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GEAP-3676
AUGUST 1968

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FULL-LENGTH EMERGENCY COOLING HEAT TRANSFER PROGRAM TEST PLAN

R. G. BOCK

PREPARED FOR THE PHILLIPS PETROLEUM CO.,
SUBCONTRACT C-619, UNDER
CONTRACT AT(10-1)-205 BETWEEN
USAEC AND PHILLIPS PETROLEUM CO.

ATOMIC POWER EQUIPMENT DEPARTMENT

GENERAL ELECTRIC

SAN JOSE, CALIFORNIA

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FULL-LENGTH EMERGENCY COOLING HEAT TRANSFER
PROGRAM TEST PLAN

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Prepared for the Phillips Petroleum Company,
Subcontract C-619, Under
Contract AT(10-1)-205 Between
USAEC and Phillips Petroleum Company

*Printed in U.S.A. Available from the
Clearing House for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia
Price: \$3.00 per copy*

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5713-Dev Eng-49
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ABSTRACT

The test program plan for the BWR portion of the Full-Length Emergency Cooling Heat Transfer (FLECHT) Program is presented in this document. The project organization, estimated program costs, and a test program schedule are included.

This report is intended for the internal use of the Phillips Petroleum Company and the U.S. Atomic Energy Commission.

SECTION I

SUMMARY OF THE BOILING WATER REACTOR PORTION OF THE FULL-LENGTH EMERGENCY COOLING HEAT TRANSFER PROGRAM PLAN

The Boiling Water Reactor Full-Length Emergency Cooling Heat Transfer Program has been planned to examine in detail the various emergency cooling conditions that will affect heat transfer from the reactor fuel during a loss-of-coolant accident prior to the onset of cladding melting.

Heat transfer tests will be conducted out of pile, using electrically-heated fuel rod simulators in single bundle BWR geometry. Both stainless steel clad and Zircaloy-2 clad heaters will be tested.

This program has been divided into a sequence of tasks that will require a 2-year period to complete. The program task sequence is as follows:

Task I—Planning and Analysis

Task II—Design, Modification, Procurement, Installation, and Pre-Test Trial of Equipment

Task III—Heater Development Program

Task IV—Stainless Steel and Zircaloy Clad Heater Bundle Tests

Task V—Final Data Reduction, Correlation, and Analysis

The data generated by the FLECHT Program will be available for design of emergency cooling systems for all water-cooled reactors.

SECTION II

TASK DESCRIPTION

2.1 TASK I—PLANNING AND ANALYSIS

Planning and analysis will be continuously applied through the time span of the program, providing overall integration of the program tasks.

Planning of the experimental work to maximize useful results and to minimize the expenditure of effort will be carried out prior to, and during, the program period. Information that is generated by related programs will be

evaluated and integrated into the FLECHT Program as it is appropriate to do so.

The FLECHT Project Engineer will be the coordinator between the Phillips Petroleum Company and the General Electric Company for the FLECHT Program. He will be responsible for ensuring that all project reports and informal monthly letters are prepared in a fashion that will be useful to all parties concerned, and that these documents will be submitted to the Phillips Petroleum Company in accordance with Article XXXV of Contract C-619.

BWR-FLECHT Program Milestones

April 12, 1968	Program starting date.
May 14, 1968	Present Phase I testing plan covering calendar 1968 to Phillips Petroleum.
June 12, 1968	Send equipment conceptual design package to Phillips Petroleum.*
June 29, 1968	Initiate stainless steel clad heater bundle tests in low pressure emergency cooling facility.
July 12, 1968	Send documents called out in Section IX of contract C-619: "Core Spray and Core Flooding Heat Transfer Effectiveness in a Full-Scale BWR Bundle," APED-5529, by F. A. Schraub and J. E. Leonard; "Fuel Rod Failures During Simulated Loss of Coolant Conditions," APED-5479, by F. A. Schraub and R. G. Bock; and "Description of Heater Development at GE-APED Pertinent to the FLECHT Program," CDTM-68-3.
July 1968	Run Zircaloy heater tests using molybdenum and tungsten - 5% rhenium versus tungsten - 26% rhenium thermocouples for evaluation of these systems.
August 1968	Submit formal program plan for complete program. Send Zircaloy tubing to heater vendor for fabrication.
September 1968	Submit final equipment design to Phillips Petroleum. Finish testing the three Phase 1 stainless steel bundles. Order materials for remaining heater bundles (contingent on Phillips' approval of the formal program test plan.
October 1968	Place order for high-pressure test facility.
December 1968	Test the first Zircaloy clad heater bundles (Phase 1).
January 1969	Test the second Zircaloy clad heater bundle (Phase 1).
January 1969	Start stainless steel bundle testing (Phase 2).
March 1969	Run elevated pressure tests in high-pressure test facility.
May 1969	Finish stainless steel (Phase 2) testing.
June 1969	Run effect of aqueous solution tests.
July 1969	Start Zircaloy (Phase 2) testing.
December 1969	Finish Zircaloy (Phase 2) testing.
December 1969 to June 1970	Finish data reduction, analysis, and program final report.

* Sent on July 12, 1968.

2.2 TASK II—DESIGN, MODIFICATION, PROCUREMENT, INSTALLATION AND PRE-TEST TRIAL OF TEST EQUIPMENT

The low-pressure loop and full-length emergency cooling test section which was used for the emergency cooling experimental work described in APED-5529, "Core Spray and Core Flooding Heat Transfer Effectiveness in a Full-Scale Boiling Water Reactor Bundle," will be used to conduct the low-pressure tests of the FLECHT Program.

The low-pressure loop consists of a 200-gallon stainless steel storage tank, an 800,000 Btu/h heat exchanger for removing energy and controlling inlet temperatures, rotometers for flow measurement, a Wetsco pump rated at 100 ft head at 20 gpm, and welding transformers to provide voltage control of heater inputs to permit radial power peaking in the test bundle.

The full-length emergency cooling test section is 14 feet long, and is designed for studying emergency cooling of 49-rod, electrically-heated, fuel bundle simulators in the spray, flooding, and combined spray and flooding modes. A plenum at the top of the test section permits viewing the top of the heater bundle during the tests, and the use of a dual channel arrangement creates a flow path simulating the flow path that occurs between a fuel bundle and the isothermal surface which will surround it due to the adjacent bundles. Since this isothermal surface is all the fuel bundle will "see," the dual channel presents a test arrangement which is a reasonable simulation of the reactor geometry for determining the heat transfer effectiveness of the BWR emergency core cooling systems.

This low-pressure test facility is shown in Figures 1, 2, 3, 4, and 5.

The addition of a steam generator to this low-pressure test facility is planned for use in testing Zircaloy clad heater bundles. This steam generator will be used to provide steam blanketing of the bundle during the heatup period required to reach the prescribed test initial temperatures. This will prevent oxidation damage of the bundle, which would result from performing the heatup cycle in an air atmosphere. The steam generator will be located in the loop, as illustrated in Figure 1.

The primary objective of the work that will be carried out under Task II is to provide a new elevated pressure facility to be used in conducting the tests concerned with the effects of pressure described in the Task IV description section of this report. A proposed flow diagram of this facility is shown in Figure 6; the conceptual design has been submitted to Phillips Petroleum in the "Equipment Conceptual Design Report for the BWR Full-Length Emergency Cooling Heat Transfer Program," for their consideration.

The schedule for completion of the elevated pressure test facility is given in the Milestones listed under Task I, and in the Program Schedule.

2.3 TASK III—HEATER DEVELOPMENT

2.3.1 Description of Heater Development at GE-APED, Pertinent to the FLECHT Program

The General Electric Company's Atomic Power Equipment Department has maintained a continuing program of development in the electrically-heated fuel rod simulator area. Electrically-heated fuel rod simulators that have been developed under this program have been used in conducting the out-of-pile emergency core

FIGURE 1. FLOW DIAGRAM OF LOW-PRESSURE EMERGENCY COOLING TEST FACILITY

FIGURE 2. CONTROL PANEL OF LOW-PRESSURE TEST FACILITY

FIGURE 3. TEST SECTION OF LOW-PRESSURE TEST FACILITY

FIGURE 4. UPPER PLENUM OF LOW-PRESSURE TEST SECTION

FIGURE 5. COMPARISON OF TEST SECTION AND REACTOR GEOMETRY

FIGURE 6. PROPOSED FLOW DIAGRAM OF HIGH-PRESSURE TEST FACILITY

cooling and fuel rod perforation experiments described in APED-5529, "Core Spray and Core Flooding Heat Transfer Effectiveness in a Full Scale Boiling Water Reactor Bundle," F. A. Schraub and J. E. Leonard; and APED-5479, "Fuel Rod Failures During Simulated Loss-of-Coolant Conditions," F. A. Schraub and R. G. Bock; as well as previous emergency core-cooling experimental work.

The electrically-heated fuel rod simulators, or heaters, which have been developed and used in this work, have been stainless steel clad, except for the two 9-rod bundles that were used in the cladding perforation experiments described in APED-5479, which were clad with Zircaloy.

Stainless clad heaters were chosen for the initial experimental work in the emergency core cooling heat transfer area because of their economy and durability, and because the heat transfer coefficient of the stainless steel clad heater rods could be determined from a series of emergency cooling experiments. This heat transfer coefficient could then be used in an analytical model with Zircaloy clad UO_2 filled fuel rod thermal characteristics to predict fuel cladding temperatures during a loss-of-coolant accident temperature transient. The stainless steel clad heaters that have been developed and used in previous experimental work are similar to standard "calrod" type heaters. They employ a helically wound resistance filament mounted in the center of tubular cladding, and insulated from the cladding by a high-purity metal oxide. The instrumentation used in these heaters is 0.040-inch-diameter, metal-sheathed, chromel-alumel thermocouples. These thermocouples are mounted in the cladding material by using a double-wall cladding, grooving the inner cladding to accept the

thermocouples, and then swaging an outer tube over them. Details of this construction are shown in Figures 7 and 8.

The heater filament is wound in the form of a uniform helix, and then modified by special techniques developed in 1964 by the General Electric Industrial Heating Department, to produce a cosine-shaped axial power distribution which approximates the axial power distribution of an actual fuel rod. The power distribution used is shown in Figure 9. The temperature profile of an actual stainless steel heater in a test bundle is shown in Figure 10.

The Nichrome V material, used in the Type I heaters, melts at 2530°F, and this limits the surface temperature to 2000°F. However, the electrical resistivity is a weak function of temperature so these heaters are best suited for flooding tests where strong axial temperature gradients exist, and for spray tests where maximum temperatures do not exceed 2000°F.

Type II heaters, using molybdenum filaments, can be operated to heater surface temperatures of 2500°F. Since resistivity of molybdenum is strongly temperature dependent ($\alpha = 0.0048^\circ\text{F}^{-1}$ at 1832°F), the power generated in the different heater rods in a bundle depends on the temperature distribution among the rods (i. e., resistance distribution) and the axial power shape depends on the axial temperature in the same manner. However, tests and calculations that compared molybdenum and nichrome heater bundles have shown that the variation in power distribution during spray cooling transients is not excessive and can be accounted for by calculation if it is necessary to do so.

* α —Thermal coefficient of resistivity- $^\circ\text{F}^{-1}$.

SPECIFICATIONS

TYPE I HEATER

- 1 NICHROME. HEATER ELEMENT
- 2 HIGH PURITY M_2O POWDER (99.5% M_2O)
- 3 TERMINAL MATERIAL AND DIAMETER
SELECTED BY GE INDUSTRIAL HEATING DEPT.
- 4 HEATER CAPACITY 11,750 WATTS AT
360 VOLTS A.C. WITH HEAT FLUX DISTRIBUTION
AS SHOWN IN FIGURE 9
- 5 DESIGN THE HEATER HEAT FLUX DISTRIBUTION
ON THE BASIS OF CONSTANT RESISTIVITY OF
NICHROME WIRE

TYPE II HEATER

- 1 MOLYBDENUM HEATER ELEMENT
- 2 HIGH PURITY M_2O POWDER (99.5% M_2O)
- 3 MOLYBDENUM. TERMINAL DIAMETER
SELECTED BY GE INDUSTRIAL HEATER DEPT.
- 4 HEATER CAPACITY 11,750 WATTS AT 360 VOLTS
A.C. WITH HEAT FLUX DISTRIBUTION AS SHOWN
IN FIGURE 9
- 5 DESIGN THE HEATER HEAT FLUX DISTRIBUTION
ON THE BASIS OF DESIGN SURFACE TEMPERATURE
SHOWN IN FIGURE 7A

FIGURE 7. HIGH-TEMPERATURE HEATERS

FIGURE 7A. HEATER AXIAL TEMPERATURE PROFILE

FIGURE 8. HIGH-TEMPERATURE HEATER DETAILS

FIGURE 9. HEATERS-TYPES I AND II POWER PROFILE

FIGURE 10. STAINLESS STEEL HEATER AXIAL TEMPERATURE PROFILE

These stainless steel clad heaters, both Type I and Type II, have performed satisfactorily through a series of emergency cooling tests to surface temperatures as high as 2400°F. During the entire series of tests, no heater filament failures have occurred.

A GE-sponsored development program was initiated in early 1967 to develop a Zircaloy clad heater with a surface temperature capability of 2500°F or higher, with a heat flux distribution as shown in Figure 11. A very promising design has been evolved and is described in Figure 12. Several of these heaters have been tested to surface temperatures exceeding 2500°F in air, and the heaters and instrumentation shown have performed satisfactorily during these tests.

Full length (12 feet heated length) prototype heaters have been fabricated at the Industrial Heating Department, and fabrication techniques have been developed for mounting the internal thermocouples and for loading and sealing the tubes with the thermocouples in place. These heaters were filled with high-purity aluminum oxide insulating material which was compacted by vibratory compaction techniques to

approximately 65% of theoretical density to ensure uniform filling and heat transfer characteristics.

It is anticipated that the stainless steel heaters and the Zircaloy heaters described in this report will simulate actual fuel rods under loss-of-coolant accident conditions closely enough to permit using the heat transfer coefficients obtained from experimental data in an analytical model to predict bundle temperatures during loss-of-coolant temperature transients. Also, the Zircaloy rods, which are made from Zircaloy tubing purchased to GE-BWR specifications, will simulate the mechanical behavior of reactor fuel rods.

A comparison of temperature response calculations of the two type of heaters with a BWR fuel pin for a theoretical spray cooling case is shown in Figure 13. Surface temperatures are compared for the sample initial condition, power input, and convective heat transfer coefficient. The material properties used were nominal values at 1000°F (see Table 1). It should be noted that the temperatures shown in Figure 13 are higher than those expected during a loss-of-coolant temperature transient.

TABLE 1

AVERAGE HEATER PROPERTIES USED FOR FIGURE 13

<u>Heater Type</u>	<u>C_p</u>	<u>P</u>	<u>K</u> *
Double-clad stainless steel with MgO	0.1755	0.215	8.88
Single-clad Zircaloy with MgO	0.2110	0.124	5.15
Zircaloy-clad UO ₂ fuel pin	0.0714	0.340	2.82

*These values are weighted averages for the entire rod, insulation, and cladding.

FIGURE 11. ZIRCALOY CLAD HEATER POWER PROFILE

SPECIFICATIONS

1. MOLYBDENUM HEATING ELEMENT
2. HIGH PURITY Al_2O_3 POWDER (99.5% Al_2O_3)
3. PLATINUM VERSUS PLATINUM 10% RHODIUM THERMOCOUPLES, QUARTZ INSULATED
4. 0.499 in. i.d. x 0.032 WALL ZIRCALOY-2 TUBE
5. MOLYBDENUM TERMINALS
6. FIBER RESIN SEAL
7. HEATER CAPACITY 7,850 WATTS AT 277 VOLTS A.C. WITH HEAT FLUX DISTRIBUTION AS SHOWN IN FIGURE 7A

FIGURE 12. ZIRCALOY CLAD HEATER

FIGURE 13. COMPARISON OF TEMPERATURE RESPONSE CALCULATIONS

There are two important points to be taken from Figure 13. First, note the good agreement between the proposed Zircaloy heater rod and the Zircaloy clad UO_2 fuel pin. This indicates that the proposed Zircaloy heater will simulate the transient thermal behavior of the true fuel rod to a high degree. It is also apparent from the figure that the stainless steel heater will give a somewhat poorer simulation of the transient thermal response of an actual fuel rod because of the higher heat capacity introduced by the thicker cladding. This higher thermal capacity will result in lower surface heat flux than either a Zircaloy clad heater or actual fuel rod will have. Relative surface heat fluxes for the stainless steel clad heaters, Zircaloy clad heaters, and actual fuel rods at the maximum temperature shown in Figure 13 are:

Zircaloy clad fuel rod	1.0
Zircaloy clad heater rod	0.95
Stainless clad heater rod	0.82

The proposed stainless steel heater is capable of the workhorse duty which will be demanded of it in the FLECHT Program.

2.3.2 Heater Development Plan for FLECHT Heaters

a. Stainless Steel Clad Heaters for Use in High Initial Temperature Flooding Tests

Nichrome V heater filaments have been used in heaters (Type I) that have been tested in the flooding mode of emergency cooling because this material's electrical resistivity is a weak function of temperature. However, surface temperatures of heaters using Nichrome V fila-

ments are limited to 2000°F by the 2530°F melting temperature filament material.

To extend the range of surface temperatures to accommodate high initial temperature flooding tests, it is planned to investigate using a Kanthal A-1 heater filament. This material is an alloy of Fe, Cr, Co, and Al, and has a melting temperature of 2750°F with an average temperature coefficient of resistivity of 18.05×10^{-6} per degree F for a temperature range of 68°F to 2507°F.

b. Zircaloy Clad Heaters

The use of internal thermocouples in Zircaloy clad heater (see Figure 11) is required so that the exterior surface of the cladding will be free of obstructions which would cause inaccuracies in temperature measurements under emergency cooling conditions. Using a double cladding, as was used on the stainless heaters with the thermocouples "in clad", is precluded by the necessity of maintaining exact cladding dimensions so that evaluation of cladding behavior resulting from internal pressure and environmental conditions will be meaningful.

The choice of a thermocouple system that will perform in the internal fuel rod simulator environment to the test temperatures required to explore the range of predicted loss-of-coolant temperature transients (i.e., 2500°F plus) will have to be made.

Experiments to determine a suitable system to be used will be conducted. Candidate materials to be tested are molybdenum versus zirconium, tungsten-5% rhenium versus tungsten-26% rhenium, platinum versus platinum-10% rhodium, zirconium versus Zircaloy-2, using different ceramic materials such as Al_2O_3 , boron nitride, and MgO .

The experimental results of the work on heater development being carried out by Phillips Petroleum in support of the SECHT and FLECHT Programs will be incorporated in this effort, as will the results of the Westinghouse FLECHT heater development work.

2.4 TASK IV—STAINLESS STEEL AND ZIRCALOY CLAD HEATER BUNDLE TESTS

The experimental heat transfer work that is the nucleus of the FLECHT Program will be performed under this task. The tests to be performed will examine heater bundle thermal behavior, as each independent variable to be studied is varied through a realistic range of values representing conditions predicted to exist during postulated loss-of-coolant accident situations. Both the bottom flooding and spray cooling modes of emergency cooling will be treated in these tests.

The general test procedure to be followed will be to vary the independent variable through the test range while holding the other independent variables constant, and observing the effects that variations in the independent variable have

on the dependent variable (bundle temperature) as a function of time.

The test series is designed to maximize the total information that can be obtained from each test bundle. Tests on any bundle start at the less severe conditions and proceed to the more severe conditions, with evaluation of the test bundle condition being made as appropriate throughout the bundle test life.

The independent variables and ranges of these variables that will be studied are shown in Table 2. The test series shown in Table 2 and described in detail on the following pages will require seven stainless steel clad bundles and eight Zircaloy clad heater bundles. A summary of tests by heater bundle is shown in Table 3.

2.4.1 BWR-FLECHT Test Plan

The following information is presented to clarify the nomenclature used in describing the BWR-FLECHT test plan.

- a. The power levels given for the transient tests refer to a full channel power at normal operation prior to the accident. The actual power tested is given by the corresponding decay power curve. The maximum power reached during the test transient is 6% of the full channel power given [i. e., $6\% \text{ } 4 \text{ MW}_t \text{ (normal operation) = } 240 \text{ kW (maximum test bundle power)}$].
- b. Unless otherwise stated, all spray tests will have water flowing in the external region (i. e., in the gap between the two channels). Its rate will be

TABLE 2

SUMMARY OF THE BWR TEST PLAN

Independent Variable	Range of Variable	Type of Test	Test Identification	Bundle Number						
Power Level (MW _t)	5%-4, 5 6%-2, 4, 6, 6.5 7.6 (if possible)	Steady-State Spray Transient Spray	1.1.A 1.1.B	SS 6						
Initial Temperature (°F/100)	12, 13, 15, 18, 20 (16 tests)	Transient Spray	1.2	SS 2, 3						
Spray Flow Rate (gpm/bundle)	3, 2, 1, 0.8, 0.4 6, 4	Transient Spray	1.3	SS 3						
Subcooling (°F)	37, 62, 112	Steady-State Spray	1.4	SS 2						
Exterior Channel Flow (no exterior flow)	4.0 MW _t —2.0 & 1.9 gpm 5.0 MW _t —2.5 & 1.25 gpm 6.5 MW _t —3.25 & 1.6 gpm	Transient Spray	1.5	SS 3						
Pressure (psig)/100)	1, 2, 3	Transient Spray	1.6	SS 7						
Bundle Distortion (Power - MW _t) (Temp - °F/100	<table><tr><td>Power</td><td>Temp.</td></tr><tr><td>4</td><td>12, 15, 13</td></tr><tr><td>5</td><td>13, 15</td></tr></table>	Power	Temp.	4	12, 15, 13	5	13, 15	Transient Spray	1.7	SS 4
Power	Temp.									
4	12, 15, 13									
5	13, 15									
Power Level (MW _t)	5%-4, 5, 6.5, 8 6%-4, 5, 6.5, 7.6	Steady-State - Flood Transient - Flood	2.1.A 2.1.B	SS 5 SS 5						
Initial Temperature (°F/100)	13, 15, 17, 18, 20	Transient - Flood	2.2	SS 1						
Flooding Rate (in./sec) (cold)	1, 3, 6, 8, 10	Transient - Flood	2.3	SS 1						
Minimum Flooding Level to Effectively Cool Bundle Length	Investigate to find minimum levels	Steady-State - Flood	2.4	SS 1						
Subcooling (°F)	12, 62, 112	Transient - Flood	2.5	SS 5						
Effect of Pressure (psig/100)	Constant Pressure 2, 4, 6, 8	Transient - Flood	2.6	SS 7						
Minimum Bundle Level at Pressure	Investigate to find minimum levels	Steady-State	2.7	SS 7						
Spray Accumulation Time (min.)	6, 12, 24	Transient	3.1	SS 5						
Combined Spray and Flooding	<table><tr><td>Spray</td><td>Flood</td></tr><tr><td>2.0</td><td>1, 3, 6, 8, 10</td></tr></table>	Spray	Flood	2.0	1, 3, 6, 8, 10	Transient	3.2	SS 5		
Spray	Flood									
2.0	1, 3, 6, 8, 10									
Spray (gpm/rod)	2.5 3, 6, 10									
Flooding (in./sec) (cold)	3.25 3, 6, 10 2.5 8 3.25 8									

TABLE 2 (Continued)

Independent Variable	Range of Variable	Type of Test	Test Identification	Bundle Number
Initial Temperature - Correlation of Zircaloy Clad and SS Clad Heater ($^{\circ}\text{F}/100$)	12, 13, 15 (same as 1.2.A)	Transient	5.1	Zr-1
Initial Temperature ($^{\circ}\text{F}/100$)	18, 24—5 MW_t	Transient - Spray	5.2	Zr-4
	20, 24—6.5 MW_t	Transient - Spray	5.2	Zr-6
Power Level and Initial Temperature ($^{\circ}\text{F}/100$)	Power Init. Temp.	Transient - Flood	5.3	Zr-3
	6%-4 13, 16 6%-6.5 20, 24 24+			
Power (MW_t)				Zr-5
Combined Spray and Flood	6%-4 MW_t	Transient - Spray and Flood	5.4	Zr-7
Internal Pressure	6%-4 MW_t Init. Temp-1500 $^{\circ}\text{F}$	Transient - Spray	5.5	Zr-2

20% of that going down the inner channel; it is introduced uniformly around the circumference.

- c. Unless otherwise stated, all tests will use cooling water at 100 $^{\circ}\text{F}$.
- d. The flooding rates quoted are determined with the bundle in a cold condition. Thus, a 6 inch/sec flooding rate means the water is being fed in at a rate that would give a 6 inch/sec level rise if the bundle were cold.
- e. Unless otherwise stated, all tests will be conducted at atmospheric pressure in an air environment.
- f. The 0.05 gpm/rod value was derived from General Electric test data on a 36-rod bundle at a power level of 3.6 MW_t . It is used as the nominal required spray rate at that power density.

- g. The following definitions of terms used in equipment descriptions are used throughout this report:

Existing Low-Pressure Test Facility - The General Electric full length emergency cooling test apparatus shown in Figures 1, 2, 3, 4, 5, and 6.

New High Pressure Test Facility - Proposed new facility shown in Figure 6 to be used for conducting elevated pressure tests as listed.

All of the tests presented in this program, except for those specifically designated for an elevated pressure environment, will be performed in the existing low-pressure test facility.

The general procedure for all transient emergency cooling heat transfer tests is listed as follows:

- a. Bring the power to some pre-determined constant level,

TABLE 3
SUMMARY OF TESTS BY HEATER BUNDLE

<u>Bundle Number</u>					<u>Number of Tests</u>
SS-1	2.2	2.3	2.4		24
SS-2	1.2	1.4			16
SS-3	1.2	1.3	1.5		39
SS-4	1.7	2.8			6
SS-5	2.1	2.5	3.1	3.2	46
SS-6	1.1				5
SS-7	1.6	2.6	2.7		13
Zr-1	5.1				4
Zr-2	5.5				1
Zr-3	5.3				3
Zr-4	5.2				2
Zr-5	5.3				2
Zr-6	5.2				2
Zr-7	5.4				2
Zr-8	Spare				Spare

and allow the rods to reach the designated initial temperature at the same time the channel reaches a predetermined temperature level.

- b. When the initial conditions have been met, simultaneously
 1. Increase the power at the maximum rate possible until the decay heat curve (corresponding to the full channel power of interest) is intersected; then follow the decay curve for the remainder of the test.
 2. Actuate the coolant flow at the prescribed rate.
- c. Terminate the test after all temperatures pass through their maximum and are well on their way down.

Sub-Task 1—Stainless Steel Spray Tests

1.1 Effect of Power Level

A. Steady-State Tests

The objective of these tests is to obtain temperature profiles for prescribed power levels at steady-state conditions. These are not accident simulation tests, but they are valuable heat transfer tests since the surface flux is known with certainty in a steady-state test. The following range of power levels will be tested:

Power - 5% of 2 MW_t
 5% of 4 MW_t
 5% of 5 MW_t

The test procedure will be as follows:

1. Set spray at 5 gpm and exterior flow at 1 gpm.
2. Bring power up approximately 10 kW every minute until the initial power level is reached.
3. During the heating process, allow inlet coolant temperature to reach 100°F , and maintain it at this level for the remainder of the test.
4. When the desired power is reached, hold the power constant until all temperatures approach steady-state.
5. After reaching steady-state, raise the power—in reasonable steps—to the next desired power level.
6. Repeat steps 4 and 5 until all powers of interest have been investigated.

B. Transient Tests

This test series will investigate the effect of power in a simulated accident mode of operation. The tests will be run using a spray rate corresponding to the 0.05 gpm/rod criteria. The range of powers to be investigated, along with the corresponding spray rates, are:

Power	Corresponding Spray Rate
4 MW _t	2 gpm
5 MW _t	2.5 gpm
6.5 MW _t	3.25 gpm
7.6 MW _t	3.8 gpm

The test procedure will be a general spray transient with 1300°F initial temperature.

1.2 Effect of Initial Temperature Transient Tests

These tests will investigate the effect of initial temperature at several power levels. The initial temperatures and corresponding power levels and spray rates are:

Power	Spray Rate	Initial Temperature
2 MW _t	1.0 gpm	1200°F
		1500°F
		1800°F
		2000°F
4 MW _t	2.0 gpm	1200°F
		1500°F
		1800°F
		2000°F
5 MW _t	2.5 gpm	1600°F
		1800°F
		2000°F
6.5 MW _t	3.25 gpm	1700°F
		2000°F
		2200°F

The test procedure will be a general spray transient.

1.3 Effect of Spray Flow Rate

A. Steady-State Tests

These tests are designed to show the effect on bundle temperature of lowering the

flow, with everything else being held in a steady condition. The tests will be run at a 5% of 4 MW_t level. The spray rates to be tested are:

Spray Rate

2 gpm
1 gpm
0.75 gpm
0.5 gpm (if possible)

The test procedure will be as follows:

1. Set spray at 2 gpm and exterior flow at 20% of this value.
2. Bring power up approximately 10 kW every minute until a power level of 200 kW (i. e. , 5% of 4 MW_t) is reached.
3. During the heating process, allow the coolant inlet temperature to reach 100°F and maintain it at this level for the rest of the test.
4. When all parameters have reached their prescribed values, they will be held constant until all temperatures approach steady-state.
5. After reaching steady-state, change the flow rate and proceed.
6. Repeat steps 4 and 5 until all spray rates have been investigated.

B. Transient Tests

The object of this series will be to investigate both the effect of spray rate and the minimum spray rate necessary to cool the bundle at several power levels. The power levels and spray rates to be tested are:

<u>Power</u>	<u>Spray Rate</u>
2 MW _t	3 gpm
	2 gpm
	1 gpm
	0.8 gpm
	0.4 gpm (lower if possible)
4 MW _t	6 gpm
	4 gpm
	2 gpm
	1 gpm
	0.5 gpm
6.5 MW _t	0.4 gpm (lower if possible)
	6.5 gpm
	3.25 gpm
	1.65 gpm
	1 gpm
	0.82 gpm (lower if possible)

The test procedure will be a general spray transient with 1300°F initial temperature.

1.4 Effect of SubcoolingSteady-State Tests

These tests will investigate the effect on the steady-state bundle temperature due to changes in inlet water temperature. The two power levels and the range of subcoolings to be investigated are:

<u>Power</u>	<u>Spray Rate</u>	<u>Subcooling</u>
5% of 4 MW _t	2.0 gpm	112°F
		62°F
		37°F
5% of 5 MW _t	2.5 gpm	112°F
		62°F
		37°F

The test procedure will be as follows:

1. Set spray rate at 2 gpm and exterior flow at 20% of that value.
2. Bring power up approximately 10 kW every minute until a level of 200 kW (i. e., 5% of 4 MW_t) is reached.
3. During the heating process, the coolant inlet temperature will be permitted to increase until it reaches 100°F; it will then be maintained at this level.
4. When all parameters have reached their prescribed values, they will be held constant until all temperatures approach steady-state.
5. After reaching steady-state, allow the coolant temperature to rise to the next desired level.
6. Repeat steps 4 and 5 until all subcoolings at this power level have been investigated.
7. Repeat steps 1 through 6 for a power level of 5% of 5 MW_t and a spray rate of 2.5 gpm.

1.5 Effect of Exterior FlowTransient Tests

This section will consist of a series of tests run with 0 and 10% exterior coolant flow. By comparing the results of this section with tests run in other sections, the effect of exterior coolant flow can be evaluated. The following power levels and spray rates will be tested:

<u>Power</u>	<u>Spray Rate</u>
4 MW _t	2 gpm
	1 gpm
5 MW _t	2.5 gpm
	1.25 gpm
6.5 MW _t	3.25 gpm
	1.6 gpm

The test procedure will be a general spray transient with 1300°F initial temperature.

1.6 Effect of PressureTransients Tests

The tests in this series will be similar to tests in other sections, except that they will be run under elevated pressure conditions. The cases to be run are:

Power:	4 MW _t
Temperature:	1400°F
Spray Rate:	2 gpm
Pressure:	100 psig
	200 psig
	300 psig

The test procedure will be as follows:

1. Bring system pressure to desired level and establish saturated conditions.
2. Bring the power to some predetermined constant value and allow the rods to reach the designated initial temperature.

3. When the initial conditions have been met, simultaneously

(a) Start increasing the power at the maximum rate possible until the decay heat curve (corresponding to the full channel power of interest) is intersected; then follow the decay curve for the remainder of the test.

(b) Actuate the spray at the prescribed rate.

4. Terminate the test when all temperatures have reached a low level.
5. Repeat steps 1 through 4 until all pressures have been tested.

1.7 Effect of Bundle DistortionTransient Tests

A distorted fuel bundle, which will employ collars welded to the heater rods, will be fabricated. These collars will be designed to simulate actual perforations and associated swollen areas that have been observed in the perforation tests performed previously at the General Electric Company. They will be placed in relative bundle locations that will simulate actual conditions observed in perforation tests.

This bundle will be tested as follows:

<u>Power</u>	<u>Initial Temperature</u>	<u>Spray Rate</u>
4 MW _t	1200°F	2 gpm
	1500°F	2 gpm
	1300°F	1 gpm
5 MW _t	1300°F	2.5 gpm
	1500°F	2.5 gpm
	1300°F	1.25 gpm

The test procedure will be a general spray transient.

Test results will be compared to similar runs made with normal bundles.

Sub-Task 2—Stainless Steel Flooding Tests

2.1 Effect of Power Level

A. Steady-State Tests

The objective of these tests will be to investigate any temperature variation due to changes in power level, while the coolant level in the bundle is held constant. The range of powers to be tested is:

Power

- 5% of 0.5 MW_t
- 5% of 1 MW_t
- 5% of 3 MW_t
- 5% of 6.5 MW_t
- 5% of 8 MW_t

The test procedure will be as follows:

1. Add water at the bottom inlet to the channels until the water level is 8 feet above the bottom of the heated length.
2. Bring power on at a low level and allow water in the test section to reach saturation temperature.
3. Increase the power, in a moderate manner, to the desired level.

4. Add water as necessary to maintain the required coolant head.
5. Allow the bundle temperatures to reach a steady-state condition.
6. After this point is reached, change power to the next desired level.
7. Repeat steps 2 through 6 with a coolant level 6 feet above the bottom of the heated length.

B. Transient Tests

This series will investigate the effect of power level in a simulated accident mode of operation (using flooding only). The tests will be run using a cold flooding rate of 6 inches/sec. The range of powers investigated will be:

Power

- 4 MW_t
- 5 MW_t
- 6.5 MW_t
- 7.6 MW_t

The test procedure will be a general flooding transient with 1300°F initial temperature.

2.2 Effect of Initial Temperature

Transient Tests

These tests will investigate the effect of initial temperature at several power levels. The following list gives the initial

temperatures which will be run, along with the corresponding power level.

<u>Power</u>	<u>Initial Temperature</u>
4 MW _t	1300°F
	1500°F
	1800°F
5 MW _t	1300°F
	1700°F
	2000°F
6.5 MW _t	1300°F
	1500°F
	1800°F
	2000°F (higher if possible)

The test procedure will be a general flooding transient with a 6-inch/sec cold flooding rate.

2.3 Effect of Flooding Rate

Transient Tests

These tests will investigate the effect of flooding rate at two power levels. The powers to be tested and flooding rates associated with each power level are:

<u>Power</u>	<u>Flooding Rate</u>
4 MW _t	1 inch/sec
	3 inches/sec
	6 inches/sec
	8 inches/sec
	10 inches/sec
6.5 MW _t	3 inches/sec
	6 inches/sec
	10 inches/sec

The test procedure will be a general flooding transient with 1300°F initial temperature.

2.4 Minimum Bundle Level

Steady-State Tests

This test series will determine the minimum level of coolant necessary to cool a bundle at a given power input. The power levels to be investigated are:

<u>Power</u>
5% of 6.5 MW _t
5% of 5 MW _t
5% of 4 MW _t
5% of 2 MW _t
5% of 0.5 MW _t

The test procedure will be as follows:

1. Add water at the bottom inlet to the channels until the water level is the prescribed distance above the bottom of the heated length.
2. Bring power on at a low level and allow water in the test section to reach saturation temperature.
3. Increase the power, in a moderate manner, to the desired level.
4. Add water as necessary to maintain the required coolant head.
5. Allow the bundle temperatures to reach a steady-state condition.
6. After this point is reached, change the coolant level and allow temperatures to come to steady-state again.

7. Repeat steps 4 through 6 until minimum bundle level has been determined for the given power level.

8. Repeat steps 1 through 7 for all power levels.

2.5 Effect of Subcooling

Transient Tests

These tests will investigate the effect on maximum temperature. The power levels, flooding rates, and range of subcoolings to be investigated are:

<u>Power</u>	<u>Flooding Rate</u>	<u>Subcooling</u>
5 MW _t	6 inches/sec	12°F
	6 inches/sec	62°F
	6 inches/sec	112°F
6.5 MW _t	6 inches/sec	12°F
	6 inches/sec	112°F
5 MW _t	1 inch/sec	12°F
	1 inch/sec	62°F
	1 inch/sec	112°F

The test procedure will be a general flooding transient with 1300°F initial temperature.

2.6 Effect of Pressure

Transient Tests

These tests will be identical with tests in other sections, except that they will be run under elevated pressure conditions. The cases to be run are:

Power:	4 MW _t
Initial Temperature:	1300°F
Flooding Rate:	3 inches/sec
Pressure:	200 psig
	400 psig
	600 psig
	800 psig

The test procedure will be as follows:

1. Bring system pressure to desired level and establish saturation conditions.
2. Bring the power to some pre-determined constant value and allow the rods to reach the designated initial temperature.
3. When the initial conditions are met, simultaneously
 - (a) Start increasing the power at the maximum rate possible until the decay heat curve (corresponding to the full channel power of interest) is intersected; then follow the decay curve for the remainder of the test.
 - (b) Actuate bottom flooding at prescribed rate.
4. Terminate the test when all temperatures have reached the saturation level.
5. Repeat steps 1 through 4 until all pressures have been tested.

2.7 Minimum Bundle Level at Pressure

Steady-State Tests

The object of these tests will be to investigate the effect of pressure on the minimum bundle coolant level necessary to cool the assembly. The tests run will be comparable to cases run at atmospheric pressure. The cases to be run are:

<u>Power</u>	<u>Pressure</u>
5% of 6.5 MW _t	400 psi
5% of 5 MW _t	400 psi
5% of 2 MW _t	400 psi
5% of 6.5 MW _t	800 psi
5% of 5 MW _t	800 psi
5% of 2 MW _t	800 psi

The test procedure will be as follows:

1. Bring the coolant up to the prescribed levels.
2. Bring the test section to saturated conditions at the desired pressure.
3. Bring the power up to the prescribed value.
4. Introduce coolant to maintain the desired coolant level.
5. Allow the temperatures to reach a steady-state condition.
6. Change the water level and re-establish saturated conditions at desired pressure.
7. Repeat steps 4 through 6 until minimum level for power level has been established.

2.8 Effect of Bundle Distortion

Tests to investigate the effects of bundle distortion on the flooding mode of emergency cooling are not considered to be as important as tests involving the spray mode of emergency cooling. In General Electric tests, perforations and distortions have not caused flow channel blockages that would seriously interfere with the advance-

ment of the flooding front upward through the bundle. Tests involving flooding of the distorted bundle used in the spray tests (1.7) will be considered if the bundle is capable of being tested after the spray tests are completed.

Sub-Task 3—Stainless Steel Combined Spray and Flooding

3.1 Spray Accumulation

Transient Tests

This series will include tests at several powers and spray rates. The objective of the series will be to investigate the effect of letting the spray accumulate. There will be a delay time between the initiation of the spray and the beginning of accumulation to account for the filling of the bottom of the vessel in a reactor. The cases to be run are delays of 6, 12, and 24 minutes at the following powers and spray rates:

<u>Power</u>	<u>Spray Rate</u>
4 MW _t	2 gpm
	1 gpm
	0.5 gpm
5 MW _t	2.5 gpm
	1.25 gpm
6.5 MW _t	3.25 gpm
	1.6 gpm

The test procedures will be as follows:

1. Bring the power to some pre-determined constant value in such a way that the channel reaches 500 to 600°F at the same time the rods reach the prescribed initial temperature 1300°F.

2. When the initial conditions have been met, simultaneously
 - (a) Start increasing the power at the maximum rate possible until the decay heat curve (corresponding to the full channel power of interest) is intersected; then follow the decay heat curve for the remainder of the test.
 - (b) Actuate spray at prescribed rate.
3. After a specified delay time, allow the spray to accumulate in the bundle.
4. Terminate test after all temperatures have reached saturation level.
5. Repeat steps 1 through 4 until all cases have been run.

3.2 Combined Spray and Flooding Transient Tests

These tests will evaluate the case where both spray and flooding systems are operating. There will be a delay time between actuation of the spray and the flooding to simulate the reactor conditions. The cases to be run are:

<u>Power</u>	<u>Initial Temperature</u>	<u>Spray Rate</u>	<u>Flooding Rate</u>
4 MW _t	1300°F	2 gpm	1 inch/sec
	1300°F	2 gpm	3 inches/sec
	1300°F	2 gpm	6 inches/sec
	1300°F	2 gpm	8 inches/sec
	1300°F	2 gpm	10 inches/sec
5 MW _t	1300°F	2.5 gpm	3 inches/sec
	1300°F	2.5 gpm	6 inches/sec
	1300°F	2.5 gpm	10 inches/sec
6.5 MW _t	1300°F	3.25 gpm	3 inches/sec
	1300°F	3.25 gpm	6 inches/sec
	1300°F	3.25 gpm	10 inches/sec
5 MW _t	1500°F	2.5 gpm	8 inches/sec
	1800°F	2.5 gpm	8 inches/sec
	2000°F (if possible)	2.5 gpm	8 inches/sec
6.5 MW _t	1500°F	3.25 gpm	8 inches/sec
	1800°F	3.25 gpm	8 inches/sec
	2000°F (if possible)	3.25 gpm	8 inches/sec

The test procedure will be as follows:

1. Bring the power to some pre-determined constant value in such a way that the channel reaches 500 to 600°F at the same time the rods reach the prescribed initial temperature.
2. When the initial conditions have been met, simultaneously
 - (a) Start increasing the power at the maximum rate possible until the decay heat curve (corresponding to the full channel power in interest) is intersected; then follow the decay heat curve for the remainder of the test.
 - (b) Actuate spray at prescribed level.
3. After a specified delay time, begin flooding from the bottom inlet.
4. Terminate test after all temperatures have reached saturation level.
5. Repeat steps 1 through 4 until all cases have been run.

Sub-Task 4—The Effect of Aqueous Solutions on Cooling Effectiveness

4.1 Minimum Bundle Level

A. Steady-State Tests

The 4 MW_t test called for in 2.4., minimum bundle level, will be repeated using 500 and 1000 parts per million of sodium

pentaborate in the coolant supply, and the effect of this additive on coolant level necessary to cool the bundle will be evaluated at this power level.

B. Transient Tests

The tests to evaluate the effect of initial temperature (1. 2) at a power level of 4 MW_t will be re-run with 500 and 1000 parts per million of sodium pentaborate in the coolant supply, and the effect of this additive on bundle temperatures during the test transients will be evaluated.

Sub-Task 5—Zircaloy Bundle Tests

5.1 Low-Temperature Spray Runs

Transient Tests

This series is designed to give information for the correlation between stainless steel and Zircaloy bundles. All the tests will be run at a 4 MW_t power level. The spray rates and initial temperatures tested will be:

<u>Spray Rate</u>	<u>Initial Temperature</u>
2 gpm	1200°F
2 gpm	1300°F
2 gpm	1500°F
1 gpm	1300°F

The test procedure will be a general spray transient.

5.2 High-Temperature Runs

Transient Tests

The object of these tests is to investigate the high-temperature emergency cooling area. The cases to be run are:

<u>Power</u>	<u>Initial Temperature</u>	<u>Spray Rate</u>
5 MW _t	1800°F	2.5 gpm
	2400°F	2.5 gpm
6.5 MW _t	2000°F	3.25 gpm
	2400°F	3.25 gpm

The test procedure will be a general spray transient.

5.3 Flooding

Transient Tests

This test series will give information for the correlation of flooding data between stainless steel and Zircaloy bundles. Also, high temperatures flooding results will be obtained. The tests that will be run are:

<u>Power</u>	<u>Initial Temperature</u>	<u>Flooding Rate</u>
4 MW _t	1300°F	6 in./sec
	1500°F	6 in./sec
6.5 MW _t	2000°F	6 in./sec
	2400°F	6 in./sec
	2500°F (if possible)	6 in./sec

The test procedure will be a general flooding transient.

5.4 Combined Spray and Flooding

Transient Test

This will be a single test designed to approximate as closely as possible a reactor accident situation. The rods in the bundle will be internally pressurized to simulate nominal fission gas pressure. The test values will be:

Power - 6.5 MW_t
 Spray Rate - 3.25 gpm
 Initial Temperature - 2400°F
 (higher is possible)
 Flooding Rate - 8 inches/sec

The test procedure will be as follows:

1. Bring the power to some pre-determined constant value and allow the rods to reach the designated initial temperature.
2. When the initial conditions have been met, simultaneously
 - (a) Start increasing the power at the maximum rate possible until the decay heat curve (corresponding to the full channel power of interest) is intersected; then follow the decay curve for the remainder of the test.
 - (b) Actuate the spray at the prescribed rate.
3. After a specified time delay, start bottom flooding at the prescribed rate.
4. Terminate the test when all temperatures have reached saturation level.

5.5 Effect of Internal Gas Pressure

This will be a single test designed to evaluate the effect of simulated fission gas pressure on the behavior of bundle temperature.

The power, spray rate, initial temperature, and internal rod pressure will be:

Power - 4 MW_t
 Spray Rate - 2 gpm
 Initial Temperature - 1500°F (1800°F)
 Internal Gas Pressure - 200 psig
 (helium or argon)

The test procedure will be as follows:

- a. Pressurize rods to $\cong$ 150 psig.
- b. Bring power to some pre-determined constant value and allow the rods to reach the designated initial temperature.
- c. When the initial conditions have been met, simultaneously
 1. Start increasing power at the maximum rate possible until the decay heat curve (corresponding to the full channel power of interest) is intersected; then follow the decay curve for the remainder of the test.
 2. Actuate the spray at the prescribed rate.
- d. Terminate the tests when all temperatures have reached the saturation level.

2.5 TASK V—FINAL DATA REDUCTION AND ANALYSIS

Data reduction and analysis of experimental results will be initiated 5 months after the FLECHT contract is awarded. This work will continue through the testing phase of the program, with a heavy concentration of effort during the last 3 months of the program period. Existing data acquisition equipment and data

reduction codes used in previous emergency cooling work are available for use on this program.

Automated data acquisition from the approximately 80 thermocouples measuring surface temperatures throughout the heater bundle is made possible by the use of the GE-owned Hewlett-Packard Dymec Data Acquisition System (Model 20170). This system is capable of scanning up to 300 thermocouples at a rate of 2 per second, with linearization to degrees Fahrenheit or 9 per second without linearization. The system includes a digital clock, guarded cross-bar switch, integrating digital voltmeter, 8-channel punched paper tape output, printed paper tape output, and visual display output. The punch paper tape may be fed directly to the GE 635 computer system and PTE-SCE provides temperature plots as well as tabulation plots of

- a. Maximum bundle temperature versus time,
- b. Temperature profile of instrumented rod at maximum temperature conditions, and
- c. Hot rod temperatures at top, center, and bottom thermocouples versus time.

Key thermocouple outputs are recorded on Sanborn strip chart recorders as an aid to test control to provide a permanent continuous record of test temperatures. Cross-plots to relate maximum temperatures for various initial temperatures, inlet subcooling, rod powers, or emergency coolant flow rates will be made.

Written interpretive analysis of all test results will be prepared and submitted to the contractor in program topical and final program reports.

SECTION III

PROGRAM SCHEDULE

The General Electric Company has maintained an active role in the area of emergency cooling heat transfer effectiveness experimental work. At the time the Full Length Emergency Cooling Heat Transfer Diagram was awarded, the General Electric Company had three stainless steel clad heater bundles and some of the materials for two Zircaloy clad heater bundles on hand for this experimental work. This material was made available at its original cost to the FLECHT program. A description of it and its planned use in Phase 1 testing is given as follows.

- a. One full-length, stainless steel clad, 49-rod, cosine axial power distribution, Nichrome filament heater bundle (heaters to Drawing HTLP 308-Type I, see Figure 7) mounted in the spray cooling rig.

1. Bundle History:

To date, 43 tests of low-power spray and flooding have been completed with this bundle in support of a General Electric experimental program.

2. Heater Bundle Testing Plan:

Test 2.4 - Minimum Bundle Level

Test 2.3 - Effect of Flooding Rate

Test 2.2 - Effect of Initial Temperature

- b. Materials for two full-length stainless steel clad, 49-rod, cosine power

distribution, molybdenum filament heater bundles (HTLP 308-Type II heaters, see Figure 7).

1. Material History:

These materials were purchased for the ESADA (Empire State Atomic Development Authority) Central Sparger Program in 1967. This program has been cancelled, leaving these materials available for transfer to the FLECHT Program.

2. Heater Bundle Testing Plan:

Test 1.4 - Effect of Subcooling (Bundle 2)

Test 1.2 - Effect of Initial Temperature (Bundle 2)

Test 1.5 - Effect of Exterior Flow (Bundle 3)

Test 1.3 - Effect of Spray Rate (Bundle 3)

If one of these bundles is in satisfactory condition at the end of its test life, we will perform a brief series of tests to determine the effect of the molybdenum power shift* on bundle temperature while the bundle is being cooled by flooding.

Planned tests are:

1. Transient flooding at 10 to 12 in./sec to 8 and 12 ft elevations, and 4 MW_t power with initial temperature of 1500°F.

*Power shift caused by strong dependence of resistivity of molybdenum on temperature.

2. Transient flooding at 6 in./sec to 8 and 12 ft elevations with initial temperature.

The axial temperature profile of the test bundle will be compared to the temperature profile of a bundle with Nichrome filaments, which has been tested under similar test conditions to indicate the extent of temperature difference caused by the molybdenum power shift.

- c. Materials for two Zircaloy clad heater bundles:

1. History:

These materials were purchased for use in a General Electric experimental program.

2. Heater Bundle Testing Plan:

Test 5.1 - Low Temperature Test for Correlation with

Stainless Steel Work
(Bundle ZR-1)

Spray Cooling with Internal Pressure Test. This test will be similar to Test 5.4 but will be run in the spray mode only with initial temperature of approximately 1800° F. This test will require that an additional Zircaloy bundle be added to the FLECHT Program requirements (Bundle No. 7).

The Phase 1 testing plan made possible by the transfer of materials to the FLECHT Program will allow for early evaluation of test data and serve as a guide to evaluate the validity of the Phase 2 testing plan.

The proposed schedule for the FLECHT Program is shown in Figure 14.

FIGURE 14. BWR FULL-LENGTH EMERGENCY COOLING AND HEAT TRANSFER PROGRAM SCHEDULE

SECTION IV

PROJECT ORGANIZATION

The Full-Length Emergency Cooling Program project organization which has been established to conduct the program is shown in Figure 15. The manner in which the key per-

sonnel of the FLECHT project fit into the Atomic Power Equipment Department's Development Engineering organization can be seen in Figure 16.

SECTION V

SUMMARY OF PROGRAM COSTS

Task		Fiscal 1968	Fiscal 1969	Fiscal 1970	Total
		(\$ × 10 ³)			
I.	Planning and analysis	5.5	15.1	1.0	21.6
II.	Design, modification, and pre-test trial of equipment	67.4	2.2	65.2	----
III.	Heater development	35.8	4.3	31.5	----
IV.	Stainless steel and Zircaloy clad bundle tests	231.0	0.5	145.1	86.4
V.	Final data reduction and analysis	60.2	1.8	20.0	38.4
	Program cost total	416.0	14.3	276.9	124.8
	G&A and GR	29.5	1.0	16.5	12.0
	FEE	35.0	0.5	23.0	11.5
	TOTAL	480.5	15.8	316.4	148.3

FIGURE 15. FLECHT PROJECT ORGANIZATION

Effective May 13, 1968

FIGURE 16. DEVELOPMENT ENGINEERING ORGANIZATION CHART

SECTION VI

RECOMMENDATIONS FOR FUTURE WORK

1. Conduct a series of tests at higher power levels (> 8.0 MW) to evaluate the effects of power levels of the next generation of power reactors on emergency cooling.	modes of emergency cooling, countercurrent steam-induced "flooding," mechanical behavior of the heater bundle during perforation, and loss-of-coolant transients, etc.
2. Construct a high-temperature glass or quartz full-length test section to facilitate visual evaluation of phenomena of spray and flooding	3. Conduct a series of tests and analyses to study core spray effectiveness to pressures of 1000 psi.

EXTERNAL DISTRIBUTION

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