaters at various locations, and passed down through the inside of the heater and out to the reference junction connections.

Fifty-four thermocouples were installed in twelve of the heaters to protect the valuable assembly from actual burnout, and simultaneously determine the extent of CHF under steady-state conditions and its origin and spread during transient conditions. The axial and radial locations of the CHF thermocouples are shown in Figure 3-1 and the accompanying table. Thermocouples (Nos. 6 and 7) were located in three of the four corners, slightly upstream of the No. 2 spacer, where frequency of steady-state CHF is known to be high. In addition, positions ahead of and in between the four downstream spacers were monitored. About half of the thermocouples were located on the high heat flux portion of the downstream 6-foot heated length, and the other half on the low heat flux portion. Pairs of rods in geometrically similar positions, such as rods 6 and 7, and 5 and 14, were instrumented at alternate high (H) and low (L) heat flux portions of the rods, as indicated in the table and dashed lines in Figure 3-1. This aided in manufacture of the rods which was simplified with fewer couples in each rod. The foregoing arrangements provided very good monitoring of CHF over the entire cross section for the total downstream 6 feet where CHF would occur.

3.1.2 Assembly No. 16R-3

This assembly, details of which are shown in Figure 3-2, was used to determine the effect of a bowed corner rod on CHF. The assembly is essentially the same as 16R-2 (Figure 3-1) except for small streamlined pins fitted and brazed to the rods to ensure a permanent bow, and additional thermocouples in the No. 16 rod to monitor CHF axially along the bowed length. Two small beads were also brazed onto the rod at the midpoint of the bow facing the channel boundary, to hold the 0.060-inch rod-wall clearance.

Figure 3-1. Radial and Axial Locations of CHF Thermocouples and Spacers (Assembly 16R-2, Uniform Radial Flux and Clearances)

ROD POSITION NO.	THERMOCOUPLE NO.								
	1	2	3	4	5	6	7	8	9
1	●		●	●	●	●	●		●
3	●	●	●	●					
4					●	●	●		●
5	●		●	●					
6	●	●	●	●					
7			●	●	●	●	●		●
10	●	●	●	●					
11'					●	●		●	●
12					●	●		●	●
13	●		●	●	●	●	●		●
14					●	●	●		●
16	(BOWED) 12 THERMOCOUPLES ARRANGED AS ABOVE								

Figure 3-2. Radial and Axial Location of CHF Thermocouples and Spacers (Assembly 16R-3, Uniform Radial Flux, Bowed Corner Rod)

Additional thermocouples were installed in the bowed rod at 2- and 3-inch intervals, as shown in Figure 3-2. These provided adequate coverage along the bow where CHF was considered likely to occur due to flow diversion.

The balance of the heaters and assembly was the same in all respects as assembly 16R-2.

3.1.3 Assembly No. 16R-4

Corner rod No. 16 was moved to within 0.060 inch of the wall in this assembly to determine effects of reduced corner clearance on CHF. Details are shown in Figure 3-3. The reduced corner clearance was obtained by milling part of the bands off two sides of spacers 2 and 3, and then shimming those two spacers toward the No. 16 rod corner. The net result was a 19-1/2-inch axial length along rod 16, between spacers 2 and 3, with a reduced uniform rod-wall clearance of 0.060 inch. In addition to the reduced clearance, some additional resistance to flow has resulted around the side rods such as 12 and 15, due to milling off the spacer bands. There is practically no probability that such a mechanical breakdown could occur in a reactor simultaneously on two spacers. However, the data obtained should indicate maximum reductions in CHF that can be expected with drastically reduced corner clearances. Thermocouple locations were the same as those in Figure 3-2.

3.1.4 Flow Channel Dimensions Before and After Testing

Figure 3-4 shows measurements between rods and rod-channel clearances which were taken before and after testing to determine whether any major dimensional changes had occurred during the test. View (a) shows the bundle with uniform radial clearance, 16R-2, with nominal clearances in the last line of the tabulation. The largest change was an increase of 0.022 inch in the No. 1 rod, in both the A and B dimensions, indicating some movement toward the No. 16 corner. The H dimension in the No. 4 corner decreased 0.014 and 0.010 inch at the No. 3 spacer and between the Nos. 2 and 3 spacers. The data indicated the No. 4 rod to be one of three preferential locations for the initial CHF. The balance of dimensions shows excellent agreement between the before and after test dimensions, indicating the assembly remained intact throughout the steady-state and transient tests. Changes that did occur would be considered normal for this type of assembly.

The channel measurements for the bowed assembly 16R-3 are shown on view (b) of Figure 3-4. Some skewness occurred between the +30 and -30 degree locations; however, this should be unimportant in affecting the results due to the minimum bow dimension. The average rod-wall dimension of the bow was about 0.055 inch—slightly less than the nominal 0.060 inch intended.

The reduced corner clearance assembly 16R-4, view (c) in Figure 3-4, was found to have maintained its reduced corner clearance dimension very well. The dimensions shown at the zero-degree position are an average of several readings at different positions between spacers 2 and 3. These axial readings were found to be very close—within ± 0.002 inch. The average after-test dimension showed an increase of the minimum rod-wall dimension of only 0.003 inch. The increase from 60 to 70 mils for the ± 30 degree positions is because the rod and corner of the channel do not have the same center of curvature.

3.2 OPERATION

3.2.1 Steady-State CHF

Steady-state data were taken by establishing steady conditions with power at about 10% below expected CHF and then increasing power in small, interrupted increments until CHF was reached. Each power increase was about 3 to 4 kilowatts, or on the order of 1/5% of the power level. The output from eight CHF thermocouples, located at the most likely CHF positions such as the corner rods, was displayed on a Beckman chart recorder. CHF was observed when the first instabilities in rod temperature were noted on the Beckman traces. These instabilities result in temperature oscillations of about 10 to 15°F.

NOTES

1. CHF THERMOCOUPLE INSTALLATION SAME AS ASSEMBLY NO. 16R-3, BOWED NO. 16 ROD (FIG. 3-2)
2. AXIAL HEAT FLUX AND SPACER LOCATIONS SAME AS ASSEMBLY NO. 16R-3, BOWED NO. 16 ROD (FIG. 3-2)

Figure 3-3. Schematic of Reduced 0.060-Inch Corner Clearance (Assembly No. 16R-4)

The H-P computer monitored the output of *all* CHF thermocouples, for protection of the test section, and would reduce or shut down the power, respectively, if either of two rod temperature levels was reached. These are called the HI and HI-HI alarms and were preset to temperatures of about 700 and 900°F, respectively. Thus, if a thermocouple was not being visually monitored on the Beckman recorder and reached 700°F, the computer automatically recorded the event, reduced the power 40%, and printed out the loop conditions and CHF thermocouple(s) on the teletype.

3.2.2 Transient Flow and Power

Transient flow and power decay runs were obtained by setting the desired initial conditions, recording those conditions for about 2 seconds, energizing the transient flow and power circuits simultaneously, and recording the resulting transient for at least 10 to 12 seconds. The maximum flow transient time was about 8 seconds for the minimum mass fluxes used. For the flow decay and loss-of-coolant transients, additional timer circuits were used to shut off the flow for a predetermined time and then reestablish it.

Flow decay and off times were controlled by varying the voltage impressed on the automatically controlled flow valve with variable resistance-capacitance circuits. Simple schematics of these circuits are shown in Figures 3-5, 3-6, and 3-7, to convey the general scheme of transient flow control.

Power decays or increasing power ramps were controlled by means of DATA TRAK equipment. A voltage-time curve was drawn on special electrical conducting rectangular paper, with the voltage proportional to the square root of the desired power. The power-time graph was attached to a rotatable drum, and an electro-mechanical control "eye," which could move both laterally (test section voltage signal) and axially (the time axis), was set over the initial point of the power curve. When the transient was started, the control "eye" was forced to stay on the desired curve, by a separate electro-mechanical mechanism, and its lateral movement controlled the voltage and power to the test bundle.

The test section power decay curve used for the most important transients (shown in Subsections 6.1 through 6.4 of this document) is delineated in Figure 3-8. This curve represents normalized calculated surface heat fluxes that result in a reactor due to a fast power decay. The test heater rods used were thin walled, and their surface heat flux response to a voltage change was very fast—in the order of milliseconds. Thus, by causing test section power decays to follow the curve of Figure 3-8, the test surface heat flux—time relationship simulated the typical surface heat flux—time in a reactor power decay with very little error in time lag.

CHF monitoring by the computer and visually on the Beckman recorder was the same as described for steady-state tests in Subsection 3.2.1. In several of the first transient tests, considerable caution was in order, and the power was reduced when CHF occurred and temperatures reached the HI alarm value of about 700°F. This power reduction precluded recording of the rewetting of the heater under realistic conditions when flow was reestablished. As more experience was gained in controlling the temperature excursions by power level flow and timing settings, the HI alarm was set at the same temperature as the HI-HI alarm—about 900°F. This allowed recording of a considerable number of temperature excursions with rewetting under realistic transient conditions.

System pressure was controlled manually by a liquid dump valve to avoid large rises in pressure, particularly during flow decay and flow ON/OFF/ON runs at constant power. A reasonably good result was obtained and system pressure was decayed at roughly 100 psi/sec, which is close to that of certain severe reactor transients.

AXIAL LOCATION	DIMENSION (inches x 10 ³)									
		A	B	C	D	E	H	I	F	G
SPACER 2	BEFORE	142	120	176	145	132	128	135	193	158
	AFTER	163	142	171	164	132	128	136	192	158
SPACERS 2-3 MIDPOINT	BEFORE	145	143	179	155	129	123	134	195	152
	AFTER	151	146	174	160	133	121	144	196	158
SPACER 3	BEFORE	137	135	189	137	128	123	133	178	164
	AFTER	130	144	189	140	129	119	141	180	164
NOMINAL		135	135	176	135	135	135	135	176	176

(a) ASSEMBLY NO. 16R-2, TYPICAL CLEARANCES

(b) ASSEMBLY NO. 16R-3, CLEARANCE DIMENSIONS FOR BOWED ROD

(c) ASSEMBLY NO. 16R-4, REDUCED CORNER CLEARANCES

Figure 3-4. Before and After Test Dimensions of Uniform, Bowed, and Reduced Clearance Assemblies

Figure 3-5. Valve Control Schematic Circuit for Flow Decay

- 1) SW 1 - OVER-RIDE SWITCH FOR EARLY CHF
- 2) SET TIMER, HIGH/LOW RESISTANCE AND CAPACITORS AT PROPER DESIRED VALUES. PRESS START FOR TRANSIENT, TIMER WILL RESET AT THE END OF TIME CYCLE.

Figure 3-6. Valve Control Schematic Circuit for Flow ON/OFF/ON

- 1) SW 1 OVERRIDE SWITCH FOR EARLY CHP
 - 2) TIMER 1 FOR FLOW HIGH TO LOW
 - 3) TIMER 2 FOR FLOW OFF
 - 4) SET TIMER 1, 2, HI/LOW RESISTANCE AND CAPACITORS AT PROPER VALVES.
- PRESS START FOR TRANSIENT, TIME 1 WILL NOT RESET, FLOW WILL STAY LOW UNTIL MANUALLY RESET TO HIGH.**

Figure 3-7. Valve Control Circuit for Flow ON/DECAY/OFF/ON (LOC or DBA)

Figure 3-8. Typical Surface Heat Flux Decay for Reactor Power Decay

4. DATA REDUCTION (D. W. Radcliffe, E. E. Polomik)

The steady-state and transient data are preserved on record magnetic tapes, as outlined in Section 2. Microfilm copies of the reduced transient output have been filed with the Atomic Energy Commission at National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia, 22151. The microfilm reels are identified as follows:

Reel Designation *	Contents
GEAP-10221-A	1-Rod Transients, Runs 125-179
GEAP-10221-B	9-Rod Transients, Runs 149-186
GEAP-10221-C	9-Rod Transients, Runs 187-241
GEAP-10221-D	16-Rod Transients, Runs 100-379

A computer program, TRDATA, was written for reducing the transient data to engineering units directly from the magnetic tape. The program calculates and prints out the initial conditions at time zero, as shown in Tables 4-1 and 4-2. It then reduces the entire run to engineering units for each 20-millisecond interval for all variables, and prints out the results of specified variables at whatever time interval is specified. The partial output of a run is shown in Table 4-2. An output interval of 40 milliseconds was used on all of the transient runs. The number of thermocouples printed out on each run of the program is limited to seven. If the reduced output of additional thermocouples is desired, the program must be rerun.

An option that was used in reduction of this data is a CALCOMPLOT subroutine which plots up to six specified transient variables versus time for specified time intervals of the run. These plots are very valuable in showing the important time intervals of the transient that can be seen at 40-millisecond intervals in the printed output. If plots of additional thermocouples or other variables than the ones first chosen are desired, the program must be rerun with the new specified variables. Typical plots of transient runs are shown in Section 6. A plot of all of the 16-rod transient runs is included in the topical report, *Transient CHF—Experimental Results*, GEAP-13295. In most cases, the salient CHF thermocouples have been selected for the plots. In many of the runs, only three or four thermocouples reached CHF and elevated temperatures, and printed output from seven thermocouples was usually sufficient to analyze the run.

The procedure used in transient data reduction was to first obtain printed millivolt output for all recorded data at 200-millisecond intervals. This was edited, with the aid of the log of the transient runs, to determine which other thermocouples besides those of the eight visually noted from the Beckman recorder log may have become critical. The sequence of criticality and the maximum temperatures reached could also be noted. The editing notes provided the necessary information to select the input for the TRDATA program printout discussed here: the seven most important thermocouples, time interval of each run to be reduced, and the thermocouples to be shown on the CALCOMPLOTS.

* Note: GEAP-10221A, B, C, and D have been combined on two 16mm reels and are available as a two reel set from NTIS. For plain reels order GEAP-10221P at \$10.00; for 3M cartridges order GEAP-10221M at \$14.00; for Recordak Cartridges order GEAP-10221R at \$14.00; and for Tread Easy Magazines order GEAP-10221T at \$14.00

Table 4-1
ATLAS TRANSIENT DATA

ATLAS TRANSIENT DATA
INITIAL CONDITIONS

DATE		STARTING TIME		RUN NUMBER	
5/15/72		21141145		211	
SYSTEM PRESSURE		995.1172	PSIA	TURBINE DATA	
INLET TEMPERATURE		520.9375	DEG F	MASS FLOW RATE	0.9965 M LB/HR/SQ FT
SUBCOOLING		26.5692	BTU/LB	FLOW RATE	55.8960 GPM
INLET ENTHALPY		513.2743	BTU/LB	FLOW RATE	5.9650 LB/SEC
TEST SECTION POWER		2224.0083	KW	ORIFICE DATA	
AVERAGE HEAT FLUX		0.2626	M BTU/HR/SQ FT	MASS FLOW RATE	0.9991 M LB/HR/SQ FT
EXIT QUALITY		0.4854		FLOW RATE	56.1356 GPM
OUTLET TEMPERATURE		543.4375	DEG F	FLOW RATE	5.9906 LB/SEC
INITIAL RECORD COUNT		1			

Table 4-2
TRANSIENT CONDITIONS RUN NO. 211

TIME	PRESSURE	INLET	TURBINE	ORIFICE	POWER	RUN NUMBER		ROD 1	ROD 1	ROD1	ROD 1	ROD 4	ROD 4	ROD 16
SEC	PSIA	TEMP	MASSFLUX	MASSFLUX	KW	TC 4	TC 5	TC 6	TC 7	TC 6	TC 9	TC 7	TC 7	TC 7
		DEG F	MLB2H/FT2	MLB2H/FT2		DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F
0.	995,1172	52049378	0.5965	0.5991	2224,0083	614,9633	621,6969	608,4023	610,3016	609,4383	607,8844	609,6109	609,6109	609,6109
0.0400	995,1172	52049378	0.5965	0.5985	2224,0083	615,3086	622,2148	608,4023	608,4023	608,4023	605,8125	608,4023	608,4023	608,4023
0.0800	995,1172	52049378	0.5965	0.5985	2224,0083	615,3086	622,2148	608,4023	612,7187	608,4023	608,4023	608,4023	608,4023	608,4023
0.1200	995,1172	52049378	0.5965	0.5999	2224,0083	615,3086	620,4883	606,6758	608,4023	608,4023	605,8125	612,7187	612,7187	612,7187
0.1600	1000,0000	52049378	0.5965	0.5985	2224,0083	615,3086	622,2148	608,4023	612,7187	608,4023	608,4023	608,4023	608,4023	608,4023
0.2000	1000,0000	52049378	0.5965	0.5985	2224,0083	613,5820	615,3086	606,6758	608,4023	608,4023	606,6758	615,3086	615,3086	615,3086
0.2400	1000,0000	52049378	0.5965	0.5918	2224,0083	615,3086	622,2148	608,4023	612,7187	608,4023	608,4023	608,4023	608,4023	608,4023
0.2800	1000,0000	52049378	0.5965	0.5918	2224,0083	612,7187	615,3086	606,6758	608,4023	608,4023	606,6758	615,3086	615,3086	615,3086
0.3200	1000,0000	52049378	0.5965	0.5985	2224,0083	615,3086	622,2148	608,4023	612,7187	608,4023	608,4023	608,4023	608,4023	608,4023
0.3600	1000,0000	52049378	0.5965	0.5985	2224,0083	612,7187	615,3086	606,6758	608,4023	608,4023	606,6758	613,5820	613,5820	613,5820
0.4000	1000,0000	52049378	0.5965	0.5985	2224,0083	615,3086	622,2148	608,4023	612,7187	612,7187	608,4023	608,4023	608,4023	608,4023
0.4400	1000,0000	52049378	0.5965	0.5999	2224,0083	613,5820	615,3086	606,6758	608,4023	608,4023	606,6758	612,7187	612,7187	612,7187
0.4800	1000,0000	52049378	0.5965	0.5999	2224,0083	615,3086	622,2148	608,4023	613,5820	612,7187	508,4023	608,4023	608,4023	608,4023
0.5200	1000,0000	52049378	0.5965	0.5999	2224,0083	613,5820	615,3086	608,4023	608,4023	608,4023	606,6758	613,5820	613,5820	613,5820
0.5600	1000,0000	52049378	0.5965	0.5985	2224,0083	615,3086	622,2148	608,4023	613,5820	612,7187	608,4023	608,4023	608,4023	608,4023
0.6000	1000,0000	52049378	0.5965	0.5985	2224,0083	613,5820	619,6250	608,4023	608,4023	608,4023	606,6758	615,3086	615,3086	615,3086
0.6400	1000,0000	52049378	0.5965	0.5985	2224,0083	615,3086	622,2148	608,4023	613,5820	612,7187	608,4023	608,4023	608,4023	608,4023
0.6800	1000,0000	52049378	0.5965	0.5985	2224,0083	613,5820	619,6250	608,4023	608,4023	608,4023	608,4023	615,3086	615,3086	615,3086
0.7200	1000,0000	52049378	0.5965	0.5999	2224,0083	615,3086	622,2148	608,4023	613,5820	612,7187	608,4023	608,4023	608,4023	608,4023
0.7600	1000,0000	52049378	0.5965	0.5985	2224,0083	614,4453	620,4883	608,4023	608,4023	608,4023	608,4023	613,5820	613,5820	613,5820
0.8000	1000,0000	52049378	0.5965	0.5985	2224,0083	615,3086	622,2148	608,4023	613,5820	612,7187	608,4023	612,7187	612,7187	612,7187
0.8400	1000,9766	52049378	0.5965	0.5985	2224,0083	613,5820	619,6250	608,4023	608,4023	608,4023	608,4023	612,7187	612,7187	612,7187
0.8800	1000,9766	52049378	0.6276	0.5985	2224,0083	615,3086	622,2148	608,4023	614,4453	612,7187	608,4023	612,7187	612,7187	612,7187
0.9200	1000,9766	52049378	0.5965	0.5918	2224,0083	614,4453	620,4883	608,4023	608,4023	608,4023	608,4023	612,7187	612,7187	612,7187
0.9600	1001,9531	52049378	0.5966	0.5918	2224,0083	615,3086	622,2148	608,4023	614,4453	612,7187	608,4023	608,4023	608,4023	608,4023
1.0000	1002,9297	52049378	0.5966	0.5986	2224,0083	615,3086	620,4883	608,4023	608,4023	608,4023	608,4023	614,4453	614,4453	614,4453
1.0400	1002,9297	52049378	0.5966	0.5986	2224,0083	615,3086	622,2148	608,4023	614,4453	608,4023	608,4023	608,4023	608,4023	608,4023
1.0800	1002,9297	52049378	0.5966	0.5986	2224,0083	615,3086	620,4883	608,4023	608,4023	608,4023	608,4023	613,5820	613,5820	613,5820
1.1200	1002,9297	52049378	0.5966	0.5918	2224,0083	615,3086	622,2148	608,4023	614,4453	608,4023	608,4023	608,4023	608,4023	608,4023
1.1600	1002,9297	52049378	0.5903	0.5918	2224,0083	615,3086	620,4883	608,4023	608,4023	608,4023	608,4023	608,4023	608,4023	608,4023
1.2000	1002,9297	52049378	0.5903	0.5918	2223,9031	615,3086	622,2148	608,4023	613,5820	608,4023	606,6758	613,5820	613,5820	613,5820
1.2400	1002,9297	52049378	0.5903	0.5918	2223,8285	615,3086	620,4883	608,4023	608,4023	608,4023	608,4023	608,4023	608,4023	608,4023
1.2800	1002,9297	52049378	0.5903	0.5918	2223,7346	615,3086	622,2148	608,4023	614,4453	608,4023	605,8125	613,5820	613,5820	613,5820
1.3200	1002,9297	52049378	0.5841	0.5891	2222,9840	615,3086	622,2148	608,4023	608,4023	608,4023	608,4023	608,4023	608,4023	608,4023
1.3600	1002,9297	52049378	0.5779	0.5878	2226,3201	615,3086	622,2148	608,4023	613,5820	608,4023	605,8125	612,7187	612,7187	612,7187
1.4000	1002,9297	52049378	0.5779	0.5810	2220,7387	615,3086	622,2148	608,4023	612,7187	608,4023	608,4023	608,4023	608,4023	608,4023
1.4400	1002,9297	52049378	0.5779	0.5810	2200,7546	615,3086	622,2148	608,4023	613,5820	608,4023	606,6758	608,4023	608,4023	608,4023
1.4800	1002,9297	52049378	0.5779	0.5699	2216,5372	615,3086	622,2148	608,4023	612,7187	608,4023	608,4023	608,4023	608,4023	608,4023
1.5200	1007,8125	52049378	0.5780	0.5699	2207,0007	615,3086	622,2148	608,4023	608,4023	608,4023	605,8125	612,7187	612,7187	612,7187
1.5600	1007,8125	52049378	0.5780	0.5685	2118,4271	615,3086	622,2148	608,4023	613,5820	608,4023	608,4023	608,4023	608,4023	608,4023
1.6000	1007,8125	52049378	0.5780	0.5586	2100,5745	615,3086	621,3516	608,4023	608,4023	608,4023	606,6758	615,3086	615,3086	615,3086
1.6400	1007,8125	52049378	0.5407	0.5557	2180,9923	615,3086	622,2148	608,4023	613,5820	612,7187	608,4023	608,4023	608,4023	608,4023
1.6800	1007,8125	52049378	0.5282	0.5470	2207,3005	614,4453	615,3086	608,4023	608,4023	608,4023	606,6758	615,3086	615,3086	615,3086
1.7200	1007,8125	52049378	0.5282	0.5426	2191,6460	615,3086	622,2148	608,4023	613,5820	612,7187	608,4023	608,4023	608,4023	608,4023
1.7600	1007,8125	52049378	0.5282	0.5352	2197,1161	613,5820	615,3086	607,5391	608,4023	608,4023	607,5391	613,5820	613,5820	613,5820
1.8000	1002,9297	52049378	0.5282	0.5231	2180,8000	615,3086	622,2148	608,4023	613,5820	612,7187	608,4023	608,4023	608,4023	608,4023
1.8400	1002,9297	52049378	0.5282	0.5231	2160,8017	613,5820	619,6250	608,4023	608,4023	608,4023	608,4023	612,7187	612,7187	612,7187
1.8800	1002,9297	52049378	0.5282	0.5185	2124,3632	615,3086	622,2148	608,4023	613,5820	612,7187	608,4023	608,4023	608,4023	608,4023
1.9200	1002,9297	52049378	0.5282	0.5108	2055,9749	613,5820	619,6250	608,4023	608,4023	608,4023	606,6758	613,5820	613,5820	613,5820
1.9600	1002,9297	52049378	0.4971	0.5092	2062,6288	615,3086	622,2148	608,4023	613,5820	613,5820	608,4023	608,4023	608,4023	608,4023

5. SIXTEEN-ROD STEADY-STATE CHF RESULTS (Y. H. Kong, E. E. Polomik)

Steady-state data were taken in the mass flux range of 0.25 to 1.0×10^6 lb/h-ft² at system pressures of 800 and 1000 psi. Inlet subcooling was varied from 20 to 240 Btu/lb to provide sufficient data for correlating purposes and analytical comparison with transient CHF results.

Usually, CHF data are presented in the heat flux—quality plane in which they are fairly well represented by a straight line. These data can also be correlated by a straight line in the heat flux (or power)—subcooling plane. For example, Figures 5-1, 5-2, and 5-3 show the nine-rod data presented in the Tenth Quarterly Report, GEAP-10221-10, on the flux-subcooling plane. Another useful correlating plane is boiling length versus critical quality which is shown in Section 8.

The 16-rod data presented here had large variation in subcooling, but the local quality range of CHF was relatively small—on the order of a few percent. Thus, the total power-subcooling coordinates were chosen as an effective means of presenting the data and making comparison between sets of data from the different assemblies.

The entire 16-rod steady-state CHF data for assemblies 16R-2, -3, and -4 are shown in Tables 5-1, 5-2, and 5-3, respectively. The 800-psi steady-state CHF data are shown in Figures 5-4, 5-5, and 5-6 for assemblies 16R-2, -3, and -4, respectively. The data are very linear, over very large changes in subcooling for all three assemblies with deviations of about 2% in a few points.

A composite plot of the data from all three assemblies at 800 psi is shown in Figure 5-7. This interesting comparison shows the result of 2 to 7% enhancement in CHF, with the 0.060 clearance, at low subcooling of 20 to 50 Btu/lb, which is the range for reactor operation. The result was obtained at all three high mass fluxes. The nine-rod, 6-foot-heated, uniform, axial flux data (Tenth Quarterly Report, GEAP-10221-10) showed essentially no change in CHF within the data scatter with a bowed rod at low subcooling and higher quality as may be noted in Figure 5-8. However, the definite enhancement in the 16-rod assembly is consistently about the same at all three mass fluxes.

The 0.048-inch bowed rod data at 800 psi for assembly 16R-4 in Figure 5-7 shows a slight increase in CHF at low subcooling and $G/10^6 = 0.5$. This assembly shows reduction in critical power of only 2 or 3% at larger subcoolings and higher mass fluxes. Corresponding reductions for the nine-rod, 6-foot-heated uniform test section were larger and on the order of 10% or more, as shown in Figure 5-3.

Considering the data scatter to be about $\pm 3\%$ in the 800-psi data, the effects on CHF of a corner-bowed and reduced-clearance rod are very small, with the bowed rod showing a slight enhancement at high mass fluxes.

The 1000-psi CHF data for all three assemblies are shown in Figures 5-9, 5-10, and 5-11. All of the assemblies show very linear variation of critical power with subcooling, with a repeatable variation of $\pm 2\%$ that may be noted in Figure 5-9. The composite comparison, Figure 5-12, shows the data to be essentially the same for all three assemblies, with no serious reductions due to a corner bowed or reduced clearance rod at low subcoolings. The latter are of prime concern for reactor application. Again, as at 800 psi, the bowed rod indicates a slight enhancement, particularly at low mass flux, but it is close to the limits of scatter.

Figure 5-10 indicates a droop in critical power at 240 subcooling for the bowed assembly at 0.75 mass flux, which was the trend observed in the nine-rod data and particularly noticeable at a mass flux of 0.50 in Figure 5-2. The high subcooling points are useful for analytical and correlating purposes but not for reactor safety determinations where subcoolings are much lower.

TABLE 5-1

ATLAS STEADY STATE CHF DATA 16 ROD 12 FT COSINE (ASSBY NO. PA55 16R-2)
 UNIFORM RADIAL HEAT FLUX AND CLEARANCE 5/12/72 TO 5/16/72
 * * * * *

		MASS	(1)	(1) CRIT	(1)(2)	(1) CRIT THERMOCOUPLE					
		FLUX	LOCAL	HEATFLUX	CORRECT	BOILING					
RUN	PRESS	(LB/H.FT ²)	CRIT	(BTU/H.FT ²)	POWER	LENGTH	SUBCOOL	ROD	ROD	ROD	ROD
NUMB	(PSIA)	X10-6	QUAL	X10-6	(KW)	(INCH)	(BTU/LB)	/TC	/TC	/TC	/TC
6	993.	0.4986	0.4863	0.2125	1990.	102.1	23.36	1 6	0 0	0 0	0 0
7	1000.	0.7492	0.3876	0.2592	2427.	98.9	24.10	1 6	0 0	0 0	0 0
8	1001.	1.0000	0.3169	0.2894	2711.	95.5	25.12	1 6	0 0	0 0	0 0
9	1000.	0.9928	0.3044	0.3128	2929.	81.9	53.56	1 6	0 0	0 0	0 0
10	801.	0.9961	0.3288	0.3105	2908.	98.6	22.22	1 6	0 0	0 0	0 0
11	806.	0.7378	0.4067	0.2807	2629.	100.4	23.83	1 6	0 0	0 0	0 0
17	1000.	0.7406	0.3810	0.2804	2626.	85.8	54.58	1 6	0 0	0 0	0 0
18	1001.	0.4967	0.4821	0.2296	2150.	89.6	55.56	1 6	0 0	0 0	0 0
21	808.	0.4953	0.4918	0.2240	2098.	103.1	22.80	1 6	0 0	0 0	0 0
22	808.	0.4926	0.4817	0.2367	2217.	91.6	52.24	1 6	0 0	0 0	0 0
23	803.	0.7478	0.3870	0.2975	2786.	88.3	51.01	1 6	0 0	0 0	0 0
24	805.	1.0030	0.3160	0.3379	3164.	84.5	51.32	1 6	0 0	0 0	0 0
25	1003.	1.0071	0.2881	0.3420	3203.	71.3	83.94	1 6	0 0	0 0	0 0
26	1001.	0.7506	0.3652	0.3019	2827.	76.5	83.70	1 6	0 0	0 0	0 0
27	998.	0.4960	0.4697	0.2418	2264.	81.6	83.67	1 6	0 0	0 0	0 0
28	1004.	0.4990	0.4486	0.2519	2359.	74.7	111.73	1 6	0 0	0 0	0 0
29	996.	0.4979	0.4597	0.2554	2392.	75.6	110.26	1 6	0 0	0 0	0 0
30	1005.	0.7534	0.3550	0.3224	3020.	69.7	111.11	1 6	0 0	0 0	0 0
31	1002.	1.0017	0.2770	0.3646	3414.	64.2	110.55	1 6	0 0	0 0	0 0
33	803.	1.0055	0.3085	0.3658	3426.	75.7	77.95	1 6	16 1	5 2	0 0
35	800.	0.7507	0.3748	0.3158	2958.	79.8	77.46	1 6	0 0	0 0	0 0
36	800.	0.4993	0.4724	0.2532	2371.	84.0	78.96	1 6	0 0	0 0	0 0
37	797.	0.4973	0.4766	0.2711	2539.	78.3	106.37	1 6	13 2	1 1	0 0
42	805.	0.7544	0.3662	0.3393	3178.	72.5	106.97	1 6	0 0	0 0	0 0
47	994.	0.2583	0.6722	0.0837	1664.	91.7	165.30	4 9	0 0	0 0	0 0
48	1005.	0.2494	0.7005	0.0757	1506.	101.2	110.61	4 9	0 0	0 0	0 0
52	1004.	0.2518	0.6820	0.0706	1404.	107.1	79.10	4 9	4 6	0 0	0 0
53	1006.	0.2509	0.7227	0.0714	1420.	112.5	60.90	4 9	4 6	0 0	0 0
54	1004.	0.2481	0.7326	0.0704	1400.	114.9	52.68	4 9	4 6	0 0	0 0
55	1008.	0.2483	0.6733	0.1461	1368.	101.9	32.91	1 6	0 0	0 0	0 0
56	1001.	0.5095	0.4951	0.2207	2067.	102.0	24.06	1 7	0 0	0 0	0 0
57	997.	0.7494	0.4043	0.2617	2535.	98.8	25.29	4 6	0 0	0 0	0 0
58	1004.	1.0090	0.3278	0.2901	2811.	96.3	24.59	4 6	0 0	0 0	0 0
162	1004.	0.9969	0.3133	0.3231	3026.	81.8	55.32	1 6	0 0	0 0	0 0
163	1001.	0.4964	0.4945	0.2343	2194.	90.1	55.37	1 6	1 7	0 0	0 0
164	1002.	0.3470	0.5872	0.1901	1780.	92.8	55.78	1 6	1 7	0 0	0 0
165	1002.	0.2992	0.6202	0.1724	1614.	93.3	56.96	1 6	1 7	4 6	0 0
166	1003.	0.4989	0.5009	0.2197	2057.	101.1	26.15	1 6	1 7	0 0	0 0
167	1004.	0.3484	0.5910	0.1793	1679.	102.7	26.91	1 6	1 7	0 0	0 0
168	998.	0.3484	0.5893	0.1786	1673.	103.1	25.87	1 6	1 7	0 0	0 0
169	1006.	0.2993	0.6231	0.1621	1518.	102.9	27.86	1 6	1 7	0 0	0 0
170	1001.	0.9881	0.3283	0.2959	2772.	95.7	25.70	1 6	0 0	0 0	0 0
259	1002.	0.5985	0.4580	0.2424	2270.	100.2	25.74	1 6	0 0	0 0	0 0
261	999.	0.5943	0.4484	0.2580	2416.	88.6	54.96	1 6	0 0	0 0	0 0
262	1005.	0.6030	0.4287	0.2815	2636.	77.3	94.35	1 6	0 0	0 0	0 0
263	991.	0.3503	0.5840	0.2078	1946.	83.9	92.73	1 6	1 7	0 0	0 0
264	1001.	0.3046	0.6118	0.1878	1758.	84.4	94.43	1 6	1 7	4 6	4 9
265	998.	0.3016	0.6843	0.0918	1827.	98.7	121.81	4 9	1 6	4 6	0 0
266	1004.	0.3496	0.5679	0.2151	2014.	77.8	122.41	1 6	4 6	4 9	0 0
267	1001.	0.6059	0.4234	0.3012	2821.	71.6	121.65	1 6	4 6	0 0	0 0

(1) QUALITY AND HEAT FLUX ARE THOSE AT THE LOCATION SHOWN IN THE FIRST COLUMN
 OF CRITICAL THERMOCOUPLES

(2) BOILING LENGTH IS FROM THEORETICAL SATURATION TO FIRST CRITICAL THERMOCOUPLE

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TABLE 5-2

ATLAS STEADY STATE CHF DATA 16 ROD 12 FT COSINE (ASSEMBY NO. PASS 16R-3)
UNIFORM RADIAL HEAT FLUX AND .045 CORNER ROD BOW 5/24/72

RUN NUMB	PRESS (PSIA)	MASS	(1)	(1) CRIT	(1)(2)	(1) CRIT THERMOCOUPLE					
		FLUX (LB/H.FT ²) X10-6	LOCAL QUAL	HEATFLUX (BTU/H.FT ²) X10-6	CORRECT BOILING (KW) (INCH)	SUBCOOL (BTU/LB)	ROD /TC	ROD /TC	ROD /TC	ROD /TC	ROD /TC
2	1000.	0.4979	0.4940	0.2157	2024.	101.3	25.36	13 6	0 0	0 0	0 0
3	1002.	0.7579	0.3789	0.2572	2414.	98.0	25.27	13 6	0 0	0 0	0 0
4	1004.	1.0133	0.3082	0.2853	2678.	95.2	25.07	13 6	0 0	0 0	0 0
5	1001.	1.0162	0.2913	0.3082	2892.	81.4	53.27	13 6	0 0	0 0	0 0
6	996.	0.7526	0.3678	0.2758	2588.	85.6	53.65	13 6	0 0	0 0	0 0
7	997.	0.5043	0.4792	0.2309	2167.	89.9	54.50	13 6	0 0	0 0	0 0
9	997.	0.5050	0.4624	0.2413	2265.	81.9	81.35	13 6	16 5	0 0	0 0
10	1003.	0.7527	0.3535	0.2942	2761.	75.0	82.97	13 6	0 0	0 0	0 0
278	1006.	1.0080	0.2824	0.3363	3155.	70.9	83.55	13 6	0 0	0 0	0 0
284	1008.	0.9946	0.2771	0.3627	3403.	63.8	111.91	13 6	16 5	1 7	0 0
286	1001.	0.7476	0.3487	0.3159	2964.	69.3	111.31	13 6	16 5	0 0	0 0
287	999.	0.4935	0.4176	0.3042	2404.	65.2	110.65	16 5	13 6	1 7	0 0
288	1003.	0.4951	0.4050	0.3203	2531.	60.0	137.87	16 5	13 6	0 0	0 0
289	1000.	0.7583	0.2958	0.4030	3185.	53.3	137.14	16 5	13 6	0 0	0 0
290	1006.	0.9993	0.2263	0.4545	3592.	47.7	135.05	16 5	13 6	0 0	0 0
291	1000.	0.5014	0.3916	0.3388	2678.	55.5	164.30	16 5	13 6	0 0	0 0
292	1010.	0.7518	0.2791	0.4188	3309.	48.0	164.39	16 5	0 0	0 0	0 0
293	1001.	0.4992	0.3847	0.3547	2803.	51.8	190.48	16 5	13 6	0 0	0 0
294	1001.	0.7589	0.2533	0.4386	3466.	42.4	193.58	16 5	0 0	0 0	0 0
295	1004.	0.5053	0.3690	0.3735	2951.	47.9	218.55	16 5	0 0	0 0	0 0
296	1001.	0.7473	0.2394	0.4499	3555.	33.7	217.55	16 5	0 0	0 0	0 0
297	1000.	0.4986	0.3579	0.3846	3039.	44.7	245.39	16 5	0 0	0 0	0 0
298	1004.	0.7462	0.2292	0.4703	3716.	35.6	241.76	16 5	0 0	0 0	0 0
300	1004.	0.2528	0.7462	0.1023	1971.	84.8	245.29	13 9	0 0	0 0	0 0
303	991.	0.2501	0.7480	0.1012	1950.	85.2	242.40	13 9	4 6	1 7	13 6
304	1003.	0.2513	0.7536	0.0951	1832.	90.7	193.19	13 9	0 0	0 0	0 0
306	1006.	0.2627	0.6470	0.1843	1729.	77.5	141.14	13 6	13 9	0 0	0 0
308	795.	0.4978	0.4824	0.2391	2244.	92.0	51.15	13 6	0 0	0 0	0 0
309	804.	0.7555	0.3810	0.2962	2779.	88.0	51.16	13 6	0 0	0 0	0 0
310	803.	1.0014	0.3126	0.3327	3122.	84.7	50.40	13 6	0 0	0 0	0 0
311	803.	0.9862	0.3308	0.3091	2900.	95.3	22.75	13 6	0 0	0 0	0 0
312	803.	0.7535	0.4005	0.2822	2648.	100.3	23.61	13 6	0 0	0 0	0 0
313	796.	0.4962	0.5147	0.2340	2195.	104.1	21.82	13 6	0 0	0 0	0 0
314	1004.	0.2528	0.6812	0.1585	1488.	94.2	59.18	13 6	13 9	4 6	1 7
315	799.	0.4986	0.4819	0.2696	2529.	79.8	100.05	13 6	0 0	0 0	0 0
316	798.	0.7530	0.3682	0.3326	3121.	74.3	99.26	13 6	0 0	0 0	0 0
317	802.	0.9952	0.2944	0.3792	3558.	63.8	101.92	13 6	0 0	0 0	0 0
318	796.	0.4970	0.4720	0.2941	2760.	71.1	147.55	13 6	13 9	0 0	0 0
319	803.	0.7502	0.3508	0.3660	3435.	64.1	148.62	13 6	0 0	0 0	0 0
320	801.	0.9970	0.2871	0.3928	3686.	65.0	117.25	13 6	0 0	0 0	0 0

- (1) QUALITY AND HEAT FLUX ARE THOSE AT THE LOCATION SHOWN IN THE FIRST COLUMN
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TABLE 5-3

ATLAS STEADY STATE CHF DATA 16 ROD 12 FT COSINE (ASSBY NO. PA55 16R-4)
 UNIFORM RADIAL HEAT FLUX AND .060 CORNER ROD TO WALL CLEARANCE 6/2/72
 * * * * *

		MASS	(1)	(1) CRIT	(1)(2)	(1) CRIT THERMOCOUPLE			
		FLUX	LOCAL	HEATFLUX	CORRECT BOILING				
RUN	PRESS (LB/H.FT2)	CRIT (BTU/H.FT2)	POWER	LENGTH	SUBCOOL	ROD	ROD	ROD	ROD
NUMB(PSIA)	X10-6	QUAL	X10-6	(KW) (INCH)	(BTU/LB)	/TC	/TC	/TC	/TC
24	997.	0.5009	0.4913	0.2096	2031.	101.0	25.93	4 6 16 9	0 0 0 0
25	998.	0.7470	0.3808	0.2470	2393.	98.0	25.41	4 6 0 0	0 0 0 0
323	1003.	1.0236	0.3065	0.2794	2707.	94.3	26.32	4 6 0 0	0 0 0 0
324	1001.	1.0062	0.3004	0.3040	2946.	81.4	54.26	4 6 16 9	0 0 0 0
325	1000.	0.7514	0.3728	0.2703	2619.	85.4	54.63	16 9 0 0	0 0 0 0
326	998.	0.7450	0.0534	0.0545	528.	59.8	25.70	16 9 0 0	0 0 0 0
325	998.	0.7450	0.0536	0.0545	528.	60.0	25.58	16 9 0 0	0 0 0 0
326	1001.	0.5017	0.4795	0.2229	2160.	89.6	55.30	16 9 0 0	0 0 0 0
327	1008.	0.5024	0.4586	0.2324	2252.	80.9	84.60	16 9 0 0	0 0 0 0
328	1006.	0.7490	0.3560	0.2855	2766.	75.9	83.73	16 9 0 0	0 0 0 0
329	1010.	0.9977	0.2841	0.3240	3139.	70.9	84.05	16 9 0 0	0 0 0 0
330	1004.	0.9914	0.2714	0.3466	3358.	63.3	112.48	16 9 0 0	0 0 0 0
331	1004.	0.7414	0.3454	0.3021	2927.	68.9	112.22	16 9 0 0	0 0 0 0
332	1010.	0.4973	0.4576	0.2468	2392.	74.8	113.32	16 9 0 0	0 0 0 0
333	998.	0.4974	0.4360	0.2673	2590.	66.1	160.20	16 9 0 0	0 0 0 0
334	1009.	0.7501	0.3162	0.3330	3227.	58.3	161.62	16 9 0 0	0 0 0 0
335	1009.	0.9939	0.2530	0.3852	3732.	53.9	156.00	16 9 0 0	0 0 0 0
336	1001.	0.4938	0.4298	0.3003	2818.	59.8	207.10	13 6 16 9	0 0 0 0
337	1002.	0.7568	0.3045	0.3714	3598.	51.6	207.42	16 9 0 0	0 0 0 0
340	1015.	0.5044	0.4054	0.3184	3084.	53.1	258.76	16 9 0 0	0 0 0 0
341	1003.	0.2484	0.7632	0.1007	2003.	84.0	259.15	1612 16 9	0 0 0 0
342	1002.	0.2566	0.7613	0.0941	1813.	94.2	166.79	13 9 0 0	0 0 0 0
343	1003.	0.2496	0.7566	0.0881	1753.	94.2	166.24	1612 13 9	0 0 0 0
344	994.	0.2547	0.7596	0.0814	1619.	104.7	100.50	1612 13 9	0 0 0 0
345	1004.	0.2535	0.7682	0.0741	1427.	123.5	27.99	13 9 1612	0 0 0 0
346	802.	0.2521	0.5011	0.2133	1414.	77.7	30.12	16 2 13 9	0 0 0 0
347	810.	0.4999	0.4974	0.2255	2185.	99.7	30.67	4 2 16 9	0 0 0 0
348	806.	0.7517	0.4065	0.2808	2720.	97.9	28.76	4 2 16 9	0 0 0 0
349	809.	1.0023	0.3406	0.3198	3098.	95.2	29.26	4 2 16 9	0 0 0 0
350	807.	0.9977	0.3152	0.3612	3500.	75.0	82.15	16 9 0 0	0 0 0 0
351	807.	0.7529	0.3828	0.3252	3051.	79.1	82.06	13 6 16 9	0 0 0 0
352	803.	0.5054	0.4797	0.2601	2441.	83.8	81.17	13 6 0 0	0 0 0 0
353	792.	0.2455	0.7702	0.0806	1604.	110.3	79.19	1612 0 0	0 0 0 0
354	807.	0.2539	0.7377	0.0875	1741.	99.4	134.33	1612 16 9	13 9 16 8
355	798.	0.5087	0.4598	0.2775	2689.	72.7	133.33	16 9 13 6	0 0 0 0
356	802.	0.7513	0.3499	0.3416	3310.	66.4	134.35	16 9 0 0	0 0 0 0
357	806.	0.9994	0.2973	0.3860	3740.	66.4	114.27	16 9 0 0	0 0 0 0
358	799.	0.7487	0.3935	0.1910	3680.	76.9	188.75	13 9 13 6	16 9 0 0
359	803.	0.5023	0.4399	0.3135	2941.	63.0	196.11	13 6 13 9	0 0 0 0
360	782.	0.2525	0.7535	0.1006	1938.	91.8	196.10	13 9 1612	0 0 0 0
361	797.	0.2653	0.7067	0.1077	2076.	85.0	244.72	13 9 1612	0 0 0 0
362	783.	0.5048	0.4177	0.3363	3156.	56.8	243.34	13 6 13 9	0 0 0 0

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Figure 5-1. Nine-Rod, 6-Foot Steady-State CHF versus Subcooling, 1000 psi, (Symmetrical Assembly)

Figure 5-2. Nine-Rod, 6-Foot Steady-State CHF versus Subcooling, 1000 psi, Bowed Corner Rod

Figure 5-3. Nine-Rod, 6-Foot Steady-State CHF versus Subcooling, 1000 psi, Reduced Corner Rod Clearance

ASSEMBLY 16R-2
16-ROD 12 foot HEATED AXIAL COSINE
UNIFORM RADIAL HEATFLUX AND CLEARANCES

Figure 5-4. Assembly 16R-2, CHF Data at 800 psi

ASSEMBLY 16-3
16-ROD 12 foot HEATED AXIAL COSINE
UNIFORM RADIAL HEAT FLUX AND 0.048" ROD-WALL
BOW AT NO. 16 ROD BETWEEN SPACERS 2 AND 3

Figure 5-5. Assembly 16R-3, CHF Data at 800 psi

ASSEMBLY 16R-4
16-ROD 12 foot HEATED AXIAL COSINE UNIFORM
RADIAL HEAT FLUX AND 0.060" ROD-WALL CLEARANCE
ON ROD NO. 16 BETWEEN SPACERS 2 AND 3

Figure 5-6. Assembly 16R-4, CHF Data at 800 psi

Figure 5-7. Assemblies 16R-2, -3, and -4, Composite CHF Data, 800 psi

Figure 5-8. Composite of Nine-Rod, Symmetrical, Bowed, and Reduced Clearance Assemblies, 1000 psi

16-ROD 12 foot HEATED AXIAL COSINE
UNIFORM RADIAL HEAT FLUX AND CLEARANCES

Figure 5-9. Assembly 16R-2, CHF Data at 1000 psi

ASSEMBLY 16R-3
16-ROD 12 foot HEATED AXIAL COSINE UNIFORM
RADIAL HEAT FLUX AND 0.048" ROD-WALL BOW
AT NO. 16 ROD BETWEEN SPACERS 2 AND 3

Figure 5-10. Assembly 16R-3, CHF Data at 1000 psi

ASSEMBLY 16R-4
 16-ROD 12 foot HEATED AXIAL COSINE UNIFORM
 RADIAL HEAT FLUX AND 0.080" ROD-WALL
 CLEARANCE ON ROD NO. 16 BETWEEN SPACERS 2 AND 3

Figure 5-11. Assembly 16R-4, CHF Data at 1000 psi

Figure 5-12. Assemblies 16R-2, -3, and -4, Composite CHF Data, 1000 psi

6. SIXTEEN-ROD TRANSIENT RESULTS

The types of transient runs made and tabulations by magnetic tape number and run number are contained in Section 2. A complete set of computer plots (CALCOMPLOTS) of all the runs and analyses is included in the topical report, *Transient CHF—Experimental Results*, GEAP-13295. The plots in the latter report show orifice flow, pressure, power, and three of the rods' thermocouples plotted versus time.

A complete tabulation of the transient runs, by type of run, is contained in each of the following subsections. Several runs of each type are also included, with brief comments, to show sensitivity of CHF occurrence to the test variables.

6.1 FLOW DECAY WITH CONSTANT POWER

These transients are somewhat more severe than a reactor one-pump trip where heat flux reductions accompany the transient and finally settle out about 30 to 35% below the initial power. The important steady-state and transient conditions for these runs are listed in order of run number in Table 6-1. The time and location for the first CHF, when it occurred, is shown, as well as the time sequence in which CHF occurred in other locations. Initial CHF was always obtained at the No. 1 rod, TC6 and 7, just upstream of the No. 2 spacer. This was also the usual CHF location for the steady-state data and may be due to the 1% radial heat flux peaking in that corner. CHF also occurred in most cases on the No. 4 rod, whose heat flux was lower by 1.6%.

Typical plots for different magnitudes and times of flow decay are shown in Figures 6-1 through 6-9.

Figures 6-1 and 6-2 are for a flow decay of $G/10^6$ from 1.0 to 0.5 in about 0.6 second with average heat fluxes of 226,700 and 250,300 Btu/h-ft², respectively. The increase of about 25,000 in heat flux was sufficient to cause CHF. These two transients are shown as lines A1 and A2 in Figure 6-10. A detailed graph such as Figure 6-10 was useful in estimating settings when tests were performed. The line A2 shows that a CHF may be expected for that transient, based on steady-state results, and it was indeed obtained, as shown in Figure 6-2. The average test heat flux (Figure 6-1) of 226,700 Btu/h-ft², and (1.385 axial peak/average) $\times 226,700 = 313,500$ Btu/h-ft² maximum at the middle of the test section, can be compared with typical 1000 MWe reactor values, at a mass flux of 1.0×10^6 lb/h-ft², of 245,000 Btu/h-ft² average in the central core and a maximum value of about 344,000 Btu/h-ft². The result of the transient in Figure 6-1 indicates that a reactor operating at 20,000 Btu/h-ft² below its average rated heat flux could be run or withstand a constant power transient to one-half its rated flow and still have some margin of safety above CHF conditions. Actual reactor transients of this nature have a reduction of heat flux due to generation of additional steam in the core causing a power reduction.

A useful approximate conversion factor for interpretation of the following plots is that (kW) $\times 1/8 = \bar{q}''/10^3$ average Btu/h-ft².

Figures 6-3 and 6-4 are almost the same transient as the previous two discussed, except that the flow decay time was increased to 1.74 and 1.46 seconds, respectively. No apparent effect of the longer decay time is evident with CHF not occurring at the lower heat flux and occurring at 262,000 Btu/h-ft².

A long flow decay time appears to stabilize conditions sufficiently to prevent CHF. Figures 6-5 and 6-6 are the same transients at 260,000 heat flux, except for decay times of 0.6 and 4.2 seconds. The first reached CHF, whereas the second did not, although both runs were close to CHF on the basis of steady-state conditions.

Figures 6-7 and 6-8 are two almost identical transients, at about 250,000 Btu/h-ft² average heat flux, $G/10^6$ from about 1.0 to 0.5, and decay times of 1.4 and 1.55 seconds, except the first was done in the uniform assembly 16R-2 and the second in the reduced clearance assembly 16R-4. CHF occurred in the first run but not in that of the reduced clearance assembly. This run (line A2 in Figure 6-10) has an endpoint which is quite sensitive to CHF. However, there are apparently no serious effects of the reduced clearance on CHF as may also be noted by runs 364 through 369 in Table 6-1.

Run 109, Table 6-1, is typical of the hypothetical seizure of the recirculation pump from one-loop operation. Initial heat flux was 176,000, about 70% of rated, and initial flow was $G/10^6 = 0.585$, about 50% of rated. No CHF occurred, so heat flux was increased to 188,300 Btu/h-ft², run 110, and CHF was obtained as shown in Figure 6-9. The latter power level is about 113% of the value expected at this time during the transient, indicating the available CHF margin for this transient in a BWR.

6.2 FLOW AND POWER DECAY

This transient, with a flow decay of $G/10^6$ from 1.0 to 0.3 in 5 to 6 seconds, is typical of a reactor two-pump trip or simultaneous closure of recirculation flow control valves. A similar transient with a flow decay of 0.6 to 0.3 in about 5 to 6 seconds is representative of a pump trip or valve closure from one-loop initial conditions. A schematic course of the transient is shown in Figure 6-10 from point C, with heat flux decreasing as flow decay time, τ_D , is increased.

A list of the data for these runs is given in Table 6-2. Runs 204 and 205, performed at heat fluxes and qualities equal to or higher than reactor central core conditions, show that this type of transient can be made with no CHF occurrence. In run 200, a transient with 298,800 heat flux occurred with no CHF, although the flow decay time was slightly higher at 8.28 seconds.

Power was increased beyond nominal reactor values to find the CHF threshold. Runs 206 and 207 in Figures 6-11 and 6-12 show CHF for these runs, with run 207 near the CHF threshold but a few percent above it.

The series of runs, 210 through 213, approximating one-loop condition cases, indicate the CHF threshold between 257,200 and 262,600 Btu/h-ft²—well above average reactor values. Run 211 at 262,600 average heat flux is shown in Figure 6-13, and from its severity indicates that the CHF threshold is slightly above 257,200 heat flux on run 213.

The additional runs, 215 through 219, were taken at lower flow decay times to allow some parametric study of the power and flow decay time on CHF.

Comparison of runs 205 and 370, at about the same conditions but in different test sections, shows a higher sensitivity to CHF in run 370, the reduced corner clearance, where CHF occurred at a slightly lower heat flux, and in the reduced clearance zone just ahead of the No. 2 spacer. Thermocouple 16-12, downstream of 16-9, also reached CHF, as may be seen in Figure 6-14. The CHF was moderate in temperature rise, although the average heat flux was above average reactor values.

6.3 FLOW ON/OFF/ON WITH CONSTANT POWER

This type of transient was reported in the Tenth Quarterly Report, GEAP-10221-10, for the nine-rod bundle assembly with 6-foot heated length. This transient provides useful data for time to CHF occurrence and the time and characteristics of rod cooling when the flow is reestablished (rewetting). Rewetting, from 900°F rod temperatures, was obtained in all cases and was most easily effected at reduced powers.

The prime steady-state and transient data for this type of transient are tabulated in Table 6-3. The main variables were the flow, heat flux, and flow OFF time. The first CHF and time are noted together with other locations becoming critical.

A low heat flux, 21,300 Btu/h-ft², is shown in Figure 6-15, which shows that saturated vertical pool boiling essentially zero flow* can continue for at least 60 seconds without CHF occurrence.

* A minimum flow of about $G/10^6 = 0.05$ lb/h-ft² is indicated on this and subsequent CALCOMLOTS. No calibration of the orifice was made for such low flows. Thus, the actual flow is probably zero at valve shutoff (barring slight leakage), or in the lower range of $G/10^6 = 0 - 0.05$, due to very low orifice coefficients at low flow.

Table 6-1
SIXTEEN-ROD TRANSIENT FLOW DECAY, CONSTANT POWER, 1000 psia
(ASSEMBLY NOS. 16R-2, 16R-4)

Computer Run Number	Assembly Number	Initial Steady-State Conditions ⁽¹⁾						Transient Values ⁽²⁾				First CHF						Other CHF ⁽³⁾	
		Pressure P (psia)	Mass Flux G/10 ⁶ (lb/h-ft ²)	Total ⁽¹⁾ Power (kW)	Average ⁽¹⁾ Heat Flux q"/10 ³ (Btu/h-ft ²)	Subcooling (Btu/lb)	Exit ⁽¹⁾ Quality x _e (wt %)	Time to Reach Low Flow τ _D (sec)	G _{hi} /G _{low} Average/10 ⁶ (lb/h-ft ²)	CHF During Transient	Power Dip During CHF	P (psia)	Location (Rod-TC No.)	τ _c ⁽²⁾ (sec)	T _{max} (°F)	(sec)	Time (Rod-TC No.)	Elapsed ⁽⁴⁾ (sec)	
100	16R-2	1005	0.9591	1920	226.7	31.71	23.96	0.62	0.960/0.480	No	No								
101		1003	0.9508	2120	250.3	30.95	27.28	0.56	0.951/0.490	Yes	Yes	961	1-6	4.32					
102		1005	0.9566	2205	260.3	30.88	28.39	0.60	0.957/0.491	Yes	Yes	1003	1-6, 1-7, 4-6	1.78			0		
103		1005	0.9571	1920	226.7	30.79	24.13	1.74	0.957/0.504	No	No								
104		1007	0.9552	2120	250.3	31.56	27.01	1.38	0.955/0.500	Yes	Yes	1034	1-6	2.16					
105		1005	0.9583	2220	262.1	30.56	28.68	1.46	0.958/0.503	Yes	Yes	1029	1-6, 1-7, 1-5	1.90			4-6, 1-4		
106		1011	0.5864	1596	188.4	32.77	34.43	0.46	0.586/0.274	Yes	Yes	1017	1-6				0.6		
107		1001	0.5928	1489	175.8	31.27	31.15	0.40	0.593/0.300	Yes	No	1032	1-6	3.82	630	4.08	1-5, 1-7, 4-6, 4-8	0.6	
108		1001	0.5856	1792	211.6	30.41	39.57	0.42	0.586/0.286	Yes	Yes	1020	1-6, 1-7	1.40			1-3, 1-4, 1-5, 4-5, 4-6, 4-8, 4-9, 16-5	1.0	
109		1007	0.5842	1491	176.0	32.22	31.89	1.32	0.584/0.298	No	No								
110		1007	0.5853	1595	188.3	32.17	34.46	0.98	0.585/0.286	Yes	Yes	988	1-6, 1-7	3.38			1-5, 4-6, 4-9	1.2	
111		1007	0.5045	1702	211.6	32.15	39.33	1.30	0.584/0.290	Yes	Yes	1015	1-6, 1-7	1.64			1-4, 1-5, 4-6, 4-5, 1-3, 4-8, 4-9, 16-5	1.2	
112		1003	0.5861	1490	175.9	31.62	31.84	3.06	0.585/0.294	Yes	Yes	1001	1-6	4.78					
113		1005	0.5826	1596	188.4	31.20	34.66	2.98	0.585/0.297	Yes	Yes	1027	1-6, 1-7	3.18			4-6, 4-9	1.2	
114		1000	0.5839	1790	211.3	31.05	39.48	4.24	0.580/0.300	Yes	Yes	1000	1-6, 1-7	2.30			4-6, 1-5, 4-8, 1-4, 4-5, 4-9	0.8	
254	16R-4	1006	1.011	2110	249.2	30.37	25.13	4.14	1.011/0.546	No	No								
255		1009	1.009	2173	256.5	31.09	26.21	4.84	1.008/0.540	No	No								
256		1005	1.009	2219	262.0	30.57	26.81	4.18	1.008/0.547	No	No								
257		1003	1.001	2425	286.4	30.16	29.16	2.58	1.001/0.570	Yes	Yes	1025	1-6	2.94			1-7, 4-6	0.6	
258		1004	0.9979	2627	310.1	29.85	33.18	2.72	1.001/0.582	Yes	Yes	1020	1-6	1.66			1-4, 1-7, 4-6, 13-3, 4-9	1.4	
364	16R-4	1006	0.9895	1924	227.2	31.46	22.97	1.02	0.987/0.506	No	No								
365		1007	0.9864	2065	243.8	30.87	25.20	1.10	0.984/0.514	No	No								
366		1006	0.9819	2121	250.4	31.17	26.09	1.14	0.983/0.499	No	No								
367		1004	0.9910	2050	242.0	31.32	24.75	1.54	0.992/0.519	No	No								
368		1008	0.9827	2106	248.6	31.13	25.86	1.55	0.983/0.519	No	No								
369		1003	0.9794	2304	272.0	29.62	29.06	4.76	0.977/0.360	Yes	Yes	1030	1-6, 1-7, 4-5	2.51			4-6, 16-9, 13-6, 13-4, 13-7, 1-4, 1-5, 16-6, 13-9, 16-10, 7-9, 11-9, 16-12, 4-8, 7-6	2.4	

(1) Initial conditions of mass flux and exit quality are based on orifice measurements. These and other initial quantities tabulated are at time zero on transient plots. Average heat flux is corrected for test section losses, but total power is not.

(2) See Figure 2-1 for nomenclature for transient values. G_{hi} is just before start of the transient.

(3) Other CHF—Any thermocouple showing about 0.3 mv rise, 10-15°F, is considered to be at incipient CHF. Thermocouples are listed in the time order in which their temperature rise occurred.

(4) Elapsed time is time from first to last CHF.

Table 6-2
SIXTEEN-ROD TRANSIENT FLOW AND POWER DECAY, 1000 psia (ASSEMBLY NOS. 16R-2, 16R-4)

Computer Run Number	Assembly Number	Initial Steady-State Conditions ⁽¹⁾						Transient Values ⁽²⁾		CHF During Transient	First CHF						Other CHF ⁽³⁾	
		Pressure P (psia)	Mass Flux G/10 ⁶ (lb/h-ft ²)	Total ⁽¹⁾ Power (kW)	Average ⁽¹⁾ Heat Flux q"/10 ³ (Btu/h-ft ²)	Subcooling (Btu/lb)	Exit ⁽¹⁾ Quality x _g (wt %)	Time to Reach Low Flow τ _D (sec)	G _{hi} /G _{low} Average/10 ⁶ (lb/h-ft ²)		Location (Rod-TC No.)	τ _c (sec)	P (psia)	Total ⁽¹⁾ Power kW _c	Average Critical ⁽¹⁾ Heat Flux q _c "/10 ³ (Btu/h-ft ²)	Mass Flux G _c /10 ⁶ (lb/h-ft ²)	(Rod-TC No.)	
196	16R-2	1005	1.015	2032	239.9	30.57	23.91	7.92	1.012/0.3840	No	—	—	—	—	—	—		
199		1006	0.9976	2330	275.1	30.82	28.65	6.85	0.996/0.386	No	—	—	—	—	—	—		
200		1007	0.9990	2531	298.8	30.33	31.57	8.28	0.999/0.360	No	—	—	—	—	—	—		
201		994	0.9980	2727	322.0	28.29	34.61	7.86	0.996/0.373	Yes	1-6	3.64	992	2188	258.4	0.506	1-7, 4-6	
202		1001	0.9991	2771	327.1	29.01	35.14	7.26	0.996/0.383	Yes	1-6	4.52	993	2030	239.6	0.447	1-7, 4-6, 13-4	
203		1003	1.002	2828	333.9	29.27	35.82	8.29	0.998/0.373	Yes	1-6	3.40	1006	2310	272.7	0.563	1-7, 4-6	
204		1008	1.012	2049	241.9	29.76	24.39	6.11	1.012/0.356	No	—	—	—	—	—	—		
205		1004	1.007	2325	274.6	28.43	28.64	6.41	1.006/0.360	No	—	—	—	—	—	—		
206		1005	1.006	2451	289.3	28.92	30.39	7.09	1.004/0.349	Yes	1-6	3.04	1020	1980	233.7	0.414	1-4, 1-7, 4-6, 4-9	
207		1004	1.006	2380	281.0	29.52	29.27	6.38	1.006/0.365	Yes	1-6	3.96	1020	1875	221.4	0.398	1-7, 4-6	
208		1009	1.017	2024	239.0	31.06	23.69	3.58	1.016/0.365	Yes	1-6	2.34	1040	1740	205.5	0.369	1-7, 4-6	
209		1004	1.013	1969	232.4	30.37	23.09	2.47	1.015/0.361	No	—	—	—	—	—	—		
210		1003	0.6039	1922	226.9	29.93	40.88	6.58	0.604/0.330	No	—	—	—	—	—	—		
211		995	0.5991	2224	262.6	28.57	48.54	7.35	0.599/0.308	Yes	1-6	2.72	1003	1970	232.6	0.398	1-7, 4-6	
212		1003	0.6049	2133	251.8	29.75	45.80	5.56	0.604/0.328	No	—	—	—	—	—	—		
213		1003	0.6041	2179	257.2	29.87	46.94	6.59	0.605/0.333	No	—	—	—	—	—	—		
214		1001	0.6100	1923	227.1	29.26	40.53	4.02	0.609/0.337	No	—	—	—	—	—	—		
215		1003	0.6076	2065	243.8	29.87	43.97	5.76	0.608/0.323	Yes	1-6	2.20	1012	1820	214.9	0.365	1-7, 1-4, 4-6	
216		1007	0.6132	2031	239.8	30.11	42.75	3.55	0.613/0.337	Yes	1-6	2.72	1007	1710	201.9	0.351	1-7	
217		1007	0.6026	1927	227.5	30.57	41.04	2.04	0.603/0.329	Yes	1-6	1.72	1012	1720	203.1	0.330	1-7, 1-4, 1-5, 4-6, 13-4	
218		1003	0.6063	1832	216.2	28.51	38.79	1.63	0.606/0.333	Yes	1-6	2.64	1010	1550	182.9	0.330	1-7, 13-4	
219		1004	0.6099	1771	209.1	29.32	37.00	1.41	0.609/0.333	Yes	1-6	2.08	1020	1520	179.5	0.335		
370	16R-4	1003	0.9812	2284	269.7	31.31	28.45	5.82	0.980/0.328	Yes	16-9	2.44	1019	2002	236.0	0.409	4-6, 16-12	
371		1003	0.9865	1922	226.9	30.28	23.18	0.98	0.985/0.328	Yes	16-9	1.76	1034	1610	190.3	0.328	4-6, 16-8, 1-7, 4-5, 16-4	

(1) Initial conditions of mass flux and exit quality are based on orifice measurements. These and other initial quantities tabulated are at time zero on transient plots. Average heat flux is corrected for test section losses, but total power is not.

(2) See Figure 2-1 for nomenclature for transient values. G_{hi} is just before start of the transient.

(3) Other CHF in time order of occurrence.

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Figure 6-1. Run 100 (16-Rod COS 12 Flow Decay)

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Figure 6-2. Run 101 (16-Rod COS 12 Flow Decay)

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Figure 6-3. Run 103 (16-Rod COS 12 Flow Decay)

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Figure 6-4. Run 105 (16-Rod COS 12 Flow Decay)

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Figure 6-5. Run 102 (16-Rod COS 12 Flow Decay)

AUGUST 10, 1972

Figure 6-6. Run 256 (16-Rod COS 12 Flow Decay)

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Figure 6-7. Run 104 (16-Rod COS 12 Flow Decay)

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Figure 6-8. Run 368 (16-Rod COS 12 Flow Decay)

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Figure 6-9. Run 110 (16-Rod COS 12 Flow Decay)

Figure 6-10. Schematic of Flow Decay Transients

Figure 6-11. Run 206 (16-Rod COS 12 Flow+Power Decay)

SEPTEMBER 15, 1972

Figure 6-12. Run 207 (16-Rod COS 12 Flow+Power Decay)

SEPTEMBER 13, 1972

Figure 6-13. Run 211 (16-Rod COS 12 Flow+Power Decay)

SEPTEMBER 14, 1972

Figure 6-14. Run 370 (16-Rod COS 12 Flow+Power Decay)

JULY 18, 1972

Figure 6-15. Run 122 (16-Rod COS Flow ON/OFF/ON)

At 51,400 Btu/h-ft², a CHF was obtained with flow near zero for 20.2 seconds, as shown in Figure 6-16. The sensitivity of CHF to the length of time flow is OFF, and a pressure increase of about 50 psi may be noted in Table 6-3 for run 132 where no CHF was observed at the same heat flux for flow OFF for 19.8 seconds.

Figure 6-17 shows a CHF at 99,200 heat flux, for an OFF time of 4.0 seconds, while no CHF was obtained on the previous run No. 138 for 2.8 seconds flow OFF time.

Runs 149 and 150 are shown in Figures 6-18 and 6-19 for 149,200 Btu/h-ft² heat flux. An increase of 1.4 seconds in run 150 in the flow OFF time was sufficient to produce a fast temperature excursion on rod 1 thermocouple 4. A power dip may be noted in Figure 6-19, and eventual rewetting and cooling of the rods at reduced power and the higher flow.

Figures 6-20 and 6-21 are both for heat fluxes of 197,200 Btu/h-ft² and flow OFF times of about 1 second, except from initial mass fluxes of G/10⁶ of 0.49 and 1.017, respectively. CHF and a power dip and power trip occurred in these runs, with the higher temperature rise occurring for the lower mass flux case, Figure 6-20, as would be expected. The rewetting rod temperature decays may be clearly noted in all of the rods about 2 seconds before temperatures return to their initial values.

Comparison of the same transients in the uniform radial and reduced clearance test sections, 16R-2 and 16R-4, at 98,100 average heat flux can be made by comparing runs 374 and 139, Figures 6-22 and 6-17. The flow OFF time was 4.0 seconds in both runs. It is notable that the transient had a generally lower temperature rise for the reduced clearance (Figure 6-22) than the uniform clearance (Figure 6-17).

Comparison of Figures 6-22 and 6-23, runs 374 and 378, both at about 98,000 average heat flux but mass fluxes of 1.0 and 0.49, indicates a mild CHF rise of about 50°F in the reduced corner clearance zone (rod 16).

6.4 FLOW ON/DECAY/OFF/ON WITH POWER DECAY (LOC OR DBA)

This type of transient approximates that which would occur in the event of a recirculation line break in the reactor system. It is also referred to as a Design Basis Accident (DBA) or Loss-of-Coolant Accident (LOCA). A typical transient of this type, as calculated by the Atomic Energy Commission's Interim Acceptance Criteria Models, is shown in the Eleventh Quarterly Report, GEAP-10221-11.

The results of these transient tests in the ATLAS facility are listed in Table 6-4 and several plots of the data shown.

The postulated occurrence of an accident of this severe nature implies that CHF will occur, and the main question is whether the reactor fuel and cladding temperatures will reach magnitudes that may endanger the cladding's integrity. It may be noted in Table 6-4 that CHF occurred in all but a few of the runs, as was expected. Flow OFF times of up to 5 to 6 seconds were desired, with the transient starting from average heat fluxes of 240,000 to 250,000 Btu/h-ft². Flow OFF times up to 3 seconds were obtained at reduced powers which were necessary to keep temperatures below 900°F, to obtain the complete temperature excursion without a power dip and for preservation of the test section's integrity. These runs provide valuable data for the early part of the temperature excursions, as well as the rewetting phase, which should, with available and additional analysis, enhance the credibility of future calculations for this type of accident.

Run 221, shown in Figure 6-24, is one of the first runs in the series, at almost rated heat flux, an initial flow decay of 5.50 seconds, and an OFF time of 2.00 seconds. CHF occurred on seven rods: the four corner rods, and three interior rods. The sharp temperature rise on the corner No. 13 rod caused the HI-HI alarm to trip the power.

Table 6-3
SIXTEEN-ROD TRANSIENT FLOW ON/OFF/ON, CONSTANT POWER, 1000 psia
(ASSEMBLY NOS. 16R-2, 16R-4)

Computer Run Number	Assembly Number	Initial Steady-State Conditions ⁽¹⁾						Transient Values ⁽²⁾			Power Dip During CHF	First CHF						Other CHF	
		Pressure P (psia)	Mass Flux ⁽¹⁾ G/10 ⁶ (lb/h-ft ²)	Power ⁽¹⁾ (kW)	Average ⁽¹⁾ Heat Flux q"/10 ³ (Btu/h-ft ²)	Subcooling (Btu/lb)	Exit ⁽¹⁾ Quality x _g (wt %)	Time Flow Off τ _o (sec)	G _{hi} /G _{low} Average/10 ⁶ (lb/h-ft ²)	CHF During Transient		Location (Rod-TC No.)	τ _c (sec)	P (psia)	Flow at CHF (Hi or Low)	τ _{max} ⁽³⁾ (sec)	T _{max} (°F)	(Rod-TC No.)	
117	16R-2	1003	1.045	180	21.3	36.83	- 3.2	3.4	1.045/0.041	No	No								
118	16R-2	Transient started before data recording started																	
120	16R-2	1003	1.039	180	21.3	30.78	- 2.3	21.0	1.039/0.041	No	No								
121	16R-2	1006	0.995	180	21.3	33.19	- 2.5	60.0	0.995/0.041	No	No								
122	16R-2	1006	0.496	180	21.3	30.04	0.6	60.0	0.496/0.041	No	No								
125	16R-2	1000	1.045	434	51.2	30.72	1.2	1.8	1.045/0.070	No	No								
126	16R-2	1004	1.033	435	51.4	31.59	1.2	3.9	1.033/0.070	No	No								
127	16R-2	984	1.038	435	51.4	29.35	1.5	6.0	1.038/0.070	No	No								
129	16R-2	1000	1.045	435	51.4	36.02	0.4	10.4	1.045/0.070	No	No								
131	16R-2	1006	?	431	50.9	34.96	?	19.8	1.0(?) / 0.055	Yes	Yes	1-4	17.2	930	Low			1-5, -6, -7, 4-5, -6, -9	
132	16R-2	1005	1.044	435	51.4	33.91	0.7	19.8	1.044/0.070	No	No								
133	16R-2	1004	1.051	435	51.4	33.49	0.8	20.2	1.051/0.070	Yes	No	4-9	16.1	990	Low	21.0	630	1-5, -8, 4-9	
134	16R-2	995	1.047	439	51.8	31.55	1.1	22.2	1.047/0.070	Yes	No	4-6	15.9	975	Low	22.6	730	1-6, -7, 4-8, -9	
135	16R-2	1008	0.488	434	51.2	29.81	8.1	15.2	0.488/0.055	Yes	No	4-6	10.4	1010	Low	16.0	730	1-6, -7, 4-8, -9	
136	16R-2	1003	0.473	840	99.2	23.78	21.7	2.8	0.473/0.070	Yes	No	1-7	3.4	1000	Hi	4.0	620	1-6, 4-6, 4-8	
137	16R-2	1004	0.480	840	99.2	27.53	20.8	3.8	0.480/0.070	Yes	Yes	1-5	3.3	1030	Low			Rods 1, 3, 4, 13, 16 (All TCs)	
138	16R-2	1007	1.045	840	99.2	32.72	6.45	2.8	1.045/0.070	No	No								
139	16R-2	1002	1.042	840	99.2	31.36	6.7	4.0	1.042/0.070	Yes	No	1-5	3.8	1020	Low	5.6	755	1-7, 1-3, 1-4, 1-6, 4-5, 4-6, 13-3	
141	16R-2	1005	0.240	180	21.3	32.69	5.7	62.0	0.240/0.070	No	No								
142	16R-2	Transient started before data recording started																	
143	16R-2	1000	0.243	433	51.1	37.05	19.7	14.8	0.243/0.070	Yes	No	1-6	12.2	985	Low	16.4	680	1-3, -5, -7, 4-5, -6, 10-2	
144	16R-2	988	0.238	840	99.2	28.32	45.9	2.2	0.238/0.070	Yes	Yes	1-6	2.9	1005	Low			Rods 1, 3, 4, 11, 13, 16	
147	16R-2	1007	0.244	840	99.2	33.03	44.1	1.8	0.244/0.070	No	No								
148	16R-2	1013	0.240	840	99.2	34.52	44.9	2.0	0.240/0.070	Yes	No	1-6	2.4	1016	Hi	4.4	730	1-3, -4, -7, 4-5, -6, -9, 16-5	
149	16R-2	979	1.022	1264	149.2	28.21	13.2	1.4	1.022/0.070	No	No								
150	16R-2	1009	1.025	1261	148.9	32.11	12.7	2.8	1.025/0.070	Yes	Yes	1-3	2.5	1050	Low			Rods 1, 3, 4, 5, 7, 11, 13, 16 (All TCs)	
171	16R-2	1005	0.508	1262	149.0	31.14	30.7	1.8	0.508/0.041	Yes	Yes	3-3	1.8	1040	Low			1-1, -2, -3, -5, -6, -7, 3-3, -4, 4-5, 11-8, 13-3	
172	16R-2	Transient started before data recording started																	
173	16R-2	1003	0.502	1264	149.2	30.88	31.2	1.4	0.502/0.041	Yes	Yes	1-4	1.9	1000	Hi			1-3, -4, -5, 4-5, -6, -9, 5-1, 5-2	
174	16R-2	1003	0.494	1260	148.8	30.87	31.7	1.4	0.494/0.041	Yes	No	1-1	2.0	1010	Hi	2.3	660	1-2, -3, -4, -5, -6, -7, 4-5, -6, -8	
175	16R-2	1007	0.500	1669	197.1	31.30	43.0	0.8	0.500/0.055	Yes	Yes	1-4	1.2	1015	Hi			Rods 1, 3, 4, 10, 11, 16 (All TCs)	
177	16R-2	1003	0.493	1670	197.2	29.95	43.8	0.6	0.493/0.139	No	No								
179	16R-2	1006	0.491	1670	197.2	31.58	43.8	1.0	0.491/0.041	Yes	Yes	1-3	1.3	1025	Hi			Rods 1, 3, 4, 13 (All TCs)	

Table 6-3 (Continued)

Computer Run Number	Assembly Number	Initial Steady-State Conditions ⁽¹⁾						Transient Values ⁽²⁾			Power Dip During CHF	First CHF						Other CHF	
		Pressure P (psia)	Mass Flux ⁽¹⁾ G/10 ⁶ (lb/h-ft ²)	Power ⁽¹⁾ (kW)	Average ⁽¹⁾ Heat Flux q"/10 ³ (Btu/h-ft ²)	Subcooling (Btu/lb)	Exit ⁽¹⁾ Quality x _e (wt %)	Time Flow Off τ _o (sec)	G _{hi} /G _{low} Average/10 ⁶ (lb/h-ft ²)	CHF During Transient		Location (Rod-TC No.)	τ _c (sec)	P (psia)	Flow at CHF (Hi or Low)	τ _{max} ⁽³⁾ (sec)	T _{max} (°F)	(Rod-TC No.)	
180	16R-2	1007	0.498	1670	197.2	29.98	43.4	0.8	0.498/0.041	Yes	Yes	1-7	1.3	1010	Hi			Rods 1, 3, 4, 10, 11, 16 (All TCs)	
181	16R-2	1005	0.493	1665	196.6	29.79	43.8	0.95	0.493/0.145	No	No								
184	16R-2	1000	0.485	1666	196.7	30.47	44.3	0.8	0.485/0.041	Yes	Yes	10-4	1.2	1020	Hi			Rods 1, 3, 4, 5, 7, 10, 11, 13, 16	
185	16R-2	1006	0.494	1666	196.7	30.64	43.5	0.8	0.494/0.041	Yes	Yes	10-4	1.3	1000	Hi			Rods 1, 3, 4, 10, 11, 13, 16	
186	16R-2	1000	0.494	1670	197.2	30.94	43.5	0.7	0.494/0.041	Yes	Yes	1-4	1.2	1025	Hi			Rods 1, 3, 4, 5, 11, 13, 16	
187	16R-2	1006	1.017	1666	196.7	31.55	18.6	1.0	1.017/0.070	No	No								
188	16R-2	1001	1.017	1670	197.2	29.76	18.9	1.2	1.017/0.070	Yes	Yes	3-3	1.8	1025	Hi			1-3, 4, 6, 7, 3-3, 4, 4-5, 6, 13-4, 16-5, 7	
374	16R-4	1005	1.007	831	98.1	30.70	7.1	4.0	1.007/0	Yes	No	4-6	4.0	1050	Low	5.3	680	14-8, 13-4, 16-6, 4-6, 12-6, 16-2, 16-8, 16-9, 1-7, 1-6, 4-6, 1-4, 12-8, 12-7, 16-11, 1-5, 11-9	
375	16R-4	1003	0.999	846	99.8	29.13	7.6	4.0	0.999/0	Yes	No	1-7	3.8	1070	Low	6.0	810	16-2, 4-5, 14-6, 1-4, 1-6, 16-6, 16-2, 16-9, 16-11, 4-6, 12-5, 13-4, 13-6, 13-7, 14-5, 12-8, 16-1, 1-5, 4-8, 7-6, 11-9, 13-3, 16-10, 14-9, 16-12, 13-9	
376	16R-4	1009	0.494	795	93.9	32.51	18.0	2.3	0.494/0	No	No								
377	16R-4	1001	0.485	823	97.2	30.85	19.5	2.5	0.485/0	No	No								
378	16R-4	1007	0.489	832	98.3	32.15	19.4	3.6	0.489/0	Yes	No	1-7	3.8	1015	Hi	4.9	650	16-6, 1-6, 4-5, 16-8, 4-6, 13-4, 14-6, 16-9, 1-4, 1-5, 12-8, 16-11, 4-8, 16-10, 16-12, 12-9, 13-7	
379	16R-4	1006	0.486	832	98.3	31.62	19.7	3.5	0.486/0	Yes	Yes	1-7	3.3	1040	Low			16-2, 1-4, 16-1, 16-6, 16-8, 1-6, 4-5, 13-4, 13-6, 14-6, 16-4, 16-9, 16-11, 12-6, 1-5, 4-8, 12-5, 12-8, 13-7, 16-10, 4-6, 16-12, 14-9, 13-3	

(1) Initial conditions of mass flux and exit quality are based on orifice measurements. These and other initial quantities tabulated are at time zero on transient plots.
(2) See Figure 2-1 for nomenclature for transient values.
(3) τ_c not corrected for thermocouple thermal inertia.

Table 6-4
SIXTEEN-ROD FLOW AND POWER DECAY WITH LOC (LOSS OF COOLANT), 1000 psia, ASSEMBLY NO. 16R-2

Computer Run Number	Initial Steady-State Conditions ⁽¹⁾					Transient Values ⁽²⁾				First CHF					Rod (TC No.) 1(9), 5(2), 13(4), 16(3,4,6) Disabled or erratic and not always reading																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
	Pressure P (psia)	Mass Flux ⁽¹⁾ G/10 ⁶ (lb/h-ft ²)	Total ⁽¹⁾ Power (kW)	Average ⁽¹⁾ Heat Flux q"/10 ³ (Btu/h-ft ²)	Subcooling (Btu/lb)	Exit ⁽¹⁾ Quality x _e (wt %)	Flow Decay Time τ _D (sec)	Flow Off Time τ _O (sec)	G _{hi} /G _d /G _{low} Average/10 ⁶ (lb/h-ft ²)	CHF During Transient	Power Dip During Transient	Location (Rod-TC No.)	τ _c ⁽²⁾ (sec)	P (psia)	G _c /10 ⁶ (lb/h-ft ²)	kW _c																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												

(1) Same as Table 6-1
(2) Same as Table 6-1
(3) Same as Table 6-1
(4) Other CHF shown in time order for each rod. Rods are in numerical and not time order of CHF.
(5) Run 220—A backward extrapolation of 0.65 sec was made on the transient plot to determine initial conditions not recorded.
(6) Actual value of G_{low} is between zero and value shown.

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Figure 6-16. Run 133 (16-Rod COS Flow ON/OFF/ON)

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Figure 6-17. Run 139 (16-Rod COS Flow ON/OFF/ON)

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Figure 6-18. Run 149 (16-Rod COS Flow ON/OFF/ON)

JULY 18, 1972

Figure 6-19. Run 150 (16-Rod COS Flow ON/OFF/ON)

JULY 28, 1972

Figure 6-20. Run 179 (16-Rod COS 12 Flow ON/OFF/ON)

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Figure 6-21. Run 188 (16-Rod COS 12 Flow ON/OFF/ON)

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Figure 6-22. Run 374 (16-Rod COS 12 Flow ON/OFF/ON)

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Figure 6-23. Run 378 (16-Rod COS 12 Flow ON/OFF/ON)

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Figure 6-24. Run 221 (16-Rod COS 12 Flow+Power Decay LOC)

Two interesting runs, 236 and 241 in Figures 6-25 and 6-26, have initial decay times of 5.9 and 8.0 seconds and flow OFF times of 1.88 and 2.15 seconds, respectively. The effect of the longer flow decay time in reducing the severity of CHF on run 241 may be noted. The additional delay of 2.1 seconds reduced the power sufficiently to offset the extant higher heat flux and longer flow OFF time in run 241. On run 236, CHF on the No. 1 rod persisted about twice as long as the other corner rods before rewetting.

Runs 239 and 248 (Figures 6-27 and 6-28) have essentially the same flow decay and OFF times, but run 239 has an average heat flux 6000 Btu/h-ft² higher. This was apparently sufficient to induce a high post CHF temperature in run 239 on the No. 13 rod, compared with no CHF indication on the same rod in run 248 (Table 6-4). It should also be noted that the flow at the end of the initial flow decay in run 239 (higher heat flux) was considerably higher than for run 248.

Figure 6-29 shows run 253, which has a long flow decay and OFF time. It shows a milder CHF, compared with run 239 in Figure 6-27 at a lower heat flux, due to the much shorter initial decay time (with resultant higher power) on run 239.

6.5 FLOW AND POWER RAMP UP

This type of reactor transient could occur due to control failures which could cause opening of the recirculation valve, with a resultant increase in flow and power. A typical case would be a flow increase from $G/10^6 = 0.6$ to 1.0 lb/h ft², with a power increase from about 65 to 120% of rated (actual transients would subsequently drop back to 100%), both occurring in the range of 3 to 6 seconds. This reactor power increase corresponds to $0.65 (250,000) = 162,500$ to $1.2 (250,000) = 300,000$ Btu/h-ft² average heat flux in the "hottest" or central portion of the core, which is equivalent to an increase of test section power from 1345 to 2490 kW. A run corresponding to this transient was made for the most severe condition of occurrence in 3 seconds, and is shown as run 230 in Table 6-5, which lists the results of runs made with this type of transient. No evidence of CHF resulted. Power levels were increased to determine CHF thresholds, and runs were made with power ramp increases of 10.2 and 15.5%/sec (based on the final power level). Final powers, 370 kW in excess of the nominal final value, were reached before CHF occurred. Run 231, with the 15.2% power ramp, is shown in Figure 6-30. Slight CHF occurred at 6 and 18 seconds and was somewhat subdued due to a 100-psi pressure rise which decayed.

Run 373, almost identical to run 231, was made with the reduced corner clearance assembly 16R-4, and is shown in Figure 6-31. CHF shifted from the No. 13 to the Nos. 4 and 16 rods due to the reduced clearance in the 16-rod corner and reduced side clearances at the No. 4 position.

6.6 POWER STEPDOWN FOR THERMOCOUPLE RESPONSE

A few of these runs were made with single-phase flow and power levels below subcooled boiling conditions to provide data for calculation of CHF thermocouple time lags (estimated at 0.2 to 0.3 second). A typical run is shown in Figure 6-32. In more detailed analysis for prediction of CHF, which is presented in *Transient CHF—Experimental Results*, GEAP-13295, it was found more desirable to use other transient runs with CHF temperature excursions of larger magnitude. Thus, it was not considered worthwhile to include a tabulation of these runs.

Table 6-5
SIXTEEN-ROD POWER AND FLOW RAMP UP, 1000 psia, ASSEMBLY NUMBERS 16R-2 AND 16R-4

Computer Run Number	Assembly Number	Initial Steady-State Conditions ⁽¹⁾						Transient Values ⁽²⁾					CHF During Transient		
		Pressure P (psia)	Mass Flux ⁽¹⁾ G/10 ⁶ (lb/h-ft ²)	Total ⁽¹⁾ Power (kW)	Average ⁽¹⁾ Heat Flux q"/10 ³ (Btu/h-ft ²)	Subcooling (Btu/lb)	Exit ⁽¹⁾ Quality x _e (wt %)	G _{low} /G _{hi} Average/10 ⁶ (lb/h-ft ²)	K _{low} /K _{hi} Average (kW)	Power Increase % of Final Value	Ramp Time τ _r (sec)		Final Average Heat Flux q"/10 ³ (Btu/h-ft ²)		Rod-Thermocouple Number
											Power	Flow			
223	16R-2 ↓	1004	0.494	1716	202.6	30.75	45.06	0.491/0.977	1717/2098	18.2	3.0	3.8	248.0	No	
224		1000	0.499	2038	240.6	29.97	53.88	0.499/0.970	2038/2494	18.2	3.0	3.9	294.5	No	
225		1005	0.505	2061	243.3	30.73	53.76	0.505/0.975	2061/2510	17.9	3.0	3.9	296.0	No	
226		1005	0.500	1676	197.8	30.17	43.67	0.500/0.975	1676/2410	20.5	3.0	3.6	284.5	No	
227		1002	0.503	1827	215.7	30.03	47.84	0.503/0.975	1827/2626	30.5	3.0	3.6	310.0	No	
228		1002	0.504	1964	231.8	30.58	51.39	0.504/0.970	1964/2830	30.0	3.0	3.6	334.0	No	
229		1003	0.506	2002	236.4	30.99	52.00	0.504/0.970	2002/2890	30.7	3.0	3.7	341.0	Yes	13-4
230		1000	0.504	1338	158.0	30.38	33.35	0.504/0.985	1338/2490	46.2	3.0	3.6	294.5	No	
231		1007	0.499	1526	180.2	32.10	39.45	0.499/0.970	1526/2860	46.6	3.0	3.4	338.0	Yes	13-4 (13 sec after end of transient. CHF suppressed at end transient by 100 psi pressure surge.)
372	16R-4 ↓	1003	0.487	1993	235.3	31.17	53.71	0.487/0.960	1993/2858	30.3	3.0	4.2	337.0	Yes	4-6, 16-9. (4-6 at 3.5 sec after start of transient, G=0.933)
373		1003	0.499	1510	178.2	32.25	38.29	0.499/0.960	1510/2844	46.9	3.0	3.9	336.0	Yes	4-6, 16-9. (4-6 at 3.9 sec after start of transient)

(1) Initial conditions of mass flux and exit quality are based on orifice measurements. These and other initial quantities tabulated are at time zero on transient plots. Average heat flux is corrected for test section losses, but total power is not.

(2) See Figure 2-1 for nomenclature for transient values.

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Figure 6-25. Run 236 (16-Rod COS 12 Flaw+Power Decay LOC)

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Figure 6-26. Run 241 (16-Rod COS 12 Flow+Power Decay LOC)

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Figure 6-27. Run 239 (16-Rod COS 12 Flow+Power Decay LOC)

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Figure 6-28. Run 248 (16-Rod COS 12 Flow+Power Decay LOC)

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Figure 6-29. Run 253 (16-Rod COS 12 Flow+Power Decay LOC)

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Figure 6-30. Run 231 (16-Rod COS 12 Power+Flow Ramp)

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RUN 373 (PA55 16ROD COS12 POWER+FLOW RAMP)

AUGUST 11, 1972

Figure 6-31. Run 373 (16-Rod COS 12 Power+Flow Ramp)

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SEPTEMBER 15, 1972

Figure 6-32. Run 195 (16-Rod COS 12 TC Time Lag)

7. ONE-ROD SWELL HEAT TRANSFER RESULTS (J. A. Kervinen, E. E. Polomik)

The purpose of the tests in this section is to determine heat transfer characteristics on the surface of a cylindrical heater, a portion of whose axial length has been enlarged in diameter or swelled. This test was run at constant heat flux so the separate effect of mass flux over the swell could be studied. Swollen fuel elements may occur in a reactor as a result of severe fuel rod overheating. Thus, this type of data is useful in clarification of questions involving CHF margins over the swollen surface and the heat transfer performance with single-phase flow.

7.1 EQUIPMENT

A single-rod direct heater made of inconel tubing with a nine-foot heated length was used for this test. Tests were conducted in the 2000-kW facility described in the Second Quarterly Report. Figure 7-1 shows the general arrangement and details of the swollen 3-inch portion, which ended 1/2 inch from the end of the heated length. The outside diameter of the swell was designed to cause an increase in mass flux, in the ratio of 1:1.5 between the upstream annulus and the minimum annulus at the 0.6-inch flat portion. The swell was made by fusion welding together two 1.5-inch-long pieces whose wall thickness varied axially to a minimum at the centerline so that surface heat flux was axially uniform over the entire heater. Accurate voltage gradient measurements showed the heat flux to be uniform within $\pm 3\%$. The two 1-inch lengths on either side of the centerline were accurately machined on the outside diameter to the shape of a normal frequency curve. Before fusion welding of the two halves of the swell, calibrated thermocouples were installed in each, the two halves were welded at the centerline, and the final welds were made at the inlet and exit ends of the swell.

Thermocouples were led out the hollow-top electrode through a gland that allowed pressurization of the interior of the heater to prevent any distortion by system pressure in the flow annulus. Thermocouple locations are listed in the table in Figure 7-1.

7.2 STEADY-STATE CHF

CHF data were taken at system pressures of 800 and 1000 psi, with mass fluxes of $G/10^6 = 0.25$, 0.50, and 1.0 lb/h-ft². Data for the runs are in Table 7-1. Three different steam qualities may be noted in the last four columns of the table: x_c , quality at the first CHF location, x_1 , quality at the start of the swell (thermocouple 20), and x_e , exit quality.

CHF occurred first at the start of the swell (TC 20) and randomly at several other axial locations a short time later. Thus, it was necessary to calculate x_1 , the lowest quality at which CHF occurred, for comparison with other data without a swell. x_1 was calculated from the exit conditions with allowance made for the power generated over the surface of the swell and heat losses. The increment in quality, Δx , from the start of the swell to the end of the heated length was occasionally over 2%, a gradient considerably larger than over the uniform diameter of the heater. This is due to the fact the heat flux was constant over the swell, while the heat transfer area was larger.

The CHF events at the start of the swell are compared with previous data, in the same test section with a 0.540-inch outside diameter over the entire length, at 800 and 1000 psi in Figures 7-2 and 7-3. The occurrence of CHF, at the lowest quality in each case, is shown to be in very good agreement. The data show no reduction of CHF over the almost constant heat flux surface of the swell, due to higher mass fluxes. A perspective comparison of the exit quality, and that at incidence of CHF, is shown for two points in Figure 7-2.

7.3 SINGLE-PHASE HEAT TRANSFER

Tests were conducted with variables in the following ranges: temperatures, 80 to 400°F; inlet mass fluxes $G/10^6$, 0.5 to 1.5 lb/h-ft²; and average heat fluxes, 100,000 to 500,000 Btu/h-ft². These principal conditions for each run are in Table 7-2. Heat transfer calculations were made at each of the 23

thermocouple locations (Figure 7-1) and are tabulated in Appendix C. Quantities calculated at each thermocouple were: measured and predicted heat transfer coefficients, local mass flux and Reynolds number, the local Nusselt number, and the ratio of (Nusselt number)/(Prandtl number)^{1/3}.

Heat transfer predictions were made using the Colburn equation,

$$\frac{hD}{k} = 0.023 \left(\frac{DG}{\mu} \right)^{0.8} \left(\frac{C_p \mu}{k} \right)^{0.333} \quad (7-1)$$

with all coolant properties evaluated at the average temperatures of the heater surface and bulk coolant.

A composite plot of all the data upstream of the swell, at thermocouples 23, 24 and 25, is shown in Figure 7-4. Thermocouple 25 was consistently hotter than 23 and 24, which agreed well, indicating a poorer heat transfer coefficient, as reflected in Figure 7-4. This may have been caused by some heater eccentricity and/or heater wall thickness variation. The 0.8 power on the Reynolds number correlates the data well, most of it within about $\pm 10\%$, but the constant in Equation (7-1) for the TC 25 location is 0.0185 to 0.0190—about 17% lower. The TC 23 data (Figure 7-5) at various heat fluxes show a constant of 0.021—much closer to the usually accepted value.

Heat flux level has no effect on heat transfer, in accordance with accepted theory, within the 10% data scatter as presented in Figure 7-5.

Figure 7-6 is an interesting plot showing the axial variation of the measured heat transfer coefficient along the swell, with upstream Reynolds number as a parameter. As Reynolds numbers increase, some stagnation of the boundary layer and reduced heat transfer are exhibited at the start of the swell ($L=3.3$) compared with upstream values. Apparently, a similar phenomenon occurs in two-phase flow, leading to CHF at this location.

Increase in Reynolds number as velocities increase caused an increase in heat transfer on the swell at $L = 2.7$.

Beyond the center of the swell, the heat transfer rate decreases due to decreasing velocity, as the flow area increases. In this region, separation occurs, leading to a higher heat transfer in the turbulent wake. At the lower Reynolds numbers (60,000 to 100,000), the separation occurred about 1/2 to 1 inch beyond the center of the swell. As the Reynolds number increases, the separation point moves further downstream.

Comparison of heat transfer for extreme positions on the swell are made, at *local* Reynolds numbers, as shown in Figure 7-7. Heat transfer rate at TC 14 was much lower than the calculated value, compared with the upstream TC 19, at local Reynolds numbers of less than 150,000. At Reynolds numbers above about 200,000, both locations of the swell exhibit heat transfer rates correlated by an equation such as (7-1). This indicates that at low Reynolds number flow structure effects cause a reduction in the heat transfer at the top of the swell. This is probably due to a tendency toward boundary layer laminarization due to the acceleration of the flow.

Table 7-1
STEADY-STATE CHF DATA FOR A SWOLLEN ROD, 800 AND 1000 psi

Run Number	System Pressure (psi)	Mass Flow (lb/sec)	Mass Flux (lb/h-ft ² /10 ⁶)	Subcooling (Btu/lb)	Heat Flux (Btu/h-ft ² /10 ⁶)	Quality at First CHF Location x_c (wt Fraction)	Quality 3.3 Inches From End Heated Length x_1 (wt Fraction)	Quality Increment $\Delta x =$ $x_e - x_1$ (wt Fraction)	Exit Quality x_e (wt Fraction)
1	1003	1.948	0.994	7.8	0.6577	0.159	0.1589	0.0071	0.166
2	1001	1.951	0.996	23.9	0.7114	0.148	0.1483	0.0077	0.156
3	995	1.953	0.997	84.9	0.9080	0.105	0.1042	0.0098	0.114
4	999	1.966	1.004	44.6	0.7660	0.129	0.1288	0.0082	0.137
5	1000	1.960	1.000	58.0	0.8178	0.122	0.1222	0.0088	0.131
6	1003	0.996	0.509	54.9	0.5618	0.201	0.2011	0.0119	0.213
7	1011	0.980	0.500	111.2	0.6681	0.175	0.1746	0.0144	0.189
8	1005	0.974	0.497	131.7	0.7189	0.171	0.1715	0.0155	0.187
9	998	0.983	0.502	225.6	0.8874	0.110	0.1100	0.0190	0.129
10	1003	0.975	0.498	187.1	0.8496	0.154	0.1537	0.0183	0.172
11	1001	0.976	0.498	158.5	0.7816	0.162	0.1627	0.0168	0.179
12	999	0.483	0.247	29.8	0.3628	0.334	0.3342	0.0158	0.350
13	1003	0.487	0.249	178.0	0.5258	0.273	0.2733	0.0227	0.296
14	1000	0.489	0.249	108.6	0.4455	0.295	0.2948	0.0192	0.314
15	775	1.958	0.999	3.3	0.6748	0.159	0.1582	0.0068	0.165
16	800	1.958	0.999	7.4	0.7091	0.162	0.1618	0.0072	0.169
17	799	1.971	1.006	20.9	0.7507	0.152	0.1514	0.0076	0.159
18	803	1.966	1.004	72.5	0.9249	0.120	0.1197	0.0093	0.129
19	797	1.966	1.003	21.3	0.7497	0.151	0.1514	0.0076	0.159
20	805	1.961	1.001	54.1	0.8499	0.129	0.1284	0.0086	0.137
21	800	0.985	0.503	26.8	0.5447	0.225	0.2250	0.0110	0.236
22	805	0.983	0.502	138.3	0.7696	0.174	0.1735	0.0155	0.189
23	803	0.979	0.500	51.0	0.5822	0.210	0.2102	0.0118	0.222
24	805	0.995	0.508	93.4	0.6771	0.190	0.1895	0.0135	0.203
25	805	0.485	0.247	19.9	0.3521	0.319	0.3186	0.0144	0.333
26	797	0.490	0.250	37.5	0.3735	0.309	0.3099	0.0151	0.325
27	803	0.490	0.250	176.4	0.5258	0.257	0.2567	0.0213	0.278
28	803	0.490	0.250	69.3	0.4153	0.304	0.3042	0.0168	0.321
29	800	0.488	0.249	186.8	0.5487	0.266	0.2657	0.0223	0.288

Table 7-2
SYSTEM CONDITIONS FOR SINGLE-PHASE HEAT TRANSFER RUNS
SIMULATED SWELLED HEATER

Run Number	Inlet Temperature T_1 (°F)	Outlet Temperature T_2 (°F)	Test Section ΔT (°F)	Pressure P3 (psi)	kW Input	Mass Flow (lb/sec)	Inlet Mass Flux (lb/h-ft ²)	Average Heat Flux (Btu/h-ft ²)
1	104.7	137.1	32.4	1025	108.7	2.9454	1503382	300356
2	110.3	142.9	32.7	1005	109.6	2.9377	1499461	303010
3	121.7	162.0	40.3	1015	109.1	2.3947	1222325	301517
4	104.0	152.0	48.0	1038	107.6	1.9813	1011290	297537
5	103.6	170.7	67.2	1015	109.0	1.4411	735584	301186
6	87.2	183.2	95.9	1000	110.3	0.9885	504561	305000
7	88.7	156.2	67.4	1015	108.6	1.4309	730388	300190
8	92.6	142.5	49.9	1005	109.0	1.9121	975956	301186
9	89.8	129.5	39.7	1000	109.4	2.3948	1222374	302512
10	93.5	125.8	32.3	1000	109.3	2.9419	1501609	302181
11	94.8	149.0	54.2	1015	179.6	2.9405	1500892	496392
12	100.6	167.3	66.7	1045	181.4	2.4169	1233658	501368
13	103.8	188.2	84.4	1060	181.7	1.9095	974664	502197
14	202.4	235.1	32.7	1015	108.7	2.9649	1513361	300356
15	199.1	238.8	39.7	1049	109.4	2.4774	1264529	302512
16	202.2	252.9	50.7	1030	109.7	1.9652	1003086	303342
17	202.0	267.5	65.5	1035	109.3	1.4663	748418	302181
18	206.8	261.3	54.5	1085	182.0	2.9641	1512951	503192
19	203.9	268.1	64.2	995	181.0	2.4712	1261367	500207
20	205.5	287.5	82.1	1015	179.7	1.9422	991366	496724
21	200.7	211.0	10.3	1013	36.2	2.9649	1513356	100008
22	197.4	210.3	12.9	1011	36.2	2.4576	1254416	100174
23	198.5	214.7	16.2	1015	36.7	1.9539	997322	101501
24	198.3	220.4	22.1	1015	37.0	1.4558	743067	102830
26	303.2	354.4	51.1	1025	181.3	2.9579	1509771	501202
27	308.5	339.3	30.8	1027	109.4	2.9516	1506551	302512
28	304.8	341.5	36.7	1019	109.0	2.4753	1263428	301186
29	304.3	349.0	44.7	1047	109.2	1.9871	1014273	301849
30	299.7	360.3	60.6	1045	108.4	1.4951	763113	299693
31	300.4	311.6	11.3	1037	36.5	2.9621	1511928	100837
32	299.7	312.1	12.4	1039	36.5	2.4758	1263693	101003
33	298.1	312.5	14.4	1043	36.5	1.9822	1011756	101003
34	294.8	315.0	20.1	1041	36.4	1.4917	761390	100672
36	392.7	421.7	29.0	1005	109.7	2.9881	1525171	303176
37	391.6	427.0	35.4	1013	109.4	2.4756	1263609	302346
38	496.0	504.8	8.8	1017	36.6	2.9010	1480739	101169
39	493.1	503.7	10.6	1025	36.8	2.3714	1210410	101667

TcNo	α	L'	L	TcNo	α	L'	L
1	0	3.25	0.25	16	0	1.0	2.50
2	180	3.25	0.25	17	0	0.8	2.70
3	0	2.8	0.70	18	0	0.6	2.90
4	90	2.8	0.70	19	0	0.4	3.10
5	120	2.8	0.70	20	0	0.2	3.30
6	-	-	-	21	-	-	-
7	0	2.4	1.10	22	180	0.2	3.30
8	0	2.2	1.30	23	0	3.5	7.00
9	0	2.0	1.50	24	90	3.5	7.00
10	0	1.65	1.85	25	180	3.5	7.00
11	90	1.65	1.85				
12	180	1.65	1.85				
13	270	1.65	1.85				
14	0	1.2	2.30				
15	180	1.2	2.30				

Figure 7-1. Details of Swollen Heater

Figure 7-2. Steady-State CHF for a Swollen Heater, 800 psi

Figure 7-3. Steady-State CHF for a Swollen Heater, 1000 psi

Figure 7-4. Composite Heat Transfer Data Upstream of Swell (TC 23)

Figure 7-5. Heat Transfer Data 3 Inches Upstream of Swell (TC 23) By Heat Flux

Figure 7-6. Axial Heat Transfer Coefficients for Swell at Zero Degree

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Figure 7-7. Heat Transfer Variation at Swell Extremes

8. STEADY-STATE DATA CORRELATION AND ANALYSIS

8.1 CORRELATION (B. S. Shiralkar)

Steady-state CHF correlations, primarily used for reactor design, have been found to yield quite accurate predictions of CHF resulting from flow, pressure, and power transients. The MAYU-2 code, developed on this project for transient CHF analysis, has used steady-state correlations with success for flow and pressure transients as previously reported.* Additional application of the code and correlations, including the 16-rod transient results reported here, is contained in the final transient topical report** for the work performed to date on this project.

CHF correlations using the heat flux—quality coordinates have been used successfully. Another correlation found useful here and by other investigators† is the local critical quality—boiling length ($x_c - L_b$) plane. This is particularly useful in that it can be used for correlation of data for a test section with different axial heat flux shapes.

The one-, and nine-rod uniform axial heat flux and 16-rod cosine axial heat flux data taken on this project at 1000 psi are shown on an $x_c - L_b$ plane in Figure 8-1. A single curve can be seen, to provide an acceptable correlation at a given mass flux for both the nine-rod 6-foot uniform axial heat flux and 16-rod 12-foot cosine axial flux. One of the reasons for this is that these two test sections, having much different axial length and heat flux shapes, have almost identical values for the ratio of heated perimeter to flow area, or thermal equivalent diameter. The latter is common to the heat balance for both test sections. The one-rod test section, having a much different thermal equivalent diameter, is correlated by a different curve at a given mass flux.

The dotted lines in Figure 8-1 are a plot of the following correlating Equation, (8-1).

Sixteen-Rod (12-foot cosine axial heat flux)

$$x_c = \frac{AL_b}{L_b + B}, \quad \left(1000 \text{ psi, and } 0.25 < \frac{G}{10} < 1.0 \right), \quad (8-1)$$

where

- x_c = Average weight fraction of steam at the axial CHF location,
- L_b = Boiling length (inches), from "equilibrium" inception of boiling to the axial CHF location,

$$A = 0.961 - 0.813 (G/10^6) + 0.34 (G/10^6)^2, \quad (8-2)$$

with G , mass flux in lb/h-ft^2 , and

$$B = 11.52 + 35.45 (G/10^6). \quad (8-3)$$

* P.A. 55 8th Quarterly Report, GEAP-10221-8
 P.A. 55 9th Quarterly Report, GEAP-10221-9
 P.A. 55 Topical Report, *The Analysis of Transient Critical Heat Flux*, GEAP-13249

** P. A. 55 Topical Report, *Transient CHF—Experimental Results*, GEAP-13295

† Bertolotti, S., et al., "Heat Transfer Crisis with Steam-Water Mixtures," *Energia Nucleare*, 12, 3, March 1965.

Figure 8-1. Nine- and 16-Rod Critical Quality versus Boiling Length, 1000 psi

Corresponding equations in the flux-quality plane, used in GEAP-13295 for one-rod and nine-rod analysis, contain additional terms for variation of CHF with pressure, for depressurization runs, and are shown as follows.

One-Rod (9-foot uniform axial heat flux)

$$\frac{q''_c}{10^6} = B(G,P) - M(G,P) x_c \cdot \left\{ \begin{array}{l} 800 \text{ psi} < P < 1000 \text{ psi} \\ 0.25 < \frac{G}{10^6} < 1.00 \end{array} \right\} \quad (8-4)$$

$$B(G,P) = 0.7074 + 3.355 \left(\frac{G}{10^6} \right) - 4.5032 \left(\frac{G}{10^6} \right)^2 + 1.9047 \left(\frac{G}{10^6} \right)^3 \\ - \left[0.4495 - 0.4018 \left(\frac{G}{10^6} \right) \right] \left(\frac{P-800}{200} \right) \quad (8-5)$$

$$M(G,P) = 0.4029 - 18.5223 \left(\frac{G}{10^6} \right) + 22.6713 \left(\frac{G}{10^6} \right)^2 - 9.3266 \left(\frac{G}{10^6} \right)^3 \\ + \left[1.8916 - 1.8590 \left(\frac{G}{10^6} \right) \right] \left(\frac{P-800}{200} \right) \quad (8-6)$$

where

- q''_c = CHF, Btu/h-ft²,
- x_c = average weight fraction of steam at the CHF location,
- G = mass flux, Btu/h-ft², and
- P = system pressure, psi.

Nine-Rod (6-foot uniform axial heat flux)

$$\frac{q''_c}{10^6} = B(G,P) - M(G,P) x_c \cdot \left\{ \begin{array}{l} 800 \text{ psi} < P < 1000 \text{ psi} \\ 0.25 < \frac{G}{10^6} < 1.00 \end{array} \right\} \quad (8-7)$$

$$B(G,P) = 1.0693 - 0.3831 \left(\frac{G}{10^6} \right) + 0.4096 \left(\frac{G}{10^6} \right)^2 + \\ + \left[-0.2429 + 0.0635 \left(\frac{G}{10^6} \right) + 0.0618 \left(\frac{G}{10^6} \right)^2 \right] \left(\frac{P-800}{200} \right) \quad (8-8)$$

$$M(G,P) = 0.9749 + 0.3618 \left(\frac{G}{10^6} \right) + 0.2467 \left(\frac{G}{10^6} \right)^2 + \\ - \left[0.1303 + 1.2879 \left(\frac{G}{10^6} \right) - 1.3472 \left(\frac{G}{10^6} \right)^2 \right] \left(\frac{P-800}{200} \right) \quad (8-9)$$

with nomenclature as above.

8.2 ANALYSIS

A preliminary correlation for CHF in the annular flow regime was derived by using a heat balance, and dimensional analysis with the principal properties and test conditions assumed to control the liquid entrainment mechanism. Details are shown in Appendix B.

APPENDIX A

ABSTRACTS OF QUARTERLY AND TOPICAL REPORTS

Quarterly Progress Reports

Abstract

First, July-September 1969:	Test planning and design of one-rod tests. Analysis of time lags in orifice pressure drop output data.
Second, October-December 1969:	Planning of one- and nine-rod tests. Calrod heater procurement. Analysis of pressure transducer transient, time lag by a low pass filter, and orifice flowmeter transient.
Third, January-March 1970:	Calrod design. Nine-rod subchannel design and preliminary results.
Fourth, April-June 1970:	Preliminary analysis for MAYU transient code. One-rod exploratory tests. Analog-digital conversion and TAPER code for reading digital tapes on GE 635 computer.
Fifth, July-September 1970:	Preliminary simplified transient results by MAYU code. Nine-rod subchannel equipment installation. TAPER code expansion. Transient flow analysis for exponential ΔP decay in orifice output.
Sixth, October-December 1970:	Nine-rod subchannel data with single-phase water.
Seventh, January-March 1971:	Nine-rod single- and two-phase subchannel data. One-rod transient flow and film boiling data.
Eighth, April-June 1971:	One-rod transient flow and depressurization data. Analysis of transient pressure by MAYU. Freon, void fraction transient data, and MAYU prediction. CHF data with bowed one-rod, and one-rod with $1/2$ sin axial flux variation.
Ninth, July-September 1971:	Nine-rod steady-state CHF data. Nine-rod transient flow and depressurization. Improved MAYU-2 using time-history input of flow, pressure, and heat flux.
Tenth, October-December 1971:	Nine-rod steady-state CHF data with various bows and clearances at 800 and 1000 psi. Summary tabulation of nine-rod transient flow and depressurization runs.
Eleventh, January-March 1972:	Description of ATLAS 8600-kW facility test section, and 16-rod test bundle. Redesign of one-rod swell test shown.
Twelfth, April-June 1972:	Sixteen-rod axial cosine heat flux steady-state CHF results with uniform radial clearances and heat flux, and with a bow and reduced corner clearance in a corner rod. Sixteen-rod transient flow and simultaneous transient flow and power with plots of typical runs. Heat transfer results with a one-rod simulated local swell.

Topical Reports

1. Lahey, R. T., Jr., Shiralkar, B. S., Radcliffe, D. W., Polomik, E. E., "Out-of-Pile Subchannel Measurements in a 9-Rod Bundle for Water at 1000 psia," Paper 3-1, International Symposium on Two-Phase Flow, Haifa, Israel, August 1971.
2. Lahey, R. T., Jr., Shiralkar, B. S., "Transient Flow Measurements with Sharp-Edged Orifices," November 1970, (ASME 71-FE-30).
3. Lahey, R. T., Jr., Shiralkar, B. S., Gonzalez, J. M., Schnebly, L. E., "The Analysis of Transient Critical Heat Flux," AEC AT(04-3)-189, P. A. 55, February 1972, (GEAP-13249).
4. Shiralkar, B. S., Polomik, E. E., Lahey, R. T., Jr., Gonzalez, J. M., Radcliffe, D. W., Schnebly, L. E., Transient CHF-Experimental Results, (GEAP-13295), under final stages of completion and expected to be distributed in October 1972.
5. Gonzalez, J. M., Lahey, R. T., Jr., "An Exact Solution of Flow Decay Transients in Two-Phase Systems by the Method of Characteristics," accepted for presentation at ASME Annual Winter Meeting, 1972.
6. GEAP-10221-A, -B, -C, -D are documentation numbers for microfilm of transient data as specified in Section 4.

APPENDIX B

STEADY-STATE CHF ANALYSIS

(E. E. Polomik)

A preliminary correlation for CHF in the annular flow regime with uniform axial heat flux is derived using a heat balance, and dimensional analysis with the principal properties and test conditions assumed to control the liquid entrainment mechanism.

The mechanism, which is assumed to have a controlling influence on CHF occurrence in a flowing boiling mixture, is the continual entrainment of liquid by the vaporized gas. As the mixture moves along the heater passage, a condition is reached where almost all of the unvaporized liquid is broken up and entrained with the vapor. When that condition is reached, cooling of the heated wall becomes unsteady and CHF is indicated by erratic oscillations in the temperature of the heated wall.

A schematic illustration of the boiling system and nomenclature used is shown in Figure B-1. The inset of the figure shows the test variables and coolant properties that are assumed to control the rate of flow of entrained liquid, W_e . These are:

- ΔV , the slip difference or average relative velocity between the gas and the liquid at the interface;
- V_b , the average velocity at which gas is passing through the coolant mixture;
- ℓ , the boiling length over which entrainment has occurred; and
- σ, ρ_f , the surface tension and density, respectively, of the liquid.

The controlling variables are arranged for dimensional analysis in the form,

$$W_e = k V_b^a \sigma^b \rho_f^c (\Delta V)^d \ell^e K^f, \quad (B-1)$$

where k is the dimensional work/heat relationship. With the M, L, Θ (time), H (heat) dimensional system, Equation (B-1) results in

$$\begin{array}{ll} a = a & d = 2c - a - 1 \\ b = 1 - c & e = 1 + c \\ c = c & f = 0, \end{array} \quad \text{and} \quad (B-2)$$

$$W_e = k \left(\frac{V_b}{\Delta V} \right)^a \left(\frac{\rho_f \Delta V^2 \ell}{\sigma} \right)^c \left(\frac{\sigma \ell}{\Delta V} \right).$$

In this preliminary analysis it will be assumed* the slip ratio, S , is constant and equal to

$$S = \frac{V_g}{V_f} = \left(\frac{\rho_f}{\rho_g} \right)^{1/3} = \beta^{1/3}, \quad (B-3)$$

where ρ_g is the vapor density, and V_g and V_f are the mass mean velocities of the gas and liquid.

* Polomik, ASME 65HT-34

Then

$$\Delta V = V_g - V_f = \frac{G}{\rho_f} \left(\beta^{1/3} - 1 \right) \left[1 + x \left(\beta^{2/3} - 1 \right) \right]. \quad (B-4)$$

Also,

$$V_b = \frac{q''}{\rho_g h_{fg}} \quad (B-5)$$

The heat balance over the boiling length is

$$\ell = \frac{GAxh_{fg}}{q''P}, \quad (B-6)$$

where

- G = mass flux,
- A = flow area,
- x = weight fraction vapor,
- h_{fg} = latent heat, and
- P = heated perimeter.

Substituting Equations (B-4), (B-5), and (B-6) into (B-2) and rearranging with

$$\beta_1 = \beta^{1/3} - 1, \text{ and } \beta_2 = \beta^{2/3} - 1$$

yields

$$W_e = k \left\{ \left(\frac{q''}{\rho_g h_{fg}} \right) \frac{1}{\left(\frac{G}{\rho_f} \right) \beta_1 (1+x\beta_2)} \right\}^a \left\{ \left(\frac{G}{\rho_f} \right)^3 \cdot \frac{1}{\left(\frac{q''}{\rho_g h_{fg}} \right)} \cdot [\beta_1 (1+x\beta_2)]^2 \right. \\ \left. \times \frac{1}{\left(\frac{\rho_g \sigma P}{\rho_f^2 A} \right)} \right\}^c \left\{ \left(\frac{\sigma}{\rho_g h_{fg}} \right) \left(\frac{\rho_f}{\rho_g} \right) \left(\frac{A}{P} \right) \frac{x}{(\beta_1) (1+x\beta_2)} \right\} \quad (B-7)$$

In this form, various velocity groups can be identified. The last term, under the (c) exponent, has the dimensions $1/V^2$ and can be associated with the energy involved in overcoming liquid surface tension forces. The frequent occurrence of the liquid/gas density ratios, ρ_f/ρ_g and β_1 and β_2 , indicates why the former has been a useful parameter in modeling CHF.

At CHF conditions, all of the unvaporized liquid is assumed to be entrained and ineffective for steady heat transfer. Then,

$$W_e = W (1 - x_c), \quad (B-8)$$

where the subscript "c" signifies critical heat transfer conditions.

Combining Equations (B-7) and (B-8) and rearranging into flux-quality relationship:

$$q''_c = \left\{ \frac{1}{k} \left[\frac{h_{fg}(\rho_f \sigma)^{(c-1)}}{\left(\frac{\rho_f}{\rho_g}\right)^a} \right] \left[\frac{(P)^{c+1}}{A^c} \right] \left[G^{(a-3c+1)} \left(\frac{1}{x_c}\right)^c \cdot \left(\frac{1-x_c}{x_c}\right) \right. \right. \\ \left. \left. \cdot \left(\beta_1 [1+x_c \beta_2] \right)^{(a-2c+1)} \right] \right\}^{\frac{1}{a-c-1}} \quad (B-9)$$

The general groups in Equation (B-9) are arranged by coolant properties, test section dimensions, and flow conditions. It should be noted there are also some property variations in the last quality group, in β_1 and β_2 . A general constant and two exponential constants must be determined from data.

A few preliminary calculations were made by fitting Equation (B-9) from steam data and then directly predicting CHF data with Freon. The results were encouraging, but Freon data were predicted high, 20 to 25%, in the high quality region where the model would be expected to give best results. Since this work has application to Freon/water modeling of the CHF phenomena, it is anticipated that it will be continued in future program tasks.

APPENDIX C

HEAT TRANSFER DATA FOR A SIMULATED SWELL

Typical trends for the single-phase heat transfer results for the simulated swelled heater are presented and discussed in Section 7 of this report. Complete reduction of all the data was done and is presented below.

The runs are presented in groups of tabulations by numerical sequence, with the following interpretation of column headings. Runs 25 and 35 were defective and not shown.

PRESS = psi

W AVG = Total flow, lb/sec

G AVG = mass flux, lb/h-ft²

Q/A AVG = heat flux, Btu/h-ft²

- L(I) = Dimension L, inches, in coordinates of figures in Section 7, with successive rows in numerical order of the thermocouples as in Figure 7-1
- T(I) = Temperature, °F, of each thermocouple
- T4 = Bulk temperature, °F, of water
- G(I) = Local mass flux, lb/h-ft²
- HME = Heat transfer coefficient, Btu/h-ft²-°F, calculated from measured temperatures
- HCA = Heat transfer coefficient, Btu/h-ft²-°F, predicted by Colburn equation
- NU/Pr^{1/3} = Local Nusselt number/(Prandtl number)^{1/3}, calculated from measured values
- NU(I) = Local Nusselt number, calculated from measured values

RUN PRESS W AVG G AVG Q/A AVG

1.	1025.	2.9454	1503400.	300356.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ³	NU(I)
.25	307.4	137.2	1504609.	2267.	2208.	126813.	285.5	350.5
.25	309.2	137.2	1504609.	2234.	2215.	127623.	282.0	345.5
.70	323.4	137.1	1527220.	2116.	2272.	128447.	261.8	318.8
.70	323.4	137.1	1527220.	2116.	2272.	128447.	261.8	318.8
.70	320.7	137.1	1527220.	2161.	2261.	127240.	266.5	325.7
1.10	295.9	136.9	1665367.	2419.	2448.	117035.	257.8	318.7
1.30	277.8	136.9	1859121.	2659.	2714.	108115.	239.9	300.0
1.50	282.2	136.8	2133464.	2440.	3206.	107735.	185.8	229.2
1.85	284.5	136.6	2283878.	2357.	3479.	107475.	165.1	202.4
1.85	287.5	136.6	2283878.	2300.	3498.	108672.	161.6	197.5
1.85	288.0	136.6	2283878.	2292.	3501.	108843.	161.1	196.8
1.85	281.4	136.6	2283878.	2417.	3460.	106281.	168.7	207.7
2.30	298.1	136.4	2283878.	2119.	3563.	112747.	150.5	181.6
2.30	300.4	136.4	2283878.	2085.	3576.	113608.	148.5	178.7
2.50	289.8	136.3	2133467.	2283.	3248.	110599.	175.2	214.1
2.70	286.7	136.2	1859124.	2445.	2756.	111444.	222.6	275.4
2.90	300.4	136.1	1665369.	2323.	2462.	118382.	248.4	306.0
3.10	314.1	136.0	1567513.	2193.	2320.	124272.	258.7	316.9
3.30	318.9	136.0	1527220.	2172.	2249.	125934.	267.0	327.5
3.30	334.0	136.0	1527220.	1940.	2309.	132784.	242.4	291.9
7.00	307.4	134.8	1504609.	2218.	2200.	125871.	278.8	343.2
7.00	310.5	134.8	1504609.	2165.	2212.	127286.	273.0	334.7
7.00	320.7	134.8	1504609.	2006.	2252.	131960.	255.7	309.7

2.	1005.	2.9377	1499470.	303010.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ³	NU(I)
.25	312.7	140.4	1500676.	2253.	2236.	130231.	288.3	348.0
.25	315.8	140.4	1500676.	2198.	2248.	131652.	280.3	339.4
.70	330.0	140.3	1523228.	2083.	2305.	132468.	260.3	313.4
.70	330.0	140.3	1523228.	2083.	2305.	132468.	260.3	313.4
.70	328.2	140.3	1523228.	2111.	2298.	131662.	263.3	317.7
1.10	303.0	140.1	1661014.	2365.	2488.	121068.	254.8	311.1
1.30	285.3	140.0	1854261.	2583.	2762.	112130.	235.8	290.8
1.50	286.7	139.9	2127887.	2439.	3243.	110389.	187.3	228.8
1.85	290.6	139.8	2282894.	2324.	3529.	110770.	164.4	199.3
1.85	292.4	139.8	2282894.	2292.	3540.	111456.	162.4	196.6
1.85	289.3	139.8	2282894.	2348.	3521.	110256.	165.9	201.5
1.85	284.5	139.8	2282894.	2442.	3491.	108375.	171.6	209.7
2.80	303.9	139.5	2282894.	2100.	3609.	115871.	150.6	179.8
2.30	307.0	139.5	2282894.	2055.	3627.	117076.	147.8	175.9
2.50	294.6	139.4	2127890.	2275.	3287.	113432.	176.1	213.2
2.70	292.0	139.3	1854264.	2427.	2792.	114554.	222.9	273.0
2.90	306.1	139.3	1661015.	2299.	2495.	121823.	248.2	302.4
3.10	319.4	139.2	1563415.	2180.	2349.	127618.	259.4	314.6
3.30	324.7	139.1	1523228.	2152.	2279.	129523.	267.0	324.0
3.30	339.7	139.1	1523228.	1926.	2338.	136378.	242.8	289.4
7.00	313.2	138.0	1500676.	2197.	2229.	129485.	278.8	339.5
7.00	317.6	138.0	1500676.	2124.	2247.	131515.	270.7	327.9
7.00	326.9	138.0	1500676.	1984.	2283.	135789.	255.4	306.0

RUN PRESS W AVG G AVG Q/A AVG

3.	1015.	2.3947	1222310.	301517.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ³	NU(I)
.25	344.6	155.7	1223293.	1965.	2051.	124171.	262.1	301.9
.25	347.3	155.7	1223293.	1929.	2059.	125151.	257.9	296.3
.70	359.7	155.5	1241677.	1851.	2105.	125140.	242.1	277.2
.70	360.6	155.5	1241677.	1840.	2107.	125462.	240.8	275.5
.70	358.3	155.5	1241677.	1868.	2101.	124657.	244.0	279.7
1.10	334.0	155.4	1353994.	2067.	2282.	115375.	233.6	270.4
1.30	317.2	155.3	1511522.	2227.	2542.	107525.	213.6	249.2
1.50	322.0	155.2	1734571.	2070.	2992.	106497.	167.4	193.0
1.85	326.9	154.9	1860928.	1975.	3254.	106743.	147.1	168.5
1.85	327.8	154.9	1860928.	1964.	3258.	107018.	146.3	167.5
1.85	326.0	154.9	1860928.	1987.	3250.	106469.	147.8	169.5
1.85	321.1	154.9	1860928.	2054.	3227.	104952.	152.2	175.3
2.30	338.0	154.7	1860928.	1835.	3304.	110093.	138.0	156.4
2.30	340.2	154.7	1860928.	1810.	3313.	110769.	136.3	154.2
2.50	328.2	154.5	1734574.	1972.	3018.	108348.	160.3	183.8
2.70	325.6	154.4	1511525.	2079.	2571.	110065.	200.8	232.5
2.90	338.9	154.3	1353996.	1988.	2293.	116569.	225.3	259.9
3.10	352.6	154.2	1274436.	1882.	2159.	122104.	235.3	270.2
3.30	356.6	154.2	1241677.	1872.	2091.	123522.	243.8	280.4
3.30	373.8	154.2	1241677.	1675.	2142.	129766.	221.5	250.6
7.00	345.9	152.8	1223293.	1903.	2047.	123703.	253.5	292.4
7.00	349.9	152.8	1223293.	1853.	2059.	125175.	247.7	284.6
7.00	359.7	152.8	1223293.	1741.	2088.	128746.	234.7	267.1

4.	1038.	1.9813	1011301.	297537.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ³	NU(I)
.25	349.5	140.7	1012114.	1693.	1738.	99835.	223.8	260.3
.25	351.3	140.7	1012114.	1675.	1743.	100381.	221.8	257.5
.70	361.9	140.5	1027324.	1628.	1777.	99904.	210.5	244.0
.70	363.2	140.5	1027324.	1615.	1781.	100308.	209.1	242.0
.70	360.1	140.5	1027324.	1645.	1773.	99364.	212.4	246.6
1.10	337.5	140.3	1120253.	1790.	1929.	92274.	200.2	234.4
1.30	327.3	140.1	1250586.	1834.	2170.	87743.	175.2	205.3
1.50	355.7	140.0	1435130.	1515.	2642.	93114.	124.6	141.1
1.85	357.9	139.7	1539673.	1483.	2861.	92532.	112.0	126.3
1.85	351.3	139.7	1539673.	1535.	2835.	90857.	115.3	130.8
1.85	357.9	139.7	1539673.	1483.	2861.	92532.	112.0	126.3
1.85	350.4	139.7	1539673.	1542.	2832.	90633.	115.8	131.4
2.30	346.8	139.4	1539673.	1570.	2816.	89614.	117.4	133.8
2.30	349.0	139.4	1539673.	1551.	2825.	90178.	116.3	132.2
2.50	335.3	139.3	1435132.	1688.	2564.	87612.	136.2	157.4
2.70	330.9	139.1	1250588.	1782.	2178.	88450.	170.6	199.5
2.90	345.5	139.0	1120254.	1694.	1948.	94142.	190.6	221.7
3.10	360.6	138.9	1054428.	1597.	1838.	99108.	198.4	229.3
3.30	365.0	138.8	1027325.	1581.	1782.	100417.	204.7	236.8
3.30	384.0	138.8	1027325.	1423.	1831.	106148.	187.5	212.9
7.00	357.9	137.2	1012114.	1573.	1752.	101493.	209.0	241.8
7.00	362.8	137.2	1012114.	1531.	1765.	102985.	204.3	235.1
7.00	372.5	137.2	1012114.	1452.	1789.	105947.	195.5	222.9

RUN	PRESS	N AVG	G AVG	Q/A AVG					
5.	1015.	1.4411	735571.	301186.					
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁹³	NU(I)	
.25	563.7	149.6	736162.	750.	1655.	112296.	114.3	116.3	
.25	569.8	149.6	736162.	738.	1660.	113094.	112.7	114.5	
.70	582.9	149.3	747225.	712.	1695.	112874.	106.4	107.9	
.70	579.4	149.3	747225.	718.	1692.	112424.	107.2	108.8	
.70	581.6	149.3	747225.	714.	1694.	112705.	106.7	108.2	
1.10	557.1	149.1	814817.	764.	1854.	105830.	99.1	100.9	
1.30	533.8	148.9	909615.	812.	2073.	99153.	89.4	91.4	
1.50	520.7	148.7	1043843.	838.	2389.	93989.	76.8	78.7	
1.85	511.0	148.3	1119883.	860.	2561.	91365.	71.8	73.8	
1.85	515.4	148.3	1119883.	849.	2567.	91866.	71.1	72.9	
1.85	434.4	148.3	1119883.	1119.	2426.	81191.	89.8	95.4	
1.85	421.2	148.3	1119883.	1164.	2404.	79687.	92.9	99.2	
2.30	401.8	147.9	1119883.	1267.	2356.	76358.	99.7	107.8	
2.30	404.0	147.9	1119883.	1255.	2361.	76713.	98.9	106.8	
2.50	388.0	147.7	1043844.	1355.	2151.	75029.	115.1	126.0	
2.70	382.3	147.5	909616.	1419.	1833.	76132.	143.2	158.2	
2.90	398.7	147.3	814817.	1344.	1639.	81121.	159.5	175.3	
3.10	415.0	147.2	766939.	1268.	1546.	85320.	166.1	181.6	
3.30	418.1	147.0	747225.	1260.	1497.	86274.	172.0	188.3	
3.30	442.1	147.0	747225.	1135.	1534.	90835.	157.6	169.7	
7.00	415.0	144.7	736162.	1237.	1477.	87722.	173.5	189.6	
7.00	420.8	144.7	736162.	1206.	1486.	88852.	169.9	184.9	
7.00	432.8	144.7	736162.	1147.	1504.	91138.	162.9	175.8	

6.	1000.	.9885	504553.	305000.					
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁹³	NU(I)	
.25	460.2	144.5	504959.	1042.	1140.	65881.	150.6	159.9	
.25	462.4	144.5	504959.	1034.	1142.	66141.	149.6	158.6	
.70	465.5	144.0	512547.	1032.	1157.	64929.	145.3	154.4	
.70	470.8	144.0	512547.	1013.	1162.	65548.	142.9	151.5	
.70	466.8	144.0	512547.	1027.	1159.	65085.	144.7	153.7	
1.10	438.1	143.6	558911.	1126.	1259.	60224.	137.1	147.0	
1.30	440.3	143.4	623936.	1100.	1433.	58653.	115.2	122.7	
1.50	562.4	143.1	716008.	749.	1800.	67214.	69.7	70.7	
1.85	506.1	142.6	768166.	868.	1883.	61830.	72.2	74.4	
1.85	505.7	142.6	768166.	869.	1882.	61795.	72.3	74.5	
1.85	518.9	142.6	768166.	837.	1896.	62841.	70.0	71.9	
1.85	507.0	142.6	768166.	866.	1884.	61901.	72.1	74.2	
2.30	465.9	141.9	768166.	983.	1833.	58300.	80.1	83.9	
2.30	469.9	141.9	768166.	970.	1838.	58658.	79.3	82.9	
2.50	451.4	141.6	716009.	1037.	1680.	57722.	91.4	96.6	
2.70	443.8	141.3	623937.	1076.	1435.	58831.	112.9	120.1	
2.90	464.2	141.1	558911.	1013.	1285.	62884.	125.1	132.3	
3.10	482.3	140.9	526070.	957.	1211.	66049.	130.5	137.4	
3.30	490.7	140.7	512547.	931.	1178.	67491.	132.7	139.4	
3.30	520.7	140.7	512547.	846.	1203.	70600.	122.5	127.0	
7.00	487.6	137.4	504959.	922.	1159.	68298.	134.8	141.6	
7.00	494.7	137.4	504959.	901.	1165.	69062.	132.2	138.5	
7.00	508.9	137.4	504959.	862.	1177.	70539.	127.5	132.6	

RUN	PRESS	N AVG	G AVG	Q/A AVG					
7.	1015.	1.4309	730364.	300190.					
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁹³	NU(I)	
.25	386.3	124.3	730952.	1285.	1381.	76690.	173.1	197.3	
.25	388.9	124.3	730952.	1270.	1386.	77269.	171.4	194.8	
.70	394.2	124.0	741936.	1265.	1403.	75798.	166.2	189.4	
.70	397.8	124.0	741936.	1245.	1410.	76561.	164.0	186.3	
.70	395.1	124.0	741936.	1260.	1405.	75989.	165.6	188.6	
1.10	369.9	123.7	809049.	1374.	1524.	70069.	156.1	179.7	
1.30	364.5	123.5	903177.	1374.	1726.	67575.	133.9	153.5	
1.50	469.0	123.4	1036455.	908.	2257.	83427.	80.0	84.5	
1.85	420.4	123.0	1111956.	1062.	2329.	74897.	83.2	90.4	
1.85	415.5	123.0	1111956.	1031.	2317.	74100.	84.4	92.0	
1.85	422.1	123.0	1111956.	1055.	2334.	75184.	82.8	89.8	
1.85	419.5	123.0	1111956.	1065.	2327.	74753.	83.4	90.7	
2.30	391.6	122.5	1111956.	1186.	2253.	69856.	90.8	101.0	
2.30	393.8	122.5	1111956.	1175.	2259.	70243.	90.2	100.1	
2.50	377.8	122.3	1036456.	1263.	2050.	68171.	104.3	117.5	
2.70	371.2	122.1	903178.	1323.	1739.	68634.	129.5	147.7	
2.90	387.1	122.0	809050.	1259.	1557.	73248.	145.0	164.4	
3.10	403.1	121.8	761511.	1192.	1470.	77192.	151.7	170.9	
3.30	409.3	121.7	741936.	1168.	1429.	78638.	155.2	174.8	
3.30	433.6	121.7	741936.	1058.	1472.	83667.	143.4	158.2	
7.00	407.1	119.4	730952.	1145.	1412.	80272.	156.5	175.6	
7.00	410.2	119.4	730952.	1130.	1417.	80928.	154.9	173.3	
7.00	423.0	119.4	730952.	1074.	1440.	83601.	148.7	164.7	

8.	1005.	1.9121	975980.	301186.					
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁹³	NU(I)	
.25	347.7	114.5	976765.	1496.	1614.	87821.	192.1	230.7	
.25	349.0	114.5	976765.	1485.	1617.	88219.	191.0	229.0	
.70	357.9	114.3	991443.	1461.	1645.	87267.	183.2	219.7	
.70	359.2	114.3	991443.	1450.	1648.	87661.	182.2	218.1	
.70	358.3	114.3	991443.	1457.	1646.	87393.	182.8	219.1	
1.10	331.3	114.1	1081126.	1614.	1775.	79759.	174.5	212.2	
1.30	325.6	114.0	1206908.	1611.	2012.	77038.	149.4	180.9	
1.50	382.3	113.9	1385006.	1203.	2569.	39949.	99.0	112.0	
1.85	364.5	113.6	1485898.	1286.	2707.	84506.	95.5	109.7	
1.85	357.9	113.6	1485898.	1325.	2681.	82848.	97.8	113.1	
1.85	365.0	113.6	1485898.	1284.	2708.	84616.	95.4	109.5	
1.85	357.0	113.6	1485898.	1330.	2677.	82626.	98.1	113.5	
2.30	344.2	113.2	1485898.	1412.	2622.	79217.	102.8	120.7	
2.30	348.1	113.2	1485898.	1385.	2639.	80223.	101.2	118.4	
2.50	333.1	113.1	1385008.	1502.	2383.	77174.	117.9	140.5	
2.70	329.1	112.9	1206910.	1570.	2021.	77720.	146.1	176.3	
2.90	345.0	112.8	1081127.	1489.	1813.	83197.	163.1	195.4	
3.10	360.1	112.7	1017601.	1411.	1712.	87722.	170.7	203.2	
3.30	365.4	112.6	991444.	1390.	1662.	89097.	175.4	208.8	
3.30	384.9	112.6	991444.	1265.	1714.	94370.	162.7	189.7	
7.00	359.2	110.9	976765.	1379.	1637.	90341.	178.7	212.5	
7.00	364.1	110.9	976765.	1347.	1650.	91802.	175.4	207.4	
7.00	373.3	110.9	976765.	1286.	1675.	94718.	169.1	197.9	

RUN PRESS W AVG G AVG Q/A AVG

9.	1000.	2.3943	1222361.	302512.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁵	NU(I)
.25	317.2	103.8	1223344.	1691.	1790.	94378.	207.4	262.6
.25	318.5	103.8	1223344.	1677.	1794.	94859.	206.1	260.4
.70	329.6	103.7	1241728.	1633.	1831.	94456.	196.0	247.2
.70	333.1	103.7	1241728.	1599.	1843.	95734.	192.8	242.0
.70	330.4	103.7	1241728.	1624.	1834.	94775.	195.2	245.9
1.10	303.9	103.5	1354051.	1802.	1976.	86392.	186.6	238.7
1.30	294.6	103.4	1511585.	1833.	2227.	82486.	162.3	207.4
1.50	323.8	103.3	1734644.	1510.	2758.	90292.	116.0	141.6
1.85	325.1	103.1	1861005.	1435.	2988.	89800.	104.8	127.4
1.85	318.9	103.1	1861005.	1532.	2956.	87845.	107.5	131.6
1.85	322.9	103.1	1861005.	1501.	2977.	89101.	105.8	128.9
1.85	316.7	103.1	1861005.	1550.	2944.	87149.	108.5	133.2
2.30	313.2	102.8	1861005.	1578.	2923.	85903.	110.0	135.7
2.30	316.3	102.8	1861005.	1553.	2940.	86875.	108.6	133.4
2.50	302.6	102.7	1734646.	1688.	2650.	83340.	126.7	158.9
2.70	299.5	102.6	1511588.	1769.	2245.	83796.	157.3	200.0
2.90	314.5	102.5	1354052.	1682.	2012.	89541.	176.0	222.3
3.10	328.7	102.4	1274489.	1598.	1899.	94248.	184.7	231.8
3.30	333.5	102.3	1241729.	1580.	1841.	95498.	190.3	239.1
3.30	352.6	102.3	1241729.	1425.	1907.	102453.	175.2	214.8
7.00	326.0	100.9	1223344.	1574.	1312.	96721.	194.5	244.2
7.00	329.6	100.9	1223344.	1543.	1324.	98013.	191.5	239.2
7.00	340.2	100.9	1223344.	1458.	1861.	101940.	183.0	225.6

10.	1000.	2.9419	1501614.	302181.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁵	NU(I)
.25	299.5	102.3	1502821.	1876.	2030.	107360.	225.0	292.6
.25	301.7	102.3	1502821.	1848.	2039.	108313.	222.3	288.2
.70	313.6	102.2	1525405.	1790.	2083.	108168.	210.5	272.1
.70	315.4	102.2	1525405.	1770.	2090.	108929.	208.6	268.9
.70	313.2	102.2	1525405.	1796.	2081.	107978.	211.0	272.9
1.10	286.7	102.0	1663388.	2005.	2241.	98321.	203.0	266.7
1.30	272.1	102.0	1855912.	2116.	2499.	91900.	182.1	240.9
1.50	284.5	101.9	2130929.	1878.	3007.	94963.	137.8	177.5
1.85	289.3	101.7	2286158.	1799.	3284.	95885.	121.8	155.4
1.85	288.4	101.7	2286158.	1809.	3278.	95555.	122.4	156.3
1.85	288.4	101.7	2286158.	1809.	3278.	95555.	122.4	156.3
1.85	280.9	101.7	2286158.	1896.	3230.	92778.	127.1	164.0
2.30	291.5	101.5	2286158.	1773.	3297.	96620.	120.3	153.1
2.30	294.2	101.5	2286158.	1745.	3314.	97614.	118.8	150.6
2.50	282.7	101.4	2130932.	1891.	2995.	94182.	138.4	178.8
2.70	279.6	101.3	1856915.	1997.	2534.	94503.	173.2	226.9
2.90	294.2	101.2	1663390.	1899.	2270.	100842.	193.7	252.2
3.10	307.9	101.1	1565650.	1805.	2141.	105998.	203.2	263.0
3.30	312.3	101.0	1525406.	1792.	2073.	107161.	210.1	272.4
3.30	330.0	101.0	1525406.	1607.	2147.	114849.	192.3	243.4
7.00	303.0	99.9	1502821.	1800.	2036.	108031.	216.3	280.6
7.00	304.8	99.9	1502821.	1779.	2043.	108795.	214.3	277.4
7.00	315.8	99.9	1502821.	1662.	2089.	113631.	202.8	258.5

RUN PRESS W AVG G AVG Q/A AVG

11.	1015.	2.9405	1500899.	496392.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁵	NU(I)
.25	411.9	106.1	1502106.	1987.	2381.	147870.	262.5	305.6
.25	416.8	106.1	1502106.	1946.	2399.	150096.	258.3	299.1
.70	436.3	105.8	1524679.	1859.	2464.	151654.	242.1	278.5
.70	438.1	105.8	1524679.	1846.	2471.	152447.	240.7	276.4
.70	435.9	105.8	1524679.	1862.	2463.	151455.	242.4	279.0
1.10	396.4	105.6	1662597.	2067.	2648.	137223.	231.3	270.7
1.30	369.0	105.5	1856028.	2238.	2920.	125346.	211.2	250.8
1.50	362.8	105.3	2129915.	2222.	3400.	121371.	175.5	207.6
1.85	361.4	105.0	2285070.	2206.	3671.	119882.	159.8	188.6
1.85	369.0	105.0	2285070.	2133.	3715.	122810.	155.6	182.3
1.85	358.3	105.0	2285070.	2237.	3653.	118676.	161.6	191.4
1.85	359.2	105.0	2285070.	2228.	3658.	119020.	161.0	190.6
2.30	396.4	104.6	2285070.	1898.	3868.	133363.	142.1	161.8
2.30	399.5	104.6	2285070.	1875.	3884.	134533.	140.8	159.8
2.50	383.6	104.5	2129918.	2015.	3510.	129539.	162.4	187.9
2.70	380.0	104.3	1856031.	2117.	2967.	129445.	201.8	237.0
2.90	401.3	104.2	1662598.	2021.	2657.	138227.	226.7	264.6
3.10	420.4	104.1	1564905.	1935.	2503.	145038.	239.4	277.9
3.30	429.2	104.0	1524680.	1901.	2432.	147574.	245.4	284.9
3.30	452.7	104.0	1524680.	1730.	2515.	158057.	228.2	258.9
7.00	411.5	102.1	1502106.	1952.	2368.	146180.	256.8	300.1
7.00	416.4	102.1	1502106.	1912.	2386.	148412.	252.8	293.9
7.00	427.0	102.1	1502106.	1831.	2423.	153252.	244.5	281.2

12.	1045.	2.4169	1233641.	501368.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁵	NU(I)
.25	455.8	167.5	1234633.	2164.	2310.	158027.	310.7	331.8
.25	454.4	167.5	1234633.	2178.	2308.	157631.	312.4	333.9
.70	479.5	167.2	1253187.	2014.	2374.	159865.	284.0	301.3
.70	479.2	167.2	1253187.	2018.	2373.	159740.	284.5	301.9
.70	476.1	167.2	1253187.	2046.	2367.	158856.	287.9	306.0
1.10	438.5	166.9	1366547.	2258.	2573.	147076.	276.1	296.0
1.30	408.8	166.7	1525535.	2499.	2855.	135843.	257.3	278.6
1.50	404.4	166.6	1750652.	2457.	3322.	131411.	211.7	228.5
1.85	407.	166.2	1878179.	2383.	3598.	130680.	188.7	202.9
1.85	415.9	166.2	1878179.	2290.	3626.	132851.	182.3	195.0
1.85	405.3	166.2	1878179.	2409.	3590.	130099.	190.5	205.1
1.85	401.8	166.2	1878179.	2452.	3578.	129160.	193.4	208.7
2.30	439.0	165.7	1878179.	2060.	3697.	138464.	166.3	175.7
2.30	443.4	165.7	1878179.	2023.	3710.	139499.	163.7	172.5
2.50	425.	165.5	1750654.	2207.	3386.	136306.	192.6	205.4
2.70	419.0	165.3	1525537.	2359.	2380.	138325.	244.2	263.0
2.90	439.8	165.2	1366548.	2248.	2569.	146613.	273.4	293.4
3.10	461.1	165.0	1286250.	2123.	2418.	153683.	284.7	304.2
3.30	469.0	164.9	1253188.	2092.	2347.	156093.	292.7	312.8
3.30	496.0	164.9	1253188.	1862.	2401.	163728.	264.7	278.8
7.00	482.2	162.6	1234633.	2145.	2294.	155687.	306.4	328.7
7.00	458.9	162.6	1234633.	2081.	2308.	157695.	298.5	319.0
7.00	470.8	162.6	1234633.	1975.	2332.	161200.	285.4	303.0

RUN	PRESS	N AVG	G AVG	Q/A AVG				
13.	1069.	1.9095	974653.	502197.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁹³	NU(I)
.25	507.4	181.7	975437.	1834.	2012.	139120.	273.0	282.5
.25	511.0	181.7	975437.	1809.	2016.	139784.	269.7	278.7
.70	529.9	181.4	990095.	1722.	2061.	139847.	251.4	259.0
.70	532.5	181.4	990095.	1705.	2064.	140325.	249.2	256.6
.70	528.1	181.4	990095.	1734.	2058.	139527.	252.8	260.7
1.10	488.1	181.0	1079656.	1924.	2242.	129650.	242.9	252.1
1.30	461.1	180.8	1205267.	2077.	2503.	121186.	222.6	232.3
1.50	468.6	180.6	1383123.	1955.	2930.	118849.	176.2	182.6
1.85	473.1	180.1	1483877.	1898.	3170.	117908.	157.1	162.5
1.85	477.0	180.1	1483877.	1869.	3177.	118537.	155.1	160.1
1.85	473.9	180.1	1483877.	1892.	3171.	118049.	158.7	161.9
1.85	466.3	180.1	1483877.	1945.	3157.	116917.	160.5	166.3
2.30	498.2	179.6	1483877.	1725.	3216.	121741.	144.4	148.1
2.30	501.7	179.6	1483877.	1704.	3222.	122270.	142.9	146.3
2.50	478.8	179.3	1383125.	1865.	2947.	120399.	168.8	174.4
2.70	471.2	179.1	1205263.	1976.	2517.	122694.	212.6	221.2
2.90	493.3	173.8	1079657.	1879.	2245.	129941.	237.4	246.2
3.10	514.9	178.7	1016217.	1778.	2110.	135803.	247.6	256.0
3.30	523.	178.5	990096.	1744.	2049.	133173.	253.5	262.1
3.30	553.6	173.5	990096.	1566.	2065.	143540.	230.7	236.1
7.00	508.8	175.6	975437.	1776.	2007.	138357.	263.9	273.4
7.00	515.4	175.6	975437.	1732.	2015.	139610.	258.2	266.9
7.00	526.	175.6	975437.	1664.	2028.	141648.	249.3	256.7

14.	1015.	2.9649	1513353.	300356.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁹³	NU(I)
.25	387.1	247.8	1514570.	2969.	2808.	207473.	436.0	456.2
.25	391.1	247.8	1514570.	2848.	2816.	208741.	419.0	437.7
.70	406.6	247.6	1537331.	2598.	2879.	208891.	374.3	389.7
.70	408.0	247.6	1537331.	2566.	2881.	209297.	369.8	384.9
.70	405.3	247.6	1537331.	2632.	2876.	208485.	378.8	394.7
1.10	382.7	247.4	1676393.	2952.	3150.	196034.	369.4	386.2
1.30	361.4	247.2	1871430.	3448.	3517.	183404.	366.3	385.2
1.50	349.0	247.1	2147589.	3766.	4051.	173669.	332.5	350.8
1.85	341.2	246.9	2304031.	4082.	4341.	168755.	328.7	347.9
1.85	344.6	246.9	2304031.	3891.	4353.	169786.	314.0	331.7
1.85	340.2	246.9	2304031.	4133.	4337.	168496.	332.7	352.2
1.85	337.1	246.9	2304031.	4321.	4326.	167581.	347.2	368.2
2.30	364.5	246.6	2304031.	3066.	4418.	175305.	250.1	261.7
2.30	366.8	246.6	2304031.	2997.	4425.	175902.	244.7	255.9
2.50	364.1	246.5	2147592.	3128.	4096.	177822.	278.3	291.6
2.70	364.2	246.4	1871432.	3315.	3521.	183879.	352.4	370.3
2.90	376.9	246.2	1676395.	3124.	3133.	193753.	389.3	408.4
3.10	388.0	246.1	1577890.	2981.	2934.	200906.	408.4	428.0
3.30	396.0	246.1	1537331.	2853.	2854.	205031.	408.3	427.4
3.30	410.2	246.1	1537331.	2485.	2882.	209436.	358.3	372.9
7.00	381.4	244.4	1514570.	3040.	2790.	204567.	444.3	466.8
7.00	384.0	244.4	1514570.	2954.	2796.	205440.	432.4	453.7
7.00	392.9	244.4	1514570.	2700.	2813.	208294.	397.0	415.0

RUN	PRESS	N AVG	G AVG	Q/A AVG				
15.	1049.	2.4774	1264522.	302512.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	406.6	229.6	1265539.	2132.	2435.	173751.	313.2	327.6
.25	408.8	229.6	1265539.	2096.	2439.	174338.	308.4	322.2
.70	423.9	229.5	1284557.	1956.	2492.	174403.	281.6	293.3
.70	422.6	229.5	1284557.	1974.	2490.	174062.	284.1	296.1
.70	425.2	229.5	1284557.	1937.	2495.	174741.	279.2	290.6
1.10	400.4	229.3	1400754.	2164.	2728.	163773.	270.7	283.1
1.30	377.8	229.2	1563722.	2460.	3043.	152869.	261.1	274.8
1.50	366.8	229.1	1794474.	2596.	3509.	145063.	229.2	241.8
1.85	358.8	228.9	1925194.	2745.	3759.	140960.	221.0	233.9
1.85	362.	228.9	1925194.	2657.	3770.	141822.	214.4	226.5
1.85	357.5	228.9	1925194.	2779.	3755.	140634.	223.6	236.8
1.85	355.2	228.9	1925194.	2838.	3748.	140087.	228.0	241.8
2.30	388.5	228.6	1925194.	2146.	3843.	147842.	175.6	183.3
2.30	349.9	228.6	1925194.	2978.	3731.	138725.	238.5	253.7
2.50	383.6	228.5	1794477.	2252.	3551.	148895.	200.6	210.0
2.70	381.4	228.44	1563725.	2376.	3049.	153512.	252.5	265.4
2.90	394.2	228.3	1400755.	2264.	2712.	161766.	282.1	296.0
3.10	406.6	228.2	1318448.	2153.	2543.	168110.	295.0	309.1
3.30	414.	228.1	1284558.	2083.	2473.	171457.	298.2	312.1
3.30	430.1	228.1	1284558.	1859.	2500.	175577.	268.3	278.9
7.00	400.4	226.7	1265539.	2184.	2419.	171350.	319.4	335.4
7.00	402.2	226.7	1265539.	2154.	2422.	171834.	315.3	330.8
7.00	412.4	226.7	1265539.	1997.	2440.	174564.	294.0	307.0

16.	1030.	1.9652	1003083.	303342.					
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ⁹³	NU(I)	
1	.25	441.2	237.4	1003890.	1769.	2079.	146332.	265.3	273.0
2	.25	442.9	237.4	1003890.	1749.	2081.	146662.	262.6	270.0
3	.70	458.0	237.2	1018976.	1642.	2126.	146544.	241.2	247.4
4	.70	457.5	237.2	1018976.	1646.	2125.	146464.	241.8	248.0
5	.70	454.9	237.2	1018976.	1672.	2122.	145980.	245.3	251.9
7	1.10	432.8	237.0	1111150.	1821.	2326.	137528.	232.4	239.2
8	1.30	410.2	236.9	1240424.	2034.	2599.	128316.	220.4	228.0
7	1.50	401.3	236.7	1423468.	2097.	3003.	122775.	189.3	196.0
10	1.85	396.4	236.5	1527162.	2144.	3227.	120049.	176.9	183.4
11	1.85	398.2	236.5	1527162.	2117.	3231.	120345.	174.8	181.1
12	1.85	393.3	236.5	1527162.	2194.	3221.	119528.	180.7	187.6
13	1.85	389.4	236.5	1527162.	2260.	3213.	118851.	185.8	193.2
14	2.30	425.2	236.1	1527162.	1770.	3283.	124652.	147.9	151.9
15	2.30	429.7	236.1	1527162.	1725.	3291.	125339.	144.4	148.1
16	2.50	417.7	236.0	1423470.	1867.	3032.	125404.	169.7	174.7
17	2.70	415.5	235.8	1240426.	1949.	2606.	129540.	211.6	218.6
19	2.90	430.1	235.7	1111151.	1844.	2320.	136727.	234.7	242.0
20	3.10	442.9	235.6	1045860.	1754.	2175.	142066.	245.7	253.0
21	3.30	449.1	235.5	1018977.	1716.	2113.	144577.	250.9	258.2
22	3.30	465.9	235.5	1018977.	1554.	2133.	147643.	228.9	234.3
23	7.00	434.5	233.8	1003890.	1800.	2067.	144421.	268.8	277.5
24	7.00	437.2	233.8	1003890.	1770.	2070.	144923.	264.7	273.0
25	7.00	448.7	233.8	1003890.	1650.	2084.	147086.	248.0	254.8

RUN	PRESS	W AVG	G AVG	Q/A AVG				
17.	1035.	1.4663	748433.	302181.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ³	NU(I)
.25	487.1	241.9	749035.	1389.	1690.	116112.	213.0	215.9
.25	485.4	241.9	749035.	1401.	1689.	115878.	214.7	217.8
.70	502.1	241.6	760292.	1312.	1726.	115977.	196.9	199.2
.70	498.6	241.6	760292.	1335.	1723.	115513.	200.0	202.5
.70	497.3	241.6	760292.	1343.	1722.	115340.	201.1	203.8
1.10	475.7	241.3	829065.	1448.	1888.	108767.	188.7	191.5
1.30	453.1	241.1	925521.	1539.	2113.	102079.	175.8	179.2
1.50	452.2	241.0	1062096.	1563.	2452.	98242.	144.6	147.1
1.85	455.8	240.6	1139465.	1520.	2647.	97065.	129.0	131.1
1.85	455.8	240.6	1139465.	1520.	2647.	97065.	129.0	131.1
1.85	453.6	240.6	1139465.	1538.	2644.	96818.	130.4	132.6
1.85	445.6	240.6	1139465.	1604.	2633.	95926.	135.6	138.1
2.30	476.	240.1	1139465.	1370.	2674.	99353.	117.3	118.6
2.30	481.4	240.1	1139465.	1340.	2680.	99901.	114.9	116.1
2.50	463.7	239.9	1062098.	1464.	2465.	99471.	136.0	138.0
2.70	458.4	239.8	925522.	1533.	2117.	102540.	170.0	173.0
2.90	473.02	239.6	829066.	1459.	1884.	108160.	189.7	192.8
3.10	488.9	239.5	780350.	1373.	1768.	112747.	196.6	199.4
3.30	494.2	239.3	760292.	1349.	1717.	114631.	201.6	204.5
3.30	511.23	239.3	760292.	1242.	1732.	116951.	186.9	188.8
7.00	483.6	237.1	749035.	1379.	1683.	115042.	210.7	214.1
7.00	485.3	237.1	749035.	1364.	1685.	115334.	208.6	211.8
7.00	496.	237.1	749035.	1297.	1694.	116736.	199.3	201.8

18.	1085.	2.9641	1512945.	503192.					
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ³	NU(I)	
.25	506.6	235.9	1514162.	2348.	2946.	230688.	357.8	364.2	
.25	507.9	235.9	1514162.	2333.	2948.	231042.	355.7	361.9	
.70	535.2	235.6	1536916.	2116.	3023.	233102.	316.8	321.0	
.70	535.2	235.6	1536916.	2116.	3023.	233102.	316.8	321.0	
.70	533.8	235.6	1536916.	2129.	3021.	232753.	318.6	322.9	
1.10	500.2	235.4	1675941.	2325.	3309.	218747.	302.3	307.3	
1.30	465.5	235.3	1870925.	2646.	3687.	203480.	291.4	297.9	
1.50	443.8	235.1	2147009.	2870.	4239.	191749.	262.2	269.0	
1.85	427.4	234.8	2303410.	3121.	4528.	185033.	259.4	267.4	
1.85	433.6	234.8	2303410.	3003.	4544.	186519.	250.3	257.5	
1.85	427.0	234.8	2303410.	3130.	4527.	184926.	260.0	268.1	
1.85	425.2	234.8	2303410.	3165.	4522.	184497.	262.8	271.1	
2.30	457.5	234.4	2303410.	2614.	4604.	192030.	220.1	224.8	
2.30	458.9	234.4	2303410.	2596.	4607.	192333.	218.7	223.3	
2.50	463.3	234.3	2147012.	2563.	4282.	196168.	236.1	240.9	
2.70	465.5	234.1	1870928.	2639.	3684.	203056.	290.3	297.0	
2.90	486.7	234.0	1675942.	2495.	3280.	214505.	322.1	328.9	
3.10	505.2	233.9	1577465.	2376.	3075.	222991.	337.5	344.1	
3.30	517.6	233.8	1536917.	2288.	2993.	227800.	339.7	346.0	
3.30	538.7	233.8	1536917.	2070.	3025.	233392.	310.1	314.1	
7.00	494.7	231.9	1514162.	2442.	2922.	226504.	369.6	377.8	
7.00	497.3	231.9	1514162.	2408.	2926.	227222.	365.0	372.8	
7.00	511.4	231.9	1514162.	2245.	2948.	231016.	342.2	348.2	

RUN	PRESS	W AVG	G AVG	Q/A AVG				
19.	995.	12.4712	1261357.	500207.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ³	NU(I)
.25	533.4	232.8	1262372.	2016.	2579.	197932.	310.5	314.0
.25	536.0	232.8	1262372.	1993.	2582.	198525.	307.3	310.6
.70	563.2	232.5	1281343.	1824.	2649.	200382.	276.2	278.1
.70	561.5	232.5	1281343.	1837.	2646.	199982.	277.9	279.9
.70	558.9	232.5	1281343.	1856.	2643.	199384.	280.6	282.8
1.10	526.8	232.2	1397249.	2008.	2896.	187561.	263.7	266.4
1.30	488.	232.1	1559809.	2286.	3223.	173932.	254.0	258.2
1.50	467.7	231.9	1789983.	2453.	3707.	164066.	226.1	230.6
1.85	452.2	231.5	1920376.	2623.	3964.	158647.	220.1	225.3
1.85	458.9	231.5	1920376.	2533.	3979.	159919.	213.2	217.8
1.85	451.8	231.5	1920376.	2629.	3963.	158561.	220.6	225.9
1.85	450.0	231.5	1920376.	2654.	3960.	158220.	222.6	228.0
2.30	492.0	231.1	1920376.	2156.	4046.	166146.	183.9	186.3
2.30	494.2	231.1	1920376.	2135.	4050.	166562.	182.3	184.6
2.50	493.	230.9	1789986.	2160.	3755.	168871.	201.2	203.8
2.70	492.0	230.7	1559811.	2244.	3225.	174186.	249.5	253.5
2.90	513.6	230.5	1397250.	2126.	2873.	184085.	277.4	281.3
3.10	532.230	230.4	1315148.	2026.	2694.	191482.	290.9	294.6
3.30	546.	230.3	1281343.	1944.	2623.	195914.	291.9	295.3
3.30	568.1	230.3	1281343.	1778.	2651.	200854.	269.4	271.2
7.00	522.4	228.1	1262372.	2070.	2560.	194515.	316.7	321.5
7.00	525.	228.1	1262372.	2041.	2564.	195201.	312.8	317.3
7.00	542.6	228.1	1262372.	1898.	2585.	199041.	292.9	295.9

20.	1015.	1.9422	991344.	496724.					
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR ³	NU(I)	
.25	584.2	236.5	992141.	1649.	2188.	166130.	260.1	259.8	
.25	593.0	236.5	992141.	1599.	2198.	167918.	253.3	252.4	
.70	615.2	236.1	1007051.	1501.	2251.	169030.	233.4	231.9	
.70	613.0	236.1	1007051.	1512.	2249.	168559.	234.8	233.5	
.70	611.3	236.1	1007051.	1521.	2247.	168185.	236.0	234.7	
1.10	576.4	235.8	1098145.	1655.	2456.	157252.	222.7	222.2	
1.30	538.	235.6	1225907.	1850.	2732.	145574.	210.3	211.0	
1.50	518.9	235.4	1406809.	1953.	3144.	137502.	184.3	185.4	
1.85	505.7	234.9	1509289.	2042.	3367.	133374.	175.6	177.1	
1.85	514.0	234.9	1509289.	1972.	3381.	134652.	170.2	171.3	
1.85	503.5	234.9	1509289.	2061.	3364.	133041.	177.1	178.7	
1.85	507.0	234.9	1509289.	2031.	3370.	133575.	174.7	176.1	
2.30	559.3	234.4	1509289.	1661.	3459.	142044.	146.2	145.7	
2.30	562.4	234.4	1509289.	1643.	3465.	142589.	144.9	144.3	
2.50	549.2	234.1	1406811.	1729.	3191.	142366.	165.3	165.1	
2.70	542.6	233.9	1225909.	1812.	2734.	145896.	206.2	206.8	
2.90	563.7	233.7	1098146.	1728.	2435.	154196.	230.9	231.2	
3.10	582.9	233.5	1033620.	1650.	2284.	160585.	242.6	242.6	
3.30	597.3	233.3	1007051.	1584.	2226.	164578.	243.8	243.4	
3.30	624.7	233.3	1007051.	1445.	2259.	170365.	225.4	223.7	
7.00	574.2	230.5	992141.	1670.	2171.	163077.	261.7	262.2	
7.00	579.4	230.5	992141.	1639.	2176.	164090.	257.4	257.6	
7.00	596.	230.5	992141.	1547.	2195.	167411.	244.9	244.2	

RUN	PRESS	W AVG	G AVG	Q/A AVG				
21.	1013.	2.9649	1513353.	100008.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	266.8	203.4	1514570.	1959.	2435.	154005.	261.3	300.9
.25	268.1	203.4	1514570.	1906.	2440.	154610.	254.5	292.7
.70	273.9	203.3	1537331.	1789.	2490.	154074.	233.6	268.0
.70	273.4	203.3	1537331.	1805.	2488.	153875.	235.5	270.3
.70	273.4	203.3	1537331.	1805.	2488.	153875.	235.5	270.3
1.10	264.6	203.3	1676393.	2010.	2727.	144957.	228.2	262.8
1.30	256.	203.3	1871430.	2269.	3052.	136406.	219.2	253.6
1.50	252.7	203.2	2147589.	2389.	3524.	129866.	192.2	222.8
1.85	249.6	203.2	2304031.	2539.	3780.	126607.	186.6	216.8
1.85	250.203.2	2304031.	2455.	3788.	127122.	180.6	209.6	
1.85	249.6	203.2	2304031.	2539.	3780.	126607.	186.6	216.8
1.85	248.7	203.2	2304031.	2598.	3775.	126264.	190.8	221.9
2.30	259.8	203.1	2304031.	2007.	3837.	130516.	148.9	171.2
2.30	261.1	203.1	2304031.	1954.	3844.	131026.	145.1	166.7
2.50	258.9	203.1	2147592.	2067.	3555.	132250.	167.2	192.7
2.70	258.0	203.1	1871432.	2190.	3057.	136853.	211.8	244.8
2.90	262.4	203.0	1676395.	2100.	2716.	143849.	237.8	274.6
3.10	266.8	203.0	1577890.	2003.	2544.	149158.	249.4	287.7
3.30	269.	203.0	1537331.	1964.	2471.	151697.	255.1	294.3
3.30	275.6	203.0	1537331.	1719.	2495.	154688.	224.7	257.4
7.00	264.6	202.6	1514570.	2020.	2425.	152659.	268.7	310.3
7.00	265.0	202.6	1514570.	2000.	2427.	152861.	266.2	307.3
7.00	269.5	202.6	1514570.	1826.	2442.	154879.	244.1	280.5

RUN	PRESS	W AVG	G AVG	Q/A AVG				
22.	1011.	2.4576	1254416.	100174.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	269.9	200.0	1255424.	1727.	2095.	127554.	230.3	265.3
.25	271.7200.0	1255424.	1672.	2101.	128222.	223.4	256.8	
.70	276.5	200.0	1274291.	1603.	2141.	127448.	209.1	240.1
.70	276.1	200.0	1274291.	1615.	2139.	127283.	210.6	241.9
.70	276.1	200.0	1274291.	1615.	2139.	127283.	210.6	241.9
1.10	267.7	199.9	1389559.	1770.	2346.	120054.	200.9	231.5
1.30	259.3	199.9	1551224.	1990.	2624.	112816.	192.2	222.5
1.50	256.2	199.9	1780132.	2046.	3033.	107692.	164.7	190.9
1.85	254.0	199.8	1909807.	2115.	3258.	105272.	155.5	180.6
1.85	255.	199.8	1909807.	2037.	3267.	105840.	150.1	173.9
1.85	254.0	199.8	1909807.	2115.	3258.	105272.	155.5	180.6
1.85	252.3	199.8	1909807.	2198.	3250.	104703.	161.4	187.7
2.30	265.0	199.7	1909807.	1705.	3311.	108787.	126.7	145.5
2.30	266.8	199.7	1909807.	1655.	3320.	109350.	123.1	141.1
2.50	262.0	199.7	1780135.	1819.	3058.	109515.	147.1	169.6
2.70	261.	199.6	1551227.	1911.	2629.	113321.	184.8	213.6
2.90	265.9	199.6	1389560.	1822.	2338.	119272.	206.3	238.2
3.10	270.8	199.6	1307910.	1729.	2191.	123838.	215.3	248.2
3.30	273.0	199.5	1274291.	1696.	2128.	125947.	220.4	254.0
3.30	280.0	199.5	1274291.	1499.	2150.	128589.	196.1	224.5
7.00	269.5	199.1	1255424.	1710.	2091.	127042.	227.8	262.7
7.00	269.5	199.1	1255424.	1710.	2091.	127042.	227.8	262.7
7.00	273.9	199.1	1255424.	1581.	2104.	128714.	211.5	242.8

RUN	PRESS	W AVG	G AVG	Q/A AVG				
23.	1015.	1.9539	997316.	101501.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	282.2	200.3	998118.	1432.	1775.	105163.	193.1	219.7
.25	283.6	200.3	998118.	1403.	1778.	105556.	189.5	215.3
.70	289.3	200.3	1013117.	1333.	1814.	105161.	175.9	199.5
.70	288.4200.3	1013117.	1350.	1812.	104903.	178.1	202.1	
.70	288.0	200.3	1013117.	1359.	1811.	104774.	179.2	203.4
1.10	279.6	200.2	1104760.	1475.	1986.	98866.	169.2	192.7
1.30	271.	200.2	1233292.	1628.	2222.	92973.	159.0	181.9
1.50	269.5	200.1	1415283.	1631.	2574.	89103.	132.9	152.0
1.85	270.8	200.0	1518381.	1580.	2780.	88012.	118.1	134.8
1.85	271.200.0	1518381.	1553.	2783.	88234.	116.5	132.9	
1.85	271.7	200.0	1518381.	1558.	2783.	88234.	116.5	132.9
1.85	267.7	200.0	1518381.	1662.	2768.	87232.	123.8	141.7
2.30	279.2	199.9	1518381.	1392.	2811.	90089.	104.7	118.6
2.30	280.5	199.9	1518381.	1366.	2816.	90419.	103.0	116.5
2.50	275.6	199.9	1415285.	1474.	2596.	90634.	120.7	137.3
2.70	273.9	199.8	1233293.	1551.	2230.	93590.	151.8	173.2
2.90	279.6	199.8	1104761.	1467.	1985.	98726.	168.3	191.6
3.10	284.5	199.7	1039846.	1401.	1860.	102478.	176.6	200.9
3.30	286.2	199.7	1013117.	1384.	1805.	104086.	182.0	207.1
3.30	294.	199.7	1013117.	1237.	1825.	106409.	163.8	185.0
7.00	281.8	199.1	998118.	1414.	1771.	104691.	190.5	217.1
7.00	282.2	199.1	998118.	1405.	1772.	104822.	189.3	215.6
7.00	288.199.1	998118.	1294.	1785.	106523.	175.3	198.5	

RUN	PRESS	W AVG	G AVG	Q/A AVG				
24.	1015.	1.4558	743074.	102330.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	299.0	220.5	743671.	1521.	1470.	86263.	211.5	233.1
.25	300.8	220.5	743671.	1479.	1473.	86626.	205.9	226.6
.70	304.8	220.4	754847.	1439.	1499.	85867.	195.5	215.1
.70	303.9	220.4	754847.	1459.	1497.	85688.	193.1	218.0
.70	304.8	220.4	754847.	1439.	1499.	85867.	195.5	215.1
1.10	295.	220.3	823128.	1600.	1642.	80866.	189.0	208.7
1.30	288.4	220.2	918893.	1722.	1843.	76535.	173.5	192.0
1.50	294.6	220.2	1054491.	1516.	2155.	74747.	128.2	141.0
1.85	297.7	220.0	1131306.	1434.	2330.	74055.	111.3	122.1
1.85	297.3	220.0	1131306.	1443.	2329.	73979.	112.0	122.8
1.85	300.4	220.0	1131306.	1381.	2336.	74507.	107.5	117.6
1.85	294.	220.0	1131306.	1510.	2320.	73448.	106.9	128.6
2.30	297.7	219.9	1131306.	1431.	2329.	74029.	111.1	121.8
2.30	299.9	219.9	1131306.	1387.	2335.	74406.	107.8	118.1
2.50	292.8	219.8	1054492.	1549.	2150.	74380.	130.8	144.0
2.70	291.1	219.8	918895.	1633.	1848.	76943.	164.8	182.1
2.90	296.4	219.7	823129.	1552.	1643.	80999.	183.6	202.5
3.10	301.7	219.7	774762.	1470.	1540.	84111.	191.1	210.5
3.30	303.	219.6	754847.	1442.	1496.	85533.	195.6	215.5
3.30	312.7	219.6	754847.	1268.	1511.	87312.	173.2	189.5
7.00	301.2	218.9	743671.	1431.	1471.	86398.	199.2	219.4
7.00	302.1	218.9	743671.	1413.	1472.	86579.	196.7	216.5
7.00	307.4	218.9	743671.	1309.	1481.	87660.	183.0	200.6

RUN	PRESS	M. AVG	G. AVG	Q/A AVG				
26.	1025.	2.9579	1509780.	501202.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	581.2	346.4	1510994.	2307.	3268.	294321.	469.2	456.2
.25	590.4	346.4	1510994.	2660.	3290.	299600.	447.3	433.7
.70	614.3	346.1	1533701.	2405.	3385.	304853.	398.6	384.7
.70	616.9	346.1	1533701.	2372.	3392.	306351.	393.9	379.8
.70	616.5	346.1	1533701.	2378.	3391.	306100.	394.7	380.6
1.10	583.8	345.9	1672435.	2619.	3702.	286248.	376.4	364.3
1.30	546.	345.8	1867011.	3096.	4095.	260501.	374.0	364.7
1.50	524.2	345.7	2142518.	3420.	4697.	243896.	341.8	334.6
1.85	508.8	345.4	2293592.	3758.	5014.	234767.	341.2	335.2
1.85	512.3	345.4	2293592.	3659.	5026.	236031.	332.9	326.7
1.85	508.3	345.4	2293592.	3771.	5013.	234611.	342.3	336.3
1.85	503.5	345.4	2293592.	3917.	4998.	232914.	354.5	348.8
2.30	519.3	345.0	2293592.	3470.	5047.	238450.	316.9	310.5
2.30	522.	345.0	2293592.	3396.	5058.	239613.	310.7	304.2
2.50	535.6	344.9	214252.	3154.	4730.	248069.	317.2	309.6
2.70	544.0	344.7	1867014.	3133.	4084.	258778.	377.5	368.6
2.90	564.6	344.6	1672437.	2937.	3641.	274335.	415.9	405.3
3.10	582.9	344.5	1574165.	2775.	3418.	286180.	433.0	421.3
3.30	596.9	344.4	1533702.	2630.	3335.	294104.	430.0	417.6
3.30	619.5	344.4	1533702.	2327.	3393.	306474.	386.4	372.6
7.00	568.9	342.6	1510994.	2951.	3232.	287214.	488.5	477.1
7.00	571.6	342.6	1510994.	2903.	3238.	288454.	481.2	469.7
7.00	589.3	342.6	1510994.	2604.	3281.	297614.	436.8	424.1

RUN	PRESS	M. AVG	G. AVG	Q/A AVG				
27.	1027.	2.9516	1506565.	302512.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	479.2	331.9	1507776.	2713.	3082.	257243.	431.0	429.0
.25	483.2	331.9	1507776.	2612.	3089.	258544.	415.9	413.5
.70	500.4	331.8	1530435.	2340.	3160.	259395.	365.2	362.2
.70	500.4	331.8	1530435.	2340.	3160.	259395.	365.2	362.2
.70	499.9	331.8	1530435.	2349.	3159.	259245.	366.4	363.6
1.10	481.9	331.7	1663873.	2525.	3471.	245380.	343.1	340.8
1.30	456.7	331.6	1863035.	3019.	3876.	229179.	347.8	346.7
1.50	442.9	331.5	2137955.	3326.	4468.	217178.	318.5	318.1
1.85	432.8	331.3	2293696.	3677.	4790.	211121.	321.0	321.2
1.85	439.0	331.3	2293696.	3414.	4805.	212693.	298.9	298.6
1.85	432.3	331.3	2293696.	3697.	4789.	211010.	322.7	322.9
1.85	430.1	331.3	2293696.	3802.	4783.	210456.	331.6	331.9
2.30	441.	331.1	2293696.	3322.	4810.	213199.	291.1	290.7
2.30	443.4	331.1	2293696.	3242.	4815.	213773.	284.3	283.8
2.50	450.9	331.0	2137958.	3039.	4485.	219165.	291.9	291.0
2.70	455.8	330.9	1863038.	3036.	3872.	228656.	349.4	348.5
2.90	467.7	330.8	1663875.	2833.	3442.	240542.	338.8	337.5
3.10	478.3	330.8	1570312.	2746.	3222.	249394.	407.1	405.5
3.30	487.1	330.7	1530435.	2617.	3135.	254555.	405.5	403.6
3.30	502.1	330.7	1530435.	2291.	3161.	259529.	357.5	354.7
7.00	471.7	329.7	1507776.	2853.	3067.	254180.	451.3	450.2
7.00	473.5	329.7	1507776.	2803.	3070.	254734.	443.7	442.4
7.00	483.6	329.7	1507776.	2544.	3086.	257993.	404.7	402.6

RUN	PRESS	M. AVG	G. AVG	Q/A AVG				
28.	1019.	2.4753	1263450.	301186.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	493.8	329.8	1264466.	2315.	2697.	219343.	370.1	367.3
.25	498.6	329.8	1264466.	2225.	2704.	220755.	356.6	353.5
.70	515.4	329.6	1283468.	2023.	2766.	221541.	317.8	314.2
.70	514.5	329.6	1283468.	2036.	2765.	221272.	319.7	316.2
.70	514.5	329.6	1283468.	2036.	2765.	221272.	319.7	316.2
1.10	494.2	329.4	1399567.	2219.	3033.	208696.	303.2	300.3
1.30	468.6	329.4	1562397.	2613.	3385.	194640.	302.5	300.9
1.50	456.2	329.2	1792953.	2811.	3904.	184685.	270.5	269.5
1.85	446.0	329.0	1923562.	3059.	4185.	179474.	268.4	267.9
1.85	451.8	329.0	1923562.	2887.	4197.	180748.	254.0	253.2
1.85	447.4	329.0	1923562.	3017.	4188.	179766.	264.9	264.4
1.85	442.	329.0	1923562.	3191.	4176.	178608.	279.5	279.2
2.30	459.8	328.8	1923562.	2672.	4215.	182499.	235.9	234.8
2.30	464.	328.8	1923562.	2559.	4226.	183634.	226.5	225.1
2.50	467.3	328.7	1792955.	2528.	3926.	187167.	244.5	243.0
2.70	469.5	328.6	1562399.	2580.	3385.	194603.	298.7	297.1
2.90	482.3	328.5	1399568.	2441.	3010.	204999.	331.2	329.1
3.10	493.8	328.4	1317330.	2323.	2819.	212720.	346.6	344.2
3.30	502.	328.3	1283469.	2223.	2743.	217174.	346.7	344.0
3.30	518.9	328.3	1283469.	1958.	2769.	222138.	307.9	304.3
7.00	486.7	327.1	1264466.	2398.	2682.	216645.	381.6	379.5
7.00	488.	327.1	1264466.	2353.	2686.	217257.	374.9	372.7
7.00	500.8	327.1	1264466.	2138.	2703.	220666.	342.6	339.7

RUN	PRESS	M. AVG	G. AVG	Q/A AVG				
29.	1047.	1.9871	1014262.	301849.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	520.7	330.7	1015077.	1903.	2300.	183076.	308.8	304.3
.25	526.8	330.7	1015077.	1826.	2308.	184730.	297.3	292.6
.70	541.3	330.5	1030332.	1703.	2360.	185113.	271.7	266.8
.70	542.2	330.5	1030332.	1694.	2361.	185361.	270.3	265.4
.70	542.6	330.5	1030332.	1689.	2362.	185485.	269.7	264.7
1.10	516.7	330.3	1123532.	1898.	2580.	173237.	262.5	258.5
1.30	493.3	330.2	1254247.	2150.	2881.	161728.	252.2	249.3
1.50	478.8	330.1	1439331.	2327.	3318.	152872.	226.6	224.5
1.85	467.	329.8	1544181.	2514.	3553.	148260.	223.0	221.4
1.85	476.1	329.8	1544181.	2347.	3570.	149911.	209.0	207.1
1.85	470.4	329.8	1544181.	2459.	3559.	148775.	218.4	216.7
1.85	464.2	329.8	1544181.	2592.	3546.	147583.	229.5	228.1
2.30	492.9	329.5	1544181.	2065.	3605.	153355.	185.5	183.1
2.30	499.5	329.5	1544181.	1974.	3619.	154813.	177.9	175.4
2.50	494.7	329.4	1439333.	2055.	3348.	156137.	201.7	199.1
2.70	493.	329.3	1254249.	2138.	2879.	161467.	250.6	247.8
2.90	507.4	329.1	1123533.	2015.	2563.	170494.	277.1	273.6
3.10	519.8	329.0	1057515.	1913.	2403.	177229.	289.5	285.6
3.30	529.0	329.0	1030332.	1828.	2339.	181260.	289.3	285.2
3.30	546.6	329.0	1030332.	1637.	2365.	186074.	261.6	256.7
7.00	511.3	327.4	1015077.	1975.	2283.	180010.	318.3	314.7
7.00	515.	327.4	1015077.	1921.	2289.	181008.	310.3	306.5
7.00	530.8	327.4	1015077.	1742.	2310.	184955.	283.7	279.1

RUN	PRESS	W AVG	G AVG	Q/A AVG				
30.	1045.	1.4951	763133.	299693.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	563.7	360.6	763747.	1721.	1928.	155673.	292.5	282.3
.25	569.3	360.6	763747.	1658.	1933.	157493.	283.0	272.6
.70	582.9	360.3	775225.	1560.	1983.	158089.	261.1	250.9
.70	579.4	360.3	775225.	1592.	1977.	157020.	265.7	255.6
.70	581.6	360.3	775225.	1572.	1980.	157636.	262.8	252.7
1.10	557.1	360.0	845349.	1746.	2160.	146739.	252.6	243.3
1.30	533.8	359.9	943699.	1964.	2406.	136093.	240.3	233.0
1.50	520.7	359.7	1032957.	2095.	2769.	128437.	212.6	206.7
1.85	511.0	359.4	1161846.	2223.	2963.	124363.	205.5	200.2
1.85	515.4	359.4	1161846.	2151.	2973.	125300.	199.4	194.1
1.85	509.6	359.4	1161846.	2246.	2960.	124093.	207.4	202.2
1.85	506.1	359.4	1161846.	2308.	2953.	123367.	212.6	207.5
2.30	549.2	359.0	1161846.	1718.	3049.	133151.	162.9	156.9
2.30	553.6	359.0	1161846.	1675.	3060.	134279.	159.3	153.2
2.50	538.2	358.8	1032959.	1846.	2804.	132371.	189.5	183.3
2.70	533.8	358.6	943701.	1949.	2403.	135745.	238.2	231.1
2.90	548.3	358.5	845350.	1835.	2142.	143798.	263.4	255.1
3.10	562.4	358.3	795677.	1724.	2012.	150267.	273.0	263.8
3.30	570.7	358.2	775225.	1659.	1959.	153738.	274.8	265.3
3.30	593.8	358.2	775225.	1455.	1997.	160775.	245.0	234.8
7.00	555.8	356.1	763747.	1757.	1911.	152261.	296.0	286.8
7.00	560.2	356.1	763747.	1709.	1917.	153476.	288.9	279.5
7.00	572.4	356.1	763747.	1589.	1935.	157021.	270.9	261.1

31.	1037.1	2.9621	1511924.	100837.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	357.5	310.7	1513140.	2999.	2917.	225817.	453.6	463.9
.25	360.1	310.7	1513140.	2763.	2922.	226539.	418.4	427.6
.70	365.9	310.7	1535879.	2506.	2976.	224999.	370.5	378.3
.70	365.4	310.7	1535879.	2536.	2975.	224380.	375.0	382.9
.70	365.9	310.7	1535879.	2506.	2976.	224999.	370.5	378.3
1.10	358.3	310.7	1674310.	2784.	3273.	213922.	359.0	366.8
1.30	350.4	310.6	1869662.	3299.	3679.	202547.	362.7	371.2
1.50	346.4	310.6	2145560.	3557.	4254.	193421.	326.0	333.8
1.85	342.3	310.5	2301856.	3970.	4573.	189287.	330.6	340.8
1.85	344.2	310.5	2301856.	3768.	4577.	189595.	315.9	323.6
1.85	342.8	310.5	2301856.	3970.	4573.	189287.	332.6	340.8
1.85	341.9	310.5	2301856.	4116.	4571.	189081.	340.8	353.4
2.30	346.4	310.5	2301856.	3466.	4532.	190090.	290.8	297.7
2.30	347.7	310.5	2301856.	3311.	4535.	190396.	278.0	284.5
2.50	349.5	310.4	2145563.	3181.	4261.	194110.	291.9	293.6
2.70	350.8	310.4	1869665.	3228.	3679.	202592.	355.0	363.3
2.90	355.2	310.4	1674811.	3042.	3267.	212633.	39.6	400.5
3.10	359.2	310.3	1576400.	2892.	3056.	219985.	409.0	418.3
3.30	362.3	310.3	1535880.	2745.	2970.	223940.	405.2	414.2
3.30	367.2	310.3	1535880.	2396.	2977.	225246.	354.5	361.9
7.00	357.0	309.9	1513140.	2961.	2916.	225487.	447.6	453.0
7.00	357.0	309.9	1513140.	2961.	2916.	225487.	447.6	458.0
7.00	361.0	309.9	1513140.	2629.	2922.	226571.	398.1	406.8

RUN	PRESS	W AVG	G AVG	Q/A AVG				
32.	1039.	2.4758	1263705.	101003.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	364.5	310.1	1264722.	2407.	2536.	190218.	365.0	372.7
.25	366.8	310.1	1264722.	2277.	2539.	190718.	345.7	352.7
.70	372.1	310.1	1283728.	2114.	2586.	189318.	313.3	319.5
.70	371.2	310.1	1283728.	2158.	2585.	189121.	319.7	326.1
.70	371.2	310.1	1283728.	2158.	2585.	189121.	319.7	326.1
1.10	363.2	310.0	1399849.	2402.	2842.	179378.	310.3	316.7
1.30	355.2	310.0	1562712.	2784.	3194.	170166.	306.7	313.4
1.50	351.3	310.0	1793315.	2971.	3494.	162502.	272.8	278.9
1.85	347.3	309.9	1923951.	3302.	3970.	158947.	277.1	283.7
1.85	349.0	309.9	1923951.	3117.	3974.	159289.	261.8	267.9
1.85	347.3	309.9	1923951.	3302.	3970.	158947.	277.1	283.7
1.85	345.9	309.9	1923951.	3455.	3968.	158691.	289.8	296.8
2.30	353.9	309.8	1923951.	2696.	3984.	160208.	226.9	231.8
2.30	354.4	309.8	1923951.	2663.	3985.	160292.	224.2	229.0
2.50	355.2	309.8	1793318.	2638.	3702.	163243.	242.6	247.8
2.70	354.8	309.7	1562715.	2801.	3193.	170016.	308.4	315.3
2.90	359.7	309.7	1399851.	2620.	2836.	178534.	337.9	345.2
3.10	364.1	309.7	1317596.	2471.	2654.	184805.	350.1	357.6
3.30	367.6	309.7	1283728.	2331.	2579.	188224.	344.7	351.9
3.30	373.4	309.7	1283728.	2034.	2587.	189508.	301.6	307.4
7.00	361.4	309.2	1264722.	2549.	2531.	189316.	386.0	394.4
7.00	362.3	309.2	1264722.	2489.	2532.	189516.	377.0	385.2
7.00	366.3	309.2	1264722.	2250.	2537.	190417.	341.4	343.4

33.	1043.	1.9822	1011761.	101003.				
L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	375.6	312.6	1012574.	1968.	2138.	154750.	300.3	305.4
.25	373.8	312.6	1012574.	2044.	2136.	154432.	311.7	317.1
.70	378.7	312.6	1027791.	1927.	2175.	153212.	286.7	291.5
.70	378.7	312.6	1027791.	1927.	2175.	153212.	286.7	291.5
.70	378.7	312.6	1027791.	1927.	2175.	153212.	286.7	291.5
1.10	370.3	312.5	1120762.	2150.	2391.	145249.	278.8	283.8
1.30	362.3	312.5	1251154.	2457.	2687.	137801.	271.8	277.0
1.50	358.3	312.4	1435782.	2605.	3108.	131598.	240.1	244.9
1.85	353.9	312.4	1540373.	2894.	3340.	128661.	243.8	248.9
1.85	355.7	312.4	1540373.	2751.	3343.	128931.	231.9	236.7
1.85	353.0	312.4	1540373.	2971.	3338.	128526.	250.2	255.5
1.85	352.6	312.4	1540373.	3011.	3337.	128458.	253.5	258.9
2.30	363.7	312.2	1540373.	2245.	3356.	130128.	190.0	193.4
2.30	365.9	312.2	1540373.	2138.	3360.	130464.	181.0	184.2
2.50	362.8	312.2	1435784.	2318.	3115.	132251.	214.1	218.1
2.70	362.3	312.2	1251156.	2439.	2687.	137745.	269.7	275.0
2.90	366.8	312.1	1120763.	2319.	2386.	144567.	300.2	305.9
3.10	371.	312.1	1054907.	2195.	2232.	149642.	312.2	318.1
3.30	374.7	312.1	1027791.	2079.	2170.	152406.	308.8	314.4
3.30	380.0	312.1	1027791.	1857.	2176.	153348.	276.3	281.0
7.00	369.0	311.6	1012574.	2230.	2129.	153362.	339.0	345.5
7.00	369.4	311.6	1012574.	2206.	2130.	153442.	335.6	342.0
7.00	373.4	311.6	1012574.	2017.	2134.	154157.	307.2	312.7

RUN PRESS W AVG G AVG Q/A AVG

34. 1041. 1.4917 761398. 100672.

L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	382.7	315.1	762010.	1784.	1711.	117756.	273.3	277.3
.25	385.4	315.1	762010.	1698.	1714.	118114.	260.4	264.0
.70	391.1	315.0	773462.	1583.	1745.	117306.	237.0	240.2
.70	390.2	315.0	773462.	1608.	1745.	117188.	240.6	243.9
.70	390.2	315.0	773462.	1608.	1745.	117188.	240.6	243.9
1.10	381.4	314.9	843427.	1789.	1918.	111037.	233.3	236.6
1.30	373.4	314.9	941553.	2005.	2155.	105349.	223.0	226.5
1.50	370.3	314.8	1080494.	2068.	2494.	100710.	191.8	194.9
1.85	366.8	314.7	1159204.	2202.	2681.	98571.	186.8	189.9
1.85	368.5	314.7	1159204.	2119.	2684.	98772.	179.8	182.7
1.85	366.8	314.7	1159204.	2202.	2681.	98571.	186.8	189.9
1.85	365.0	314.7	1159204.	2293.	2679.	98369.	194.3	197.7
2.30	377.8	314.6	1159204.	1760.	2696.	99816.	150.0	152.0
2.30	380.0	314.6	1159204.	1693.	2699.	100068.	144.4	146.3
2.50	376.1	314.5	1080496.	1832.	2501.	101344.	170.3	172.8
2.70	374.3	314.5	941555.	1952.	2156.	105402.	217.2	220.6
2.90	379.6	314.4	843427.	1834.	1915.	110734.	239.0	242.6
3.10	384.9	314.4	793868.	1717.	1793.	114738.	245.9	249.5
3.30	387.1	314.3	773462.	1679.	1741.	116677.	250.9	254.5
3.30	393.8	314.3	773462.	1497.	1747.	117563.	224.3	227.2
7.00	382.3	313.6	762010.	1748.	1710.	117501.	267.5	271.5
7.00	382.7	313.6	762010.	1733.	1710.	117561.	265.4	269.3
7.00	387.6	313.6	762010.	1589.	1714.	118217.	243.8	247.1

36. 1005. 2.9881 1525195. 303176.

L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	554.9	421.9	1526422.	3102.	3505.	345486.	548.8	520.4
.25	560.2	421.9	1526422.	2932.	3522.	349433.	521.0	493.0
.70	577.3	421.7	1549360.	2579.	3618.	354478.	451.1	425.2
.70	578.6	421.7	1549360.	2547.	3622.	355507.	446.2	420.3
.70	577.3	421.7	1549360.	2579.	3618.	354478.	451.1	425.2
1.10	558.9	421.6	1689511.	2808.	3966.	333548.	426.8	403.0
1.30	536.5	421.5	1886073.	3326.	4412.	308478.	427.0	405.3
1.50	522.9	421.5	2164393.	3706.	5071.	290105.	394.1	375.2
1.85	511.4	421.3	2322060.	4224.	5413.	279146.	408.0	389.8
1.85	516.2	421.3	2322060.	3952.	5436.	281944.	383.2	365.4
1.85	512.7	421.3	2322060.	4146.	5419.	279903.	400.9	382.8
1.85	510.1	421.3	2322060.	4305.	5407.	278393.	415.4	397.0
2.30	513.2	421.1	2322060.	4114.	5420.	279997.	397.8	379.8
2.30	515.8	421.1	2322060.	3968.	5433.	281526.	384.5	366.8
2.50	522.4	421.0	2164396.	3713.	5066.	289472.	394.5	375.7
2.70	529.0	420.9	1886076.	3625.	4379.	302988.	462.1	440.0
2.90	543.1	420.9	1689512.	3320.	3905.	321317.	497.4	472.7
3.10	554.5	420.8	1590237.	3122.	3662.	334451.	515.1	488.9
3.30	562.4	420.7	1549361.	2972.	3566.	342159.	512.9	486.2
3.30	575.9	420.7	1549361.	2594.	3610.	352415.	452.8	427.1
7.00	547.9	419.7	1526422.	3274.	3478.	338917.	574.9	546.8
7.00	547.9	419.7	1526422.	3274.	3478.	338917.	574.9	546.8
7.00	558.4	419.7	1526422.	2916.	3510.	346610.	516.5	489.4

RUN PRESS W AVG G AVG Q/A AVG

37. 1013. 2.4756 1263603. 302346.

L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	572.4	427.2	1264619.	2713.	3079.	301218.	489.7	460.4
.25	578.6	427.2	1264619.	2561.	3096.	305363.	464.7	436.0
.70	594.7	427.0	1283624.	2296.	3179.	309478.	410.0	383.2
.70	594.7	427.0	1283624.	2296.	3179.	309478.	410.0	383.2
.70	594.7	427.0	1283624.	2296.	3179.	309478.	410.0	383.2
1.10	575.1	426.9	1399736.	2518.	3480.	290143.	390.2	365.6
1.30	551.4	426.8	1562586.	2977.	3866.	267231.	383.8	366.4
1.50	536.5	426.7	1793170.	3333.	4436.	250376.	360.1	340.5
1.85	524.6	426.5	1923795.	3769.	4733.	240456.	369.6	350.8
1.85	531.7	426.5	1923795.	3459.	4762.	244126.	341.2	323.0
1.85	525.9	426.5	1923795.	3707.	4738.	241136.	363.9	345.2
1.85	522.9	426.5	1923795.	3856.	4725.	239555.	377.5	358.5
2.30	531.2	426.2	1923795.	3469.	4759.	243739.	341.9	323.8
2.30	534.3	426.2	1923795.	3348.	4772.	245372.	330.9	313.0
2.50	542.2	426.1	1793173.	3116.	4457.	253178.	338.1	319.1
2.70	546.6	426.0	1562588.	3117.	3845.	263777.	405.1	382.5
2.90	559.7	425.9	1399738.	2905.	3427.	279366.	443.5	418.0
3.10	571.1	425.9	1317490.	2743.	3214.	290905.	461.1	434.1
3.30	580.3	425.8	1283624.	2587.	3134.	298585.	455.5	428.2
3.30	597.3	425.8	1283624.	2231.	3183.	310219.	398.8	372.6
7.00	565.9	424.6	1264619.	2817.	3054.	295285.	5047.4	475.8
7.00	566.8	424.6	1264619.	2792.	3057.	295855.	500.4	471.9
7.00	577.3	424.6	1264619.	2528.	3086.	302835.	457.1	429.4

38. 1017. 2.9010 1480737. 101169.

L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	546.1	504.1	1481928.	3374.	3738.	419159.	653.3	600.3
.25	547.9	504.1	1481928.	3173.	3743.	420605.	615.4	565.3
.70	554.0	504.1	1504198.	2741.	3817.	419617.	520.2	477.6
.70	554.0	504.1	1504198.	2741.	3817.	419617.	520.2	477.6
.70	554.0	504.1	1504198.	2741.	3817.	419617.	520.2	477.6
1.10	548.3	504.0	1640263.	2949.	4200.	398451.	488.0	448.0
1.30	540.4	504.0	1831096.	3564.	4716.	376398.	501.9	461.2
1.50	536.0	504.0	2101303.	3966.	5450.	358439.	464.8	427.3
1.85	531.7	504.0	2254375.	4683.	5851.	349305.	500.6	460.6
1.85	533.4	504.0	2254375.	4323.	5859.	350557.	462.9	425.7
1.85	532.1	504.0	2254375.	4587.	5853.	349618.	490.6	451.3
1.85	531.2	504.0	2254375.	4782.	5850.	343991.	511.1	470.2
2.30	532.5	503.9	2254375.	4485.	5855.	349880.	479.8	441.3
2.30	533.0	503.9	2254375.	4397.	5857.	350194.	470.6	432.8
2.50	535.6	503.9	2101306.	4018.	5448.	358009.	470.6	432.6
2.70	538.2	503.8	1831099.	3852.	4708.	374579.	541.3	497.6
2.90	542.2	503.3	1640265.	3617.	4181.	393441.	595.1	547.0
3.10	546.1	503.3	1543883.	3382.	3913.	407582.	611.7	562.1
3.30	548.8	503.3	1504199.	3219.	3803.	415081.	607.9	558.5
3.30	553.6	503.3	1504199.	2755.	3815.	418988.	522.5	479.7
7.00	543.5	503.5	1481928.	3631.	3729.	416439.	701.1	644.5
7.00	544.8	503.5	1481928.	3455.	3733.	417538.	667.8	613.8
7.00	548.8	503.5	1481928.	3018.	3743.	420802.	584.9	537.2

RUN PRESS W AVG G AVG Q/A AVG

39. 1025. 2. 3714 1210417. 101657.

L(I)	T(I)	T4	G(I)	H ME	H CA	NR(I)	NU/PR	NU(I)
.25	551.9	502.0	1211391.	2644.	3189.	344992.	513.6	471.6
.25	553.2	502.0	1211391.	2550.	3192.	345006.	493.0	453.2
.70	559.7	501.9	1229595.	2234.	3256.	345279.	425.2	390.1
.70	559.3	501.9	1229595.	2257.	3255.	344993.	429.5	394.2
.70	560.2	501.9	1229595.	2210.	3257.	345560.	420.9	386.2
1.10	553.2	501.9	1340820.	2439.	3581.	327344.	404.4	371.2
1.30	545.7	501.8	1496815.	2817.	4023.	309542.	397.7	365.2
1.50	540.0	501.8	1717694.	3198.	4644.	294030.	375.3	344.9
1.85	535.2	501.7	1842821.	3706.	4985.	286293.	396.7	364.9
1.85	536.9	501.7	1842821.	3479.	4991.	287313.	372.9	342.9
1.85	535.2	501.7	1842821.	3706.	4985.	286293.	396.7	364.9
1.85	535.2	501.7	1842821.	3706.	4985.	286293.	396.7	364.9
2.30	536.9	501.7	1842821.	3470.	4991.	287265.	371.9	342.0
2.30	536.9	501.7	1842821.	3470.	4991.	287265.	371.9	342.0
2.50	540.9	501.6	1717697.	3095.	4647.	294431.	363.5	334.0
2.70	542.2	501.6	1496818.	3114.	4012.	307243.	438.2	402.7
2.90	546.1	501.6	1340822.	2949.	3563.	322697.	486.0	446.5
3.10	550.5	501.6	1262036.	2745.	3335.	334563.	497.4	456.9
3.30	552.7	501.5	1229595.	2663.	3240.	340420.	503.6	462.6
3.30	558.9	501.5	1229595.	2264.	3254.	344440.	430.4	395.0
7.00	548.3	501.2	1211391.	2862.	3180.	342109.	553.7	508.9
7.00	549.2	501.2	1211391.	2737.	3182.	342702.	539.8	495.9
7.00	553.2	501.2	1211391.	2496.	3190.	345348.	484.9	445.3

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