The PWR-Blowdown Heat Transfer Program is an experimental, separate effects, study of the relations among the principal variables that can alter the rate of blowdown, the presence of flow reversal and re-reversal, and time delay to critical heat flux, the rate at which dryout progresses, and similar time-related functions that are important to LOCA analysis. Primary test results will be obtained from the Thermal Hydraulic Test Facility (THTF), a large, non-nuclear pressurized-water loop which incorporates a 49-pin electrically heated bundle. Ancillary experiments are carried out in two additional test loops — the Forced Convection Test Facility (FCTF), a small, high-pressure facility in which single heater pins can be tested in annular geometry, and an air-water loop which is used to evaluate two-phase flow-measuring instrumentation.

The THTF is an all stainless steel recirculating loop, fabricated from 4-in. pipe, whose principal components are the test section, (ν19 ft of 10-in. Sch. 140 pipe and flanges); three Graham "Heliflow" heat exchangers with a total heat removal capacity of 7.5 MW; a pressurizer (ν11 ft of 12-in. Sch. 140 pipe); a two-stage Bingham pump which develops ν1940 ft of fluid head at a flow rate of 700 gpm; four instrumented spool pieces containing drag disks, gamma densitometers, turbine meters, transient pressure and temperature sensors; as well as appropriate flow control valves and bypass lines. The 1160-gal pressure suppression tank contains three spray nozzle manifolds (each containing 24 nozzles) installed parallel to the tank axis. A 1500 gpm pump recirculates water at an initial temperature of less than 100°F through these nozzles. The tank is connected to the primary loop and vented to the atmosphere through 8-in.-diam pipe.

The rod bundle consists of 49, 0.422-in.-diam indirect electrically heated rods spaced on 0.563-in. centers contained in a 4-in. square shroud box. Based on an estimate of the conditions required for equal enthalpy rise in wall channels and interior channels, the centers of the heater rods adjacent to the shroud box wall are spaced 0.312-in. from the side walls. Low pressure drop grid spacers are provided at ν12 in. intervals along the shroud box and a subchannel thermocouple flange is provided at the shroud box outlet which permits temperature measurement in the fluid in each of 64 flow subchannels between heater rods. Steady-state temperatures and pressures are monitored at four different levels along the shroud box.
Although the heater rod length varies from 18 1/2 to 21 1/2 ft, the active heated section consists of 12 ft of Inconel 600 or cupronickel heating elements on the interior of the rod arranged to give a stepped power profile with local to average power ratio varying from 0.422 to 1.67. The integrated power distribution of the heater rod closely matches the integrated power distribution of a symmetrical chopped cosine profile typical of a nuclear fuel rod. Each heater rod contains from 5 to 17 thermocouples, from 1 to 5 at various levels along the center of the rod and from 4 to 12 at various levels imbedded in grooves in the dual wall sheath. Bundle one contains a total of 347 sheath thermocouples and 73 center thermocouples.

With the pressurizer half full the total system volume is 21.4 ft³. Based on a peak heater rod power of 17 kW/ft and a peak-to-average power ratio of 1.67, the power requirements for a single rod are 122 kW or a total of 5,98 MW for the 49-rod bundle. Thus the volume to power ratio is 3.58 ft³/MW, a value typical of PWR reactors. At a power level of 122 kW/rod and an inlet temperature of 547°F, the outlet temperature is 640°F when the mass flow rate is 2.5 x 10⁶ lb/hr ft². System pressure is 2250 psi. At blowdown the system will be vented to atmospheric pressure through either or both of the rupture disks; the contents of the loop (≈ 160 gal) will then be transferred to the pressure suppression system within 20 to 100 sec depending on the size of the blowdown nozzle. From immediately before till immediately after blowdown over 500 sensors will be scanned at a rate of 20 times a sec resulting in over 3 x 10⁶ readings per test.

RELAP4 calculations for the THTF indicate that when both rupture disks are blown with 20 to 40% of the total break area at the outlet, the flow may be expected to reverse at blowdown with a reversal to positive flow at 3 to 5 sec after blowdown and another reversal to negative flow at 8 to 10 sec after blowdown. These times to flow reversal and re-reversal are typical of those calculated for a PWR LOCA with a guillotine break on the cold leg side of the reactor.

The Forced Convection Test Facility (FCTF) is, at present, limited to 1500 psi operating pressure with a temperature at the inlet to the test section of 550°F and an outlet temperature of 592°F when the rod power is 144 kW. The test section is a concentric annulus formed by a 1 1/2-in.-OD, 1 1/4-in.-ID core barrel inside a pressure housing fabricated from 2-in. Schedule 80 pipe (ID = 1.939 in.). In its present configuration, the FCTF has a volume to power ratio of 11 ft³/MW and only single-ended, cold-leg, breaks are possible.

Current two-phase flow instrumentation tests utilize a duplicate of a THTF spool piece with turbine meter, drag disk and gamma densitometer identical to those used in the THTF. Air and water are metered separately into 4 in. glass pipe connected to the THTF spool piece; maximum air and water flow rates are 1000 SCFM and 500 gpm respectively. Techniques for improving the accuracy of two-phase flow measurements currently under investigation are (1) screen dispersers to produce uniformly dispersed flow upstream of flow measuring stations, (2) measurements of ΔP across screens as an indication of mass flow rate, and (3) use of pressure drop measurement across elbows as a means for determining mass flow rate.
OAK RIDGE NATIONAL LABORATORY
BLOWDOWN HEAT TRANSFER-SEPARATE EFFECTS PROGRAM

FACILITIES

FCTF: SINGLE 12-FT HEATED-LENGTH ROD IN ANNULAR GEOMETRY
THTF: 7 x 7 ARRAY OF 12-FT HEATED-LENGTH RODS

PRIMARY OBJECTIVES

TO CONCURRENTLY DETERMINE FOR A WIDE RANGE OF PARAMETERS:
1. PRE-CHF HEAT FLUXES, ΔT, AND HEAT TRANSFER COEFFICIENTS
2. TIME TO CHF
3. POST-CHF HEAT FLUXES, ΔT, AND HEAT TRANSFER COEFFICIENTS

THE PARAMETERS TO BE STUDIED INCLUDE:
  a. SINGLE- AND DOUBLE-ENDED COOLANT LINE BREAKS OF VARYING AREA RATIO,
  b. DEPRESSURIZATION RATES VARYING FROM "FAST" TO "SLOW",
  c. DIFFERENT COMBINATIONS OF SYSTEM POWER AND PRESSURE TO OBTAIN
     DIFFERENT VALUES OF DEPARTURE FROM NUCLEAR BOILING RATIO (DNBR),
  d. A RANGE OF POWER CUTOFF DELAYS,
  e. A RANGE OF POWER DECAY RATES, AND
  f. A RANGE OF POWER TO SYSTEM VOLUME RATIOS.

SECONDARY OBJECTIVES

1. TO OBTAIN CHF DATA UNDER STEADY-STATE CONDITIONS OVER A RANGE OF
   COOLANT PRESSURES, INLET AND EXIT SUBCOOLING, AND INLET FLOW RATE
   APPROPRIATE TO PWR INTERESTS.
2. TO EVALUATE THE THERMAL-HYDRAULIC BEHAVIOR OF THE TEST LOOPS DURING
   SIMULATED OPERATIONAL UPSETS THAT INCLUDE VARIATIONS IN LOCAL POWER,
   SYSTEM PRESSURE, OR COOLANT FLOW USING ATWS (WASH-1270) AS A GUIDE.
3. TO TEST THE ABILITY OF EXISTING CODES, SUCH AS RELAP, TO PREDICT THE
   BEHAVIOR OF THE SINGLE- AND 49-ROD BUNDLE LOOP UNDER BLOWDOWN CONDITIONS.
4. TO DETERMINE THE EFFECT OF DIFFERENT Spacer GRIDS AND POWER DISTRIBUTION
   PROFILES ON BOTH TRANSIENT AND STEADY-STATE CHF.
TEST SECTION USING INDIRECT HEATER ROD IN 49 ROD BUNDLE
Fig. 1. Power profile of prototype heater.
Fig. RELAP4 model of THTF for 7.06 MW blowdowns.
JUNCTION 19
0.0135 ft² TOTAL BREAK AREA
7.06 MW
PUMP OFF DURING BLOWDOWN

Fig. Influence of break area distribution on calculated bundle interior flow. Curves are not smoothed.
Fig. 1. Pressures at inlet plenum of test section, pressurizer and pump suction and liquid level in pressurizer.
Fig. Flow rate from turbine meter. Spool piece 1, inlet side of test section. (FE-18)
Fig.  . Flow rate from turbine meter. Spool piece 2, outlet side of test section. (FE-34)
So—if I

Fig. Density at spool piece 2, outlet side of test section. (DE-36)
Fig. Flow rate from turbine meter. Spool piece 1, outlet side of test section. (FE-216)
HEATER ROD
0.422 in.

HEATER RESTRAINT
3 PER LEVEL AT
9 in. SPACING

CORE BARREL
1 1/2-in. OD X 1/8 in. THICK

CORE BARREL RESTRAINT LUG
3 PER LEVEL X 2 LEVELS

CONTAINMENT 2-in. sched-80 PIPE
316 stainless steel, 0.218-in. WALL

Fig. FCTF test section cross-sectional view.
Fig. Time response of sheath thermocouples in heater rod.

\[ \tau = \frac{\rho V_c p}{hA} \]

- **AIR** – NATURAL CONVECTION
- **H_2O** – FORCED CONVECTION

\( \tau = 2.1 \text{ sec} \)
\( \tau = 330 \text{ sec} \)
<table>
<thead>
<tr>
<th>LENGTH OF ZONE</th>
<th>kW/H / TOTAL kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 5/16&quot;</td>
<td>4.68/7.14</td>
</tr>
<tr>
<td>13 1/64&quot;</td>
<td>6.90/7.48</td>
</tr>
<tr>
<td>10 3/8&quot;</td>
<td>12.66/10.95</td>
</tr>
<tr>
<td>11 3/4&quot;</td>
<td>16.08/15.74</td>
</tr>
<tr>
<td>35 1/4&quot;</td>
<td>20.23/19.57</td>
</tr>
<tr>
<td>11 3/4&quot;</td>
<td>18.08/17.74</td>
</tr>
<tr>
<td>10 3/8&quot;</td>
<td>12.06/10.95</td>
</tr>
<tr>
<td>13 1/16&quot;</td>
<td>6.90/7.51</td>
</tr>
<tr>
<td>18 1/8&quot;</td>
<td>4.68/7.07</td>
</tr>
</tbody>
</table>

Fig. Wallow prototype heater 150-1 Heat zone and thermocouple layout (142.15 kW)
TIME TO CHF OBSERVED IN SINGLE ROD FACILITY WITH DIFFERENT BLOWDOWN CONDITIONS
Fig. Depressurization curves and sheath thermocouple response during blowdown in FCTF. (Rod power = 144 kW, break area 0.0051 ft², system volume = 1.6 ft³)
Fig. Depressurization curves and sheath thermocouple response during blowdown in FCTF. (Rod power 144 kW, break area 0.0051 ft², system volume - 2.5 ft³)
Fig. 1. Variation in mass flow rate indicated by instrumented spool piece with water flow rate for operation with and without a disperser (LS-3 + 4) and for different orientations of the same piece (3.5-in.-1D pipe; 256 scfm air flow).
Fig. 1. Mass flow rate calculated from output of turbine and drag disk meters when drag disk was upstream of turbine and flow disperser made with three 44-mesh screens spaced by four 5-mesh screens (air-water, 90 to 110°F; vertical position, 3.5-in.-ID pipe).