

## **1.5 Requirements for Further Technical Information**

### **Introduction**

Tests were conducted during the AP600 Conceptual Design Program (1986 through 1989) to provide input for plant design and to demonstrate the feasibility of unique design features. Tests for the AP600 design certification and design program were devised to provide input for the final safety analyses, to verify the safety analysis models (computer codes), and to provide data for final design and verification of plant components. An AP1000 specific Phenomena Identification and Ranking Table (PIRT) and scaling analysis (Reference 25) and a review of safety analysis evaluations of AP1000 (Chapter 15 of this DCD) show that AP600 and AP1000 exhibit a similar range of conditions for the events analyzed. This provides justification that the database of test information generated during the AP600 Conceptual Design Program is sufficient to meet the requirements of 10 CFR Part 52 for AP1000. Table 1.5-1 is a list of the AP600 tests and AP1000 evaluations with references to test and evaluation documentation. Note that Reference 25 reviews each of the AP600 tests described and assesses their applicability to AP1000. The evaluations of Reference 25 show that the AP600 tests are sufficient to support AP1000 safety analysis.

The AP600 tests related to the plant safety functions were selected based on the plant features that are different from current PWRs and where directly applicable experimental data are not available. The tests simulate plant features as required to demonstrate the phenomena being examined. To validate the computer models, these experiments are modeled using the same computer codes used for plant analyses.

Testing of some plant component designs is required to verify their reliability and manufacturability. Other component tests provide data for design optimization. The completed component design tests are described below.

### **1.5.1 AP600 Safety-Related Tests**

The AP600 safety-related experiments are designed to meet several goals:

- Provide input for safety analysis
- Provide data on the passive safeguards systems to validate the safety analysis methods and computer codes
- Assess the design margin in the passive safety system performance

To accomplish these goals, the AP600 test program utilizes the available data from the NRC and industry light water reactor safety research programs as well as specific tests which address the uniqueness of the AP600. The AP600 safety-related test program utilizes component experiments and integral tests to determine the transient behavior of the AP600 safety system components such that computer models can be developed and verified.

The range of plant conditions for design basis accidents and transients, and the new features of the AP600 design were evaluated against current Westinghouse designs and safety-related data available in the literature (NUREG-1230). The results of this assessment were used to determine

the data needs, and to define the experiments to support the AP600 safety analysis. Based upon the experiments performed for AP600 and the AP1000 range of plant conditions for design basis accidents and transients, the tests were shown to be sufficient to support AP1000 safety analysis as well.

### **1.5.1.1 Large-Break LOCA**

For large-break LOCA safety analysis, the relevant new features of the AP600 were the core makeup tanks (CMTs), which drain by gravity, and the use of hermetically sealed, high inertia centrifugal canned-motor reactor coolant pumps (RCPs). Two-phase pump flow data exists for Westinghouse designed pumps and others (NUREG-1230) that can be used to characterize the AP600 pumps. The core makeup tank is unique to the AP600 and AP1000 design. A specific AP600 test was conducted for this component. In addition, a test of passive safety injection system check valve flow vs.  $\Delta P$  with low differential pressure has been completed. The evaluation of Reference 25 shows that these tests are applicable to AP1000.

#### **Core Makeup Tank Performance Test**

The purpose of this experiment is to verify the natural circulation and draining behavior of the core makeup tank over a full range of flowrates, pressures and temperatures, and to provide data to support the design and operation of the tank level indication which acts as a control for the automatic depressurization system (ADS). When actuated, the CMT adds water mass to the reactor coolant system (RCS) by natural circulation when the cold leg contains hot water. The water in the core makeup tank drains by gravity head into the RCS when steam is provided from the cold leg to the top of the core makeup tank. This steam replaces the water drained from the core makeup tank. Some of the steam condenses upon entry into the core makeup tank and can affect the tank draining performance. The objective of the test is to verify that the tank will drain as predicted.

A one-eighth diameter and one-half height scale core makeup tank was constructed and instrumented to obtain the condensation rates within the tank to verify the computer model. The core makeup tank water delivery was examined.

#### **Passive Safety Injection System Check Valve Tests**

The AP1000 uses check valves to isolate passive systems from the reactor coolant system. Tests have been performed in the AP600 test program on these check valves to demonstrate their operability.

Tests were conducted to measure check valve pressure drop from very low flow to full flow conditions. Detailed data on initial valve opening, valve disk behavior and flow versus differential pressure were obtained for individual check valves as well as for valves installed in series.

Initial check valve low differential opening tests have determined the characteristic valve flow under the expected gravity drain conditions. A review of existing utility information has been conducted to assess check valve performance under conditions similar to those which would be experienced by the gravity drain check valves.

### **1.5.1.2      Small-Break LOCA**

For small-break LOCA safety analysis, the relevant new features of the AP600 and the AP1000 designs are the core makeup tank, and the automatic depressurization system which depressurizes the primary system to near containment pressure.

The core makeup tank provides injection flow to the reactor vessel at any reactor coolant system pressure. The core makeup tank tests described above duplicated small-break conditions as well as the large-break conditions. The automatic depressurization system provides controlled venting of the reactor coolant system to reduce pressure to allow transition to gravity driven injection from the IRWST. Full-scale tests were conducted in the AP600 test program to obtain data on the performance of the automatic depressurization system. As shown by the AP1000 evaluations, these tests also support AP1000 safety analysis.

#### **Automatic Depressurization System Hydraulic Tests**

The purpose of these tests is to simulate the automatic depressurization system, to confirm the capacity of the automatic depressurization system valves and spargers, and to determine the dynamic effects on the IRWST structure.

A pressurized, heated water/steam source was used to simulate the water/steam flow rate from the AP600 reactor coolant system during various stages of the automatic depressurization system blowdown. Two test phases were conducted. Phase A consisted of steam only blowdowns at bounding volumetric flowrates. The flow is piped to a full sized sparger submerged in a quench tank simulating the IRWST. The Phase B1 portion of the test included steam/water blowdowns at bounding mass flowrates through a simulation of one of the two ADS stage 1,2,3 flowpaths. Instrumentation to measure water and steam flow rate, and IRWST dynamic loads was installed. Sparger behavior was obtained from ambient to fully saturated IRWST water temperatures.

### **1.5.1.3      Containment Cooling**

Tests to characterize the heat removal capabilities of the AP600 containment design were performed to provide the database for the containment cooling models. These include the following:

- Study of water film behavior and wetting of a steel plate simulating the containment exterior surface
- Heated plate tests to examine the evaporating heat transfer of water from the steel surface of the containment and heat transfer with only air cooling
- Containment external cooling air flow path pressure drop tests to characterize the hydraulic losses
- Steam condensation heat transfer experiments on a flat cool surface at different angles of inclination to simulate the condensation on the inside of the containment in the presence of noncondensable gases

In addition, tests were performed to examine the integrated behavior of the steam condensation on the inside, and the evaporative film cooling and air cooling on the outside of a pressure vessel. The cylindrical vessel used for this integral test was 3 feet wide and 24 feet high. These experiments included transient and steady-state tests which have been used as the basis for the containment analyses. The limits of coolability and the effect of cold weather conditions were also examined.

As shown by the AP1000 evaluations, these tests also support AP1000 safety analysis.

### **Integral Containment Cooling Tests**

This test examines the combined effect of natural convection and condensation on the interior of the containment while the exterior is cooled by film evaporation and air flow. This test demonstrated the operation of the passive containment cooling system over a range of operating conditions, including operation at low environmental temperatures. This test, in conjunction with completed conceptual design phase testing and the large scale containment test described below, characterize the passive containment cooling system design and performance.

### **Passive Containment Cooling System Heat Transfer Test**

A one-eighth scale steel containment structure with external water film and natural circulation air cooling and modeled containment internal compartments was constructed.

This test accurately models both the containment dome and side wall heat transfer areas. It complements the integral containment experiment which simulates the side wall condensation and evaporating film heat transfer. This test was used to verify the containment analysis analytical methods.

Instrumentation measured the condensation heat flux distribution, the resulting heat transfer coefficients, the air/steam mass ratios, and the resulting liquid film evaporation rates. Both the current integral containment cooling test and this larger scale containment test have been modeled to verify the Chapter 15 analysis computer code and to demonstrate the scalability of the results.

### **Passive Containment Cooling System Water Distribution Test**

A passive containment cooling system water distribution experiment was performed to examine and finalize the AP600 containment water distribution. The results provide input into the containment safety analysis computer codes for water coverage of the containment shell.

The test was performed on a full-scale 1/8th sector of the containment dome. The AP600 water supply/distribution arrangement was modeled. Tests were conducted to demonstrate and measure the water spreading from the top center of the dome to the outer edges. Tests have been conducted to verify the performance of the water distribution system design. Tests were conducted with the surface coated with the prototypic AP600 containment coating. Measurements of water film velocities and film thickness variation as a function of flow rate and radial distance on the dome were obtained.

## **Passive Containment Cooling System Wind Tunnel Tests**

Containment cooling relies on natural circulation of air to enhance evaporative cooling of the containment shell during a design basis event. Wind tunnel tests were performed to demonstrate that wind does not adversely affect natural circulation air cooling through the shield building and around the containment shell.

An approximately 1/100-scale model of the AP600 plant, including the adjacent buildings and cooling tower structure, was constructed and instrumented with pressure taps. The model was placed in a boundary layer wind tunnel and tested at different wind directions. The results were used to design the shield building air inlet and exhaust arrangement and to determine the loads on the air baffle. Variations in site layout and topography have been addressed using an approximately 1/800-scale model of the site buildings and local topography.

Tests were also conducted in a larger, higher speed wind tunnel on an approximately 1/30-scale model. These tests were conducted to confirm that the early test results conservatively represented those expected at full scale Reynolds numbers and to obtain better estimates of the baffle loads in the presence of a cooling tower.

### **1.5.1.4 Non-LOCA Transient Analysis**

The non-LOCA accidents are evaluated using the same transient analysis methods used on existing Westinghouse PWR designs. Passive core cooling system computer models have been developed and added to the transient analysis codes. These models consist of a core makeup tank model and a passive residual heat removal (PRHR) heat exchanger model. As shown by the AP1000 evaluations, these tests also support AP1000 safety analysis.

#### **Passive Residual Heat Removal Heat Exchanger Performance Test**

The PRHR heat exchanger is located in the IRWST. This heat exchanger, which is connected directly to the reactor coolant system, transfers core decay heat and sensible heat energy to the IRWST water and depends only on natural circulation driving forces.

The passive residual heat removal heat exchanger test determined the heat transfer characteristics of the PRHR heat exchanger and the mixing characteristics in the IRWST. These results confirm the heat exchanger size and configuration.

The test facility consisted of three full-length heat exchanger tubes placed vertically in a cylindrical tank filled with water and baffled to simulate the AP600 IRWST. Water at prototypic natural circulation and forced flow rates was run through the heat exchanger tubes at prototypic system pressure and temperatures. Data was taken with IRWST water cold to saturation temperature to define the PRHR heat transfer correlation. Tests were also conducted using a baffle to simulate the effect of other rows of tubes have on heat exchanger thermal performance and tank mixing.

### **Departure from Nucleate Boiling Test**

Due to the shorter coastdown of the AP600 canned motor reactor coolant pumps, the flow rates at the time of minimum DNBR are somewhat below previously correlated flow rates. DNB testing was performed to extend the DNB correlation to these lower flows.

These critical heat flux tests were conducted using a 5x5, full length heated rod bundle with non-uniform radial and axial heating distributions.

### **1.5.1.5 Integral Systems Testing**

In the AP600, the water injected into the reactor coolant system comes from the CMTs, accumulators, and the IRWST. Two integral systems tests were conducted in the AP600 test program, a low-pressure scaled test and a full-height, full-pressure test. In addition, the NRC conducted tests in the low-pressure scaled test facility (Reference 27). As shown in the AP1000 evaluations (Reference 25), these three test programs are sufficient to support AP1000 safety analysis.

#### **Low-Pressure Integral Systems Test**

The primary purpose of this experiment was to examine the operation of the long-term makeup path from the in-containment refueling water storage tank. In addition, analysis of this experiment demonstrates water flow through the core to limit the long-term concentration of boric acid. The facility is capable of simulating high-pressure system responses.

The test models the reactor vessel, steam generators, reactor coolant pumps, in-containment refueling water storage tank, the automatic depressurization system vent paths, the lower containment, and the connecting piping. The hot legs and cold legs are modeled as are the core makeup tanks, PRHR heat exchangers, accumulators, and pressurizer.

Water is the working fluid and the core is simulated with electric heater rods scaled to match the core power levels consistent with the test scaling approach. Tests were performed to simulate various small-break LOCAs with different break locations, break sizes, with and without nonsafety systems operating. The analysis methods in Chapter 15 were compared to the test.

#### **Full-Height, Full-Pressure Integral Systems Test**

A test was performed to provide data on system performance at high pressure. This test facility is configured as a full-height, full-pressure integral test with AP600 features including two loops with one hot leg and two cold legs per loop, two core makeup tanks, two accumulators, a PRHR heat exchanger and an automatic depressurization system. The facility includes a scaled reactor vessel, steam generators, pressurizer and reactor coolant pumps. Water is the working fluid and the core is simulated with electric heater rods.

Tests were performed simulating small break LOCAs, steam generator tube ruptures and a steam line break transient. The analysis methods in Chapter 15 were compared to the test results.

### **1.5.2      AP600 Component Design Tests**

The component design tests will provide a larger database for design optimization during the detailed design of the plant. Tests on selected plant components were performed to confirm their reliability or that materials and fabrication methods meet ASME requirements. These tests are also applicable to the AP1000 design and analysis.

#### **Incore Instrumentation System Tests**

Systems similar to the AP600 and AP1000 top mounted fixed incore detector (FID) instrumentation have been demonstrated in operating plants. A test was performed to demonstrate that the system will not be susceptible to electro-magnetic interference (EMI) from the nearby control rod drive mechanisms.

The electro-magnetic interference test was performed by mocking up instrument cables, bringing them into close proximity with an operating control rod drive mechanism, and measuring the resulting noise induced on simulated flux signals.

#### **Reactor Coolant Pump/Steam Generator Airflow Test**

The airflow test was performed to identify effects on the pump performance due to non-uniform channel head flow distribution, pressure losses of the channel head nozzle dams and pump suction nozzle, and possible vortices in the channel head induced by the pump impeller rotation.

The air test facility was constructed as an approximate one-half scale mockup of the outlet half of the channel head, the two pump suction nozzles, and two pump impellers and diffusers. The channel head tube sheet was constructed from clear plastic to allow smoke flow stream patterns to be seen.

The results of the test showed no flow anomalies or vortices in the channel head were induced by the dual impellers.

#### **Reactor Coolant Pump High Inertia Rotor/Bearing Tests**

In the AP600 a rotor, manufactured of depleted uranium clad with stainless steel, was incorporated into the hermetically sealed, high inertia centrifugal canned motor reactor coolant pump to provide the required flow coastdown performance for loss of flow transients.

Tests have been performed to verify manufacturability of the rotor, to determine friction and drag losses, to verify the operating performance of the pivoted-pad bearings, and to develop a detailed quantitative knowledge of the factors influencing bearing design and performance.

Tests were performed to verify the drag losses of the rotor with the journal bearing located on the pump shaft. Approximately 1000 cycles of starts and stops were also performed as a life test to demonstrate that the rotor will maintain its dimensional stability. These tests were performed on the specially-constructed, full-scale rotor/bearing test rig.

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The results of these tests were used to check analytical methods used in the design of the AP1000 reactor coolant pump.

### **1.5.3      Combined License Information**

This section has no requirement for additional information to be provided in support of the Combined License application.

### **1.5.4      References**

1. WCAP-14217, "Core Makeup Tank Final Data Report," (Proprietary), WCAP-14218 (Nonproprietary), November 1994.
2. WCAP-13286, "AP600 Passive Core Cooling System Check Valve Test Final Report," (Proprietary), WCAP-13287 (Nonproprietary), April 1992.
3. WCAP-13891, "AP600 Automatic Depressurization System Phase A Test Data Report," (Proprietary), WCAP-14095 (Nonproprietary), May 1994.
4. WCAP-14324, "Final Data Report for ADS Phase B1 Tests," (Proprietary), WCAP-14325 (Nonproprietary), April 1995.
5. WCAP-14134, "AP600 Passive Containment Cooling System Integral Small-Scale Tests Final Report," (Proprietary), WCAP-14137 (Nonproprietary), August 1994.
6. WCAP-13566, "AP600 1/8th Large Scale Passive Containment Cooling System Heat Transfer Baseline Data Report," (Proprietary), Revision 1, WCAP-13567 (Nonproprietary), Revision 0, December 1992.
7. WCAP-14135, "Final Test Report for PCS Large Scale Phase 2 and Phase 3 Tests," (Proprietary), WCAP-14138 (Nonproprietary), Revision 3, September 1998.
8. WCAP-13353, "Passive Containment Cooling System Water Distribution Phase 1 Test Data Report," (Proprietary), WCAP-13354 (Nonproprietary), April 1992.
9. WCAP-13296, "PCS Water Distribution Test Phase II Test Data Report," (Proprietary), WCAP-13297 (Nonproprietary), March 1992.
10. WCAP-13960, "PCS Water Distribution Phase 3 Test Data Report," (Proprietary), WCAP-13961 (Nonproprietary), December 1993.
11. WCAP-13294, "Phase I Wind Tunnel Testing for the Westinghouse AP600 Reactor," (Proprietary), WCAP-13295 (Nonproprietary), April 1992.
12. WCAP-13323, "Phase II Wind Tunnel Testing for the Westinghouse AP600 Reactor," (Proprietary), WCAP-13324 (Nonproprietary), August 1992.



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13. WCAP-14068, "Phase IVa Wind Tunnel Testing for the Westinghouse AP600 Reactor," (Proprietary), WCAP-14084 (Nonproprietary), May 1994.
14. WCAP-14169, "Phase IVa Wind Tunnel Testing for the Westinghouse AP600 Reactor, Supplemental Report," (Proprietary), WCAP-14170 (Nonproprietary), September 1994.
15. WCAP-14091, "Phase IVb Wind Tunnel Testing for the Westinghouse AP600 Reactor," (Proprietary), WCAP-14092 (Nonproprietary), July 1994.
16. WCAP-12980, "AP600 Passive Residual Heat Removal Heat Exchanger Test Final Report," (Proprietary), WCAP-13573 (Nonproprietary), Revision 3, April 1997.
17. WCAP-14371, "AP600 Low Flow Critical Heat Flux (CHF) Test Data Analysis," (Proprietary), WCAP-14372 (Nonproprietary), May 1995.
18. WCAP-14252, "AP600 Low Pressure 1/4 Height Integral Systems Tests - Final Data Report," (Proprietary), WCAP-14253 (Nonproprietary), Revision 1, November 1998.
19. WCAP-14309, "AP600 Design Certification Program, SPES-2 Tests Final Data Report," (Proprietary), WCAP-14310 (Nonproprietary), Revision 2, May 1997.
20. WCAP-12648, "AP600 Incore Instrumentation System Electromagnetic Interference Test Report," (Proprietary), WCAP-13322 (Nonproprietary), Revision 1, April 1992.
21. WCAP-13298, "RCP Air Model Test Report," (Proprietary), WCAP-13299 (Nonproprietary), August 1991.
22. WCAP-12668, "AP600 High Inertia Rotor Testing - Phase I, Test Report," (Proprietary), WCAP-13321 (Nonproprietary), March 1990.
23. WCAP-13319, "AP600 High Inertia Rotor Testing - Phase 2 Report," (Proprietary), WCAP-13320 (Nonproprietary), August 1991.
24. WCAP-13758, "High Inertia Rotor Test Phase 3 Report," (Proprietary), WCAP-13759 (Nonproprietary), June 1993.
25. WCAP-15613, "AP1000 PIRT and Scaling Assessment," (Proprietary), WCAP-15706 (Nonproprietary), March 2001.
26. Not used.
27. NUREG/CR-6641, "Final Report of NRC Research Conducted at Oregon State University," August 1999.

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| Table 1.5-1   |                              |
|---|------------------------------|
| <b>AP600 DESIGN TESTS AND AP1000 EVALUATION</b>               |                              |
| <b>Test</b>   | <b>Reference</b>             |
| <b>LOCA Mitigation</b>  |                              |
| Core Makeup Tank Performance Test                             | (1)                          |
| Passive Safety Injection System Check Valve Test              | (2)                          |
| Automatic Depressurization System Hydraulic Test              | (3), (4)                     |
| <b>Containment Cooling</b>                                    |                              |
| Integral Containment Cooling Test                             | (5)                          |
| Passive Containment Cooling System Heat Transfer Test         | (6), (7)                     |
| Passive Containment Cooling System Water Distribution Test    | (8), (9), (10)               |
| Passive Containment Cooling System Wind Tunnel Test           | (11), (12), (13), (14), (15) |
| <b>Non-LOCA Transients</b>                                    |                              |
| Passive Residual Heat Removal Heat Exchanger Performance Test | (16)                         |
| Departure from Nucleate Boiling Test                          | (17)                         |
| <b>Integral Systems Tests</b>                                 |                              |
| Low Pressure Integral Systems Test                            | (18)                         |
| Full Height Full Pressure Integral Systems Test               | (19)                         |
| NRC Low Pressure Integral Systems Test                        | (27)                         |
| <b>Component Design Tests</b>                                 |                              |
| Incore Instrumentation System Test                            | (20)                         |
| Reactor Coolant Pump/Steam Generator Airflow Test             | (21)                         |
| Reactor Coolant Pump High Inertia Rotor/Bearing Test          | (22), (23), (24)             |
| <b>AP1000 Evaluation</b>                                      |                              |
| AP1000 PIRT and Scaling Assessment                            | (25)                         |