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MARK I 1/5-SCALE BOILING WATER REACTOR PRESSURE SUPPRESSION EXPERIMENT FACILITY REPORT

Written and Compiled by
R. G. Altes, J. H. Pitts, R. F. Ingraham, and E. K. Collins
E. W. McCauley and J. H. Pitts, Principal Investigators

October 11, 1977

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LAWRENCE LIVERMORE LABORATORY
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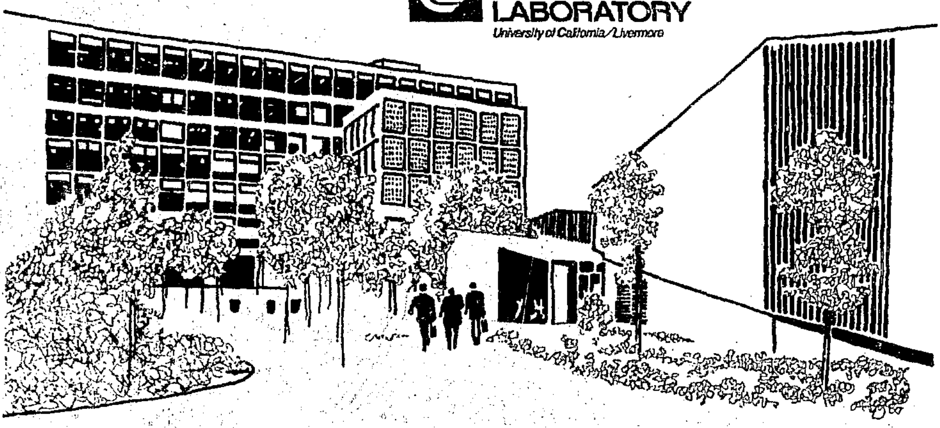

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ABSTRACT

An accurate Mark I 1/5-scale, boiling water reactor (BWR), pressure suppression facility was designed and constructed at Lawrence Livermore Laboratory (LLL) in 11 months. We performed 27 air tests using the facility, obtaining high quality data. Cost was minimized by utilizing equipment borrowed from other LLL programs. The total value of borrowed equipment exceeded the program budget of $2,020,000. We incorporated substantial flexibility in the facility to permit independent variation in the drywell presure-time history, initial pressure in the drywell and toroidal wetwells, initial toroidal wetwell water level and downcomer length, vent line flow resistance, and vent line flow asymmetry. The two- and three-dimensional sectors of the toroidal wetwell provided significant data.

1. INTRODUCTION

Scope

This report describes the Lawrence Livermore Laboratory (LLL) Mark I 1/5-scale, boiling water reactor (BWR), pressure suppression facility, designed and constructed at the request of the Water Reactor Safety Research Branch of the United States Nuclear Regulatory Commission (NRC) to:

- Obtain data [1] that would aid in the assessment of existing Mark I BWR designs and used to check theoretical predictions of the operating characteristics.
- Determine the dynamic loading of pressure suppression systems.
- Provide insight into the hydrodynamic phenomena associated with such systems.

This report is divided into nine sections. Section 1 describes the pressure suppression experiment project and provides a description of the pressure suppression facility and its operation. Section 2 contains an overview of the scaling studies conducted. The resulting scaling relationships permitted construction and operation of a 1/5-scale facility that exhibited phenomena similar to that anticipated in a full-scale Mark I BWR plant. Sections 3 through 8 describe the design and construction of the facility test pad, drywell, nitrogen storage system, toroidal wetwell test sections, flash boiler, and auxiliary systems. Section 9 describes the operation of the facility.

Experimental Project Description

In the pressure suppression containment design of a light-water reactor, the success of the system design is based on the capability of water as a heat sink to provide rapid and stable condensation of the released primary coolant during a hypothetical loss-of-coolant accident (LOCA). In the Mark I BWR design, the pressure suppression system encompasses a lightbulb-shaped drywell that contains the reactor and channels the steam released during a LOCA into a toroidal suppression pool. The reference plant used here is the 1065 MW(e) Peachbottom 2 Nuclear Power Plant.

The performance of Mark I BWR pressure suppression systems has been the subject of continuing investigation. LLL's experimental program provides a large-scale (1/5) extension of these investigations into three dimensions. The experimental program was planned to consist of two parts: air tests and steam tests. The air tests are complete, and the facility for that work is the subject of this report. The need for these tests was based not only on the need for the assessment of existing system designs, but also to provide insight

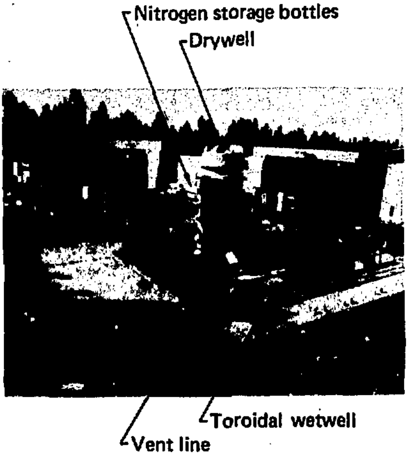

Fig. 2. Mark I 1/5-scale BWR experimental test facility.

into the basic hydrodynamic phenomena associated with wetwell behavior. In addition, the test results provide an extensive data base for computer code development and validation.

Immediately upon initiation of the project, we constructed a 1/64-scale model of a complete Mark I BWR pressure suppression system (Fig. 1). We then performed tests on the 1/64-scale model to validate the tentative selection of a 90° toroidal wetwell sector for the 1/5-scale facility. These tests confirmed that the hydrodynamic phenomena in a 90° sector are similar to those in a 360° sector.

Air scaling experiments were also conducted in a series of bench tests utilizing spherical flasks to simulate phenomena associated with downcomer clearing. The bench tests confirmed theoretical scaling relationships developed previously by others,[2] but suggested that peak vertical loads would be insensitive to changes in the flow resistance between the drywell and the toroidal wetwell.

Concurrently, a Mark I 1/5-scale BWR experimental facility (Fig. 2) was designed, suitable for simulating the three-dimensional transient conditions that are encountered in all phases of a wetwell pressure suppression system during a hypothetical LOCA. We intended the design to ensure that quality data would be obtained. Because the ultimate operating parameters were not entirely known at the start of the program, flexibility was incorporated into the facility design. The geometry of the 90° sector vent lines and all details of the wetwells were faithfully scaled from the Peachbottom 2 plant.

The instrumentation was selected to accurately measure the desired parameters in air, water, and steam environments. Eight types of instrumentation[3] were used in the 1/5-scale facility: pressure transducers, load cells, Pitot-static tube differential pressure gages, orifice differential pressure gages, visual gages, pool swell transducers, strain gages, and thermocouples as well as photographic equipment, consisting of a Storz lens system and various high-speed cameras.[4] All instrumentation was tested and calibrated prior to installation to ensure data accuracy. An electronic readout system was assembled to accurately record more than 200 channels of data anticipated.[3]

An experimental measurements program was outlined for the air test phase of the Mark I 1/5-scale BWR test facility in order to obtain the air/water-induced hydrodynamic vertical load function and to determine the response of the toroidal wetwell structure. During the air test phase, the drywell and toroidal wetwells were initially evacuated to 1/5 atmosphere so that scaling relationships developed earlier could be utilized to apply the 1/5-scale test results to full-scale plant conditions. To initiate an air test, the drywell was

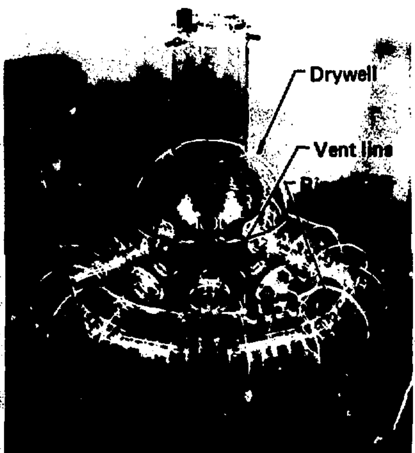

Fig. 1. Mark I 1/64-scale BWR pressure suppression system.

dynamically pressurized with nitrogen from storage bottles in a fashion simulating an LOCA. Gas flowed into the toroidal wetwells and expelled water from the partially submerged downcomers. This phase of the program focused on the vertical loading functions (both hydrodynamic and response) resulting from clearing the downcomers of water.

The second phase of testing, planned but not executed, consists of using a steam source rather than a nitrogen source. This phase of the program is presently under evaluation by NRC and remains to be completed.

Since a large amount of data must be recorded for each pressure suppression experiment, the data processing system records all data magnetically in real time for later off-line processing and reduction. Each signal source (i.e., transducer) is coupled to a low-frequency acquisition unit (LoFAU).[3] The LoFAU system contains signal conditioning, amplifying, and conversion equipment that is ultimately used to convert analog data signals to a coded-pulse format for on-line storage on magnetic tape. The tapes are later converted to digital format in preparation for final processing. Final processing to graphic or tabular form is performed by a CDC-7600 computer, using various data analysis software.

Facility Description and General Operation

LLL's Mark I 1/5-scale BWR test facility consists of two toroidal wetwells, a drywell, a flash boiler (yet to be installed), and nitrogen storage vessels (shown in Figs. 3 through 6). Extensive flexibility is permitted by independent variation of geometry, initial conditions, and drywell pressurization rate.

The toroidal wetwells consist of one 90° segment and one 7.5° segment containing 24 and 2 downcomers, respectively. The capabilities of the facility are:

- Toroidal wetwell segment configurations of 90°, 45°, and 7.5°.
- Drywell pressure-time history that includes selecting a desired initial inlet nitrogen flow rate.
- Separately-varied initial drywell pressure and toroidal wetwell pressure.

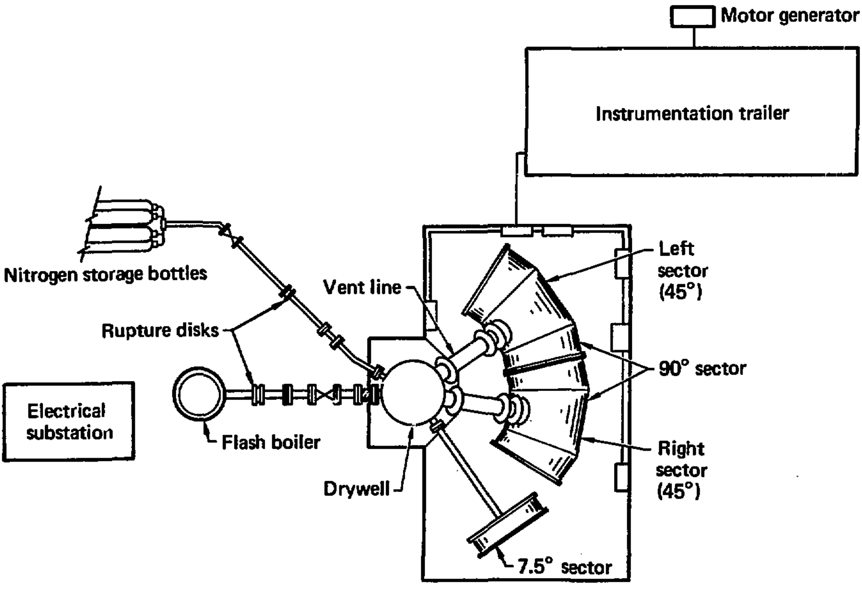

Fig. 3. Schematic of 1/5-scale pressure suppression experiment facility.

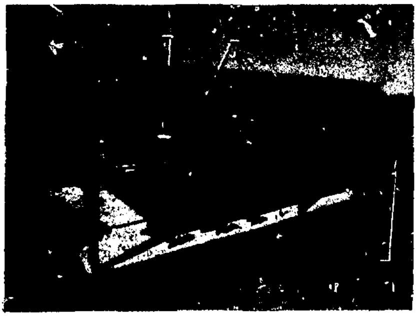

Fig. 4. Test facility.

- Initial water level in the toroidal wetwells.
- Downcomer length.
- Vent line flow asymmetry.
- Vent line flow resistance.

Downcomer submergence may be varied by changing the water level in the toroidal wetwells, changing the length of the downcomers, or changing both.

During a test, the air above the water level in the toroidal wetwells and the drywell is pumped down to 20 kPa (1/5 atmosphere). The nitrogen storage

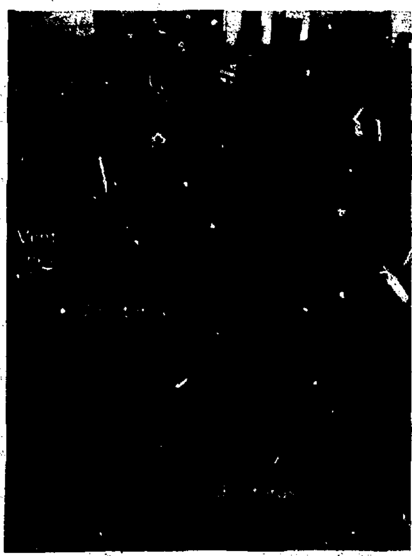

Fig. 5. Test facility from edge of pit.

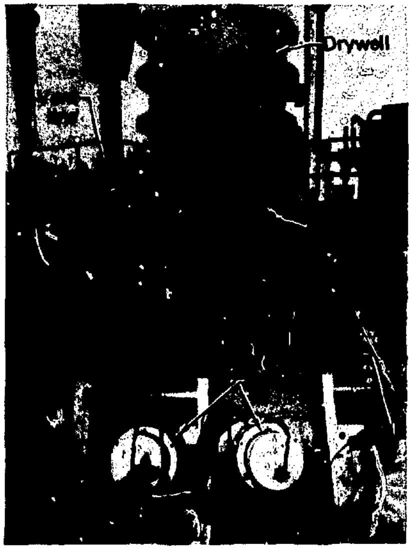

Fig. 6. Test facility from inside pit.

bottles are then charged from a portable bank of high-pressure containers to a pressure of up to 7 MPa (1000 psi), depending on the test conducted. The exit line from the nitrogen storage bottles to a rupture disk assembly is also charged. The rupture disk assembly consists of two rupture disks separated by a chamber of nitrogen pressurized to about half the pressure in the nitrogen bottles. Upon activation by solenoid valve, the chamber is opened to atmospheric conditions. As the pressure drops to atmospheric, the differential across the upstream rupture disk increases causing it and the downstream disk to rupture almost simultaneously, allowing the nitrogen to enter the drywell. The line between the rupture disk assembly and the drywell contains a flow nozzle the size of which may also be varied from test to test as desired to further control flow.

The incoming nitrogen pressurizes the drywell and exits into three vent lines simultaneously. One vent line goes to the 7.5° sector, and the other two lines connect to each side of the 90° torus. The drywell nitrogen is passed through the vent lines into the ringheaders in the two toroidal wetwell sections and from the ringheaders through the downcomers. The nitrogen exiting the downcomers then raises the water level (pool swell) in the toroidal wetwell sectors and creates forces on the wetwell structure and its supports. The force (or load) measurements are of primary interest in these tests.

Design Parameters

The design parameters for the major components of the Mark I 1/5-scale BWR test facility are given in Table 1 along with comparable values for the Peachbottom 2 reference plant. In the 1/5-scale facility, the 19-mm (0.75-in) thick toroidal wetwell outside shell, vent pipes, and drywell are designed to comply with the ASME Unfired Pressure Vessel Code, Section VIII.[5] The flash boiler is designed and fabricated to comply with the ASME Power Boiler Code, Section I.[6]

Table 1. Design parameters of test facility major components.

Item	Full-scale prototype (Peachbottom 2 reference plant)	1/5-scale, 90° sector plus 7.5° sector
Toroidal wetwell		
Air volume, m^3 [a]	3370 (119,000 ft^3)	7.6 (267 ft^3)
Water volume, m^3 [a]	4135 (146,000 ft^3)	6.9 (245 ft^3)
Maximum internal pressure, kPa	450 (65 psia)	450 (65 psia)
Minimum internal pressure, kPa	–	3 (0.5 psia)
Maximum temperature, °C	Unknown	149 (300°F)
Major diameter, m	33.99 (111.5 ft)	6.80 (22.3 ft)
Minor inside diameter, m	9.4 (31 ft)	1.9 (6.2 ft)
Wall thickness, mm	15.3 (0.604 in.) top	19 (0.75 in.)
	17.1 (0.675 in.) bottom	19 (0.75 in.)
Drywell		
Volume, m^3	4500 (159,000 ft^3)	9.87 (349 ft^3)
Maximum internal pressure, kPa	450 (65 psia)	793 (115 psia)
Minimum internal pressure, kPa	–	3 (0.5 psia)
Maximum temperature, °C	Unknown	180 (350°F)
Vent pipe		
Diameter, m	2.06 (6.75 ft)	0.412 (1.35 ft)
Wall thickness, mm	6.4 (0.25 in.) minimum	6.4 (0.25 in.)
Ringheader		
Inside diameter, m	1.45 (4.75 ft)	0.29 (0.95 ft)
Wall thickness, mm	6.4 (0.25 in.)	5.1 (0.20 in.)
Downcomer		
Inside diameter, m	0.61 (2.0 ft)	0.12 (0.40 ft)
Wall thickness, mm	6.4-9.52 (0.25-0.375 in.)	2.4 (0.095 in.)
Submergence, m	1.2 (4.0 ft)	0.2 (0.8 ft)
Nitrogen supply storage bottles		
Maximum internal pressure, MPa	–	40 (6000 psia)
Expected maximum operating pressure, kPa	–	7000 (1000 psia)
Maximum operating temperature, °C	–	40 (100°F)
Air storage capacity, m^3	–	1.3 (45 ft^3)
Steam supply		
Maximum internal pressure, kPa	–	8000 (1160 psig)
Maximum temperature, °C	–	315 (600°F)

[a] Air and water volumes in the full-scale prototype column were calculated as if the water level were at the horizontal centerline of the toroidal wetwell. In the 1/5-scale experiment, the water level was normally 0.3 m (1 ft) below the horizontal centerline. Air and water volumes in the 1/5-scale column are calculated with the water level 0.3 m (1 ft) below horizontal centerline.

2. SCALING RELATIONSHIP STUDIES

Effects of Angularly Limiting the Toroidal Wetwell

The use of the 1/5-scale model to predict the behavior of a full-scale BWR system requires an understanding of both the effects of limiting the angular extent of the toroidal wetwell and the fluid scaling relationships between the model and the prototype. To establish the suitability of limiting the angular extent of the toroidal wetwell to less than 360°, a complete 1/64-scale model of a Mark I BWR drywell and toroidal wetwell was constructed (see Fig. 1). Tests were conducted using ambient air to pressurize a partially evacuated drywell and wetwell. Pairs of disks were placed inside the toroidal wetwell at included angles of 90°, 45° and 22.5°. These disks acted as artificial boundaries so that the effects of 360°, 90°, 45° and 22.5° sectors on bubble growth and pool swell could be observed. Pressures were recorded as a function of time in the drywell and in the air space and below the water surface of the toroidal wetwell. High-speed photography was used to record the response.

Results from this series of tests indicate that neither bubble growth nor pool swell motion are affected by positioning artificial boundaries at 90°, 45° or 22.5° included angles. These results confirmed the conclusion that a 90° sector of toroidal wetwell is satisfactory for the 1/5-scale experiment. A minimum of a 90° sector was needed to study asymmetry effects in the 1/5-scale facility during some tests when one of the two vent pipes supplying the 90° sector with nitrogen was blocked.

Air Scaling Studies

Air scaling relationships were determined by both analytical and experimental means. Dimensional analysis[7] leads to two dimensionless groupings to relate pressure and time. These groupings are

$$\frac{p}{\rho g L} \qquad (1a)$$

and

$$\frac{t^2 g}{L}, \qquad (1b)$$

where p is pressure, ρ is water density, g is the gravitational constant, L is a characteristic length, and t is time. These groupings can be considered constant between model and prototype. Pressures and times on a 1/5-scale experiment correspond to pressures and times on a full-scale prototype multiplied by 1/5 and 1/5, respectively.

Limited scaling laws, valid during bubble growth and until the bubbles break the water surface, have been developed.[2] They relate the enthalpy flux (energy flow) passing through the vent lines in the model and prototype by

$$\frac{mh}{L^{7/2}} = constant, \qquad (2)$$

where m is mass flow rate through the vent pipes and h is the air specific enthalpy. If this relationship is followed, the overall vent-system loss coefficient[8] for air or nitrogen passing through the vent pipe–ringheader–downcomer system should be related by

$$L\left(\frac{f\ell}{d}\right)_{vent} = \text{constant}, \qquad (3)$$

where $(f\ell/d)_{vent}$ is the loss coefficient equal to the frictional coefficient f times the equivalent length-to-diameter ratio of the vent system, $(\ell/d)_{vent}$ (including entrance and exit losses). In a geometrically scaled experiment, $(\ell/d)_{vent}$ remains constant. The frictional coefficient f varies with the Reynolds number and relative roughness, although f does remain nearly constant for high Reynolds numbers. In the absence of any convenient method for obtaining distributed loss-coefficient increases, discrete flow-restriction devices (such as an orifice plate) need to be inserted in the vent system to satisfy Eq. (3).

Experimental work was conducted at LLL[9] where air was discharged through a partially submerged vent system into either a 5-ℓ or 0.5-ℓ spherical flask. The flask was approximately half-filled with water and simulated the wetwell as shown in Fig. 7. The results suggest that the peak download occurring at about the time of vent clearing is better scaled without the introduction of an orifice in the vent system. Further, the peak upload, occurring at about the time the bubbles break the water surface, is equally well-scaled with or without an orifice in the vent system.

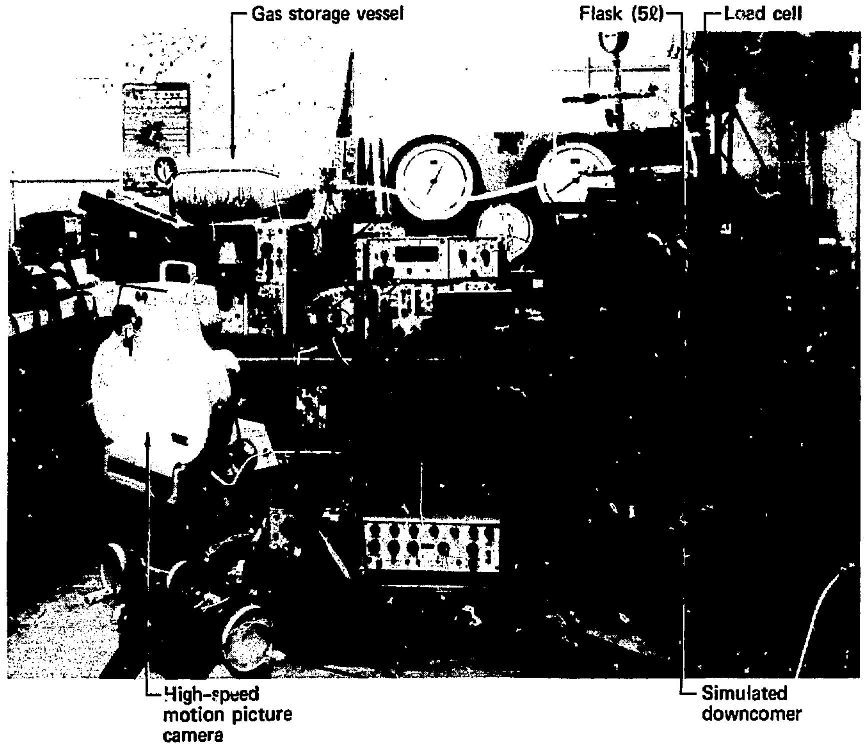

Fig. 7. Bench test facility showing spherical flask half-filled with water (simulating wetwell). Only one flask is used; mirror gives the impression two flasks are present.

3. TEST PAD

Introduction

To obtain the desired experimental data, it was necessary to provide a test facility that would permit measurement of the phenomena associated with the loads imposed upon the toroidal wetwell with negligible deflection of the wetwell mounting floor itself. The floor supporting the toroidal wetwells was designed to minimize deflections and provide a facility that would lend itself to the required geometry of the Mark I pressure suppression system.

Description

The pressure suppression experimental facility contains a reinforced concrete test pad with space available around the pad for equipment and instrumentation trailers and other required auxiliary equipment. The test pad is composed of a subgrade reinforced concrete pit surrounded by a grade level reinforced concrete slab. The toroidal wetwells are bolted to the pit floor.

The pit is 5.0 m by 6.1 m (16.5 ft by 20 ft) in area and 2.7-m (9-ft) deep. A step is located on one side of the pit 1.4 m (4.5 ft) below grade. The drywell vessel is mounted on the step secured by 36 cast-in-place steel studs. Plan and elevation views of the pit and surrounding concrete are shown in Figs. 8 and 9. (The location of the toroidal wetwells and the drywell are shown in phantom in the figures.) The toroidal wetwells are mounted in the bottom of the pit on supports bolted to the steel pads cast into the pit floor. The pads shown on the plan view have a vertical uplift capacity of 110 kN (25,000 lbf) each. A sump is incorporated in one corner of the pit and is equipped with a sump pump. The floor of the pit is sloped approximately 0.02 m per meter (0.25 in. per ft) toward the sump.

The floor of the pit is reinforced concrete, 0.3 m (1 ft) thick. Beneath the slab is an additional 0.9-m by 0.9-m (3-ft by 3-ft) reinforced concrete beam in line with the main 90° toroidal wetwell trunnion supports. The beam is shown *in phantom in* Fig. 8. Foundation deflections were calculated using a finite element, structural-analysis code. Input loads for the analysis were approximately two times the expected peak test loads. Specifically, downloads of 200 kN (45,000 lbm) under each of the two trunnion supporting the 90° torus, 110 kN (25,000 lbm) under each end of the 90° torus, and 90 kN (18,000 lbm) under each support for the 7.5° sector were applied. All of the computed deflections were equal

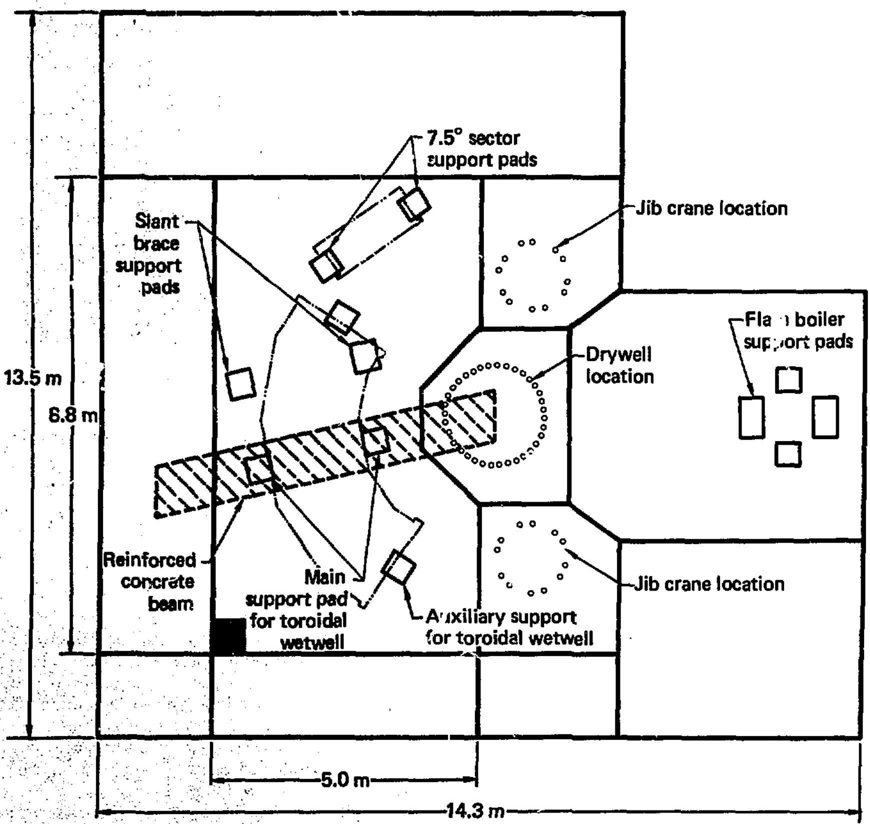

Fig. 8. Plan view of the 1/5-scale pressure suppression experiment facility test pad.

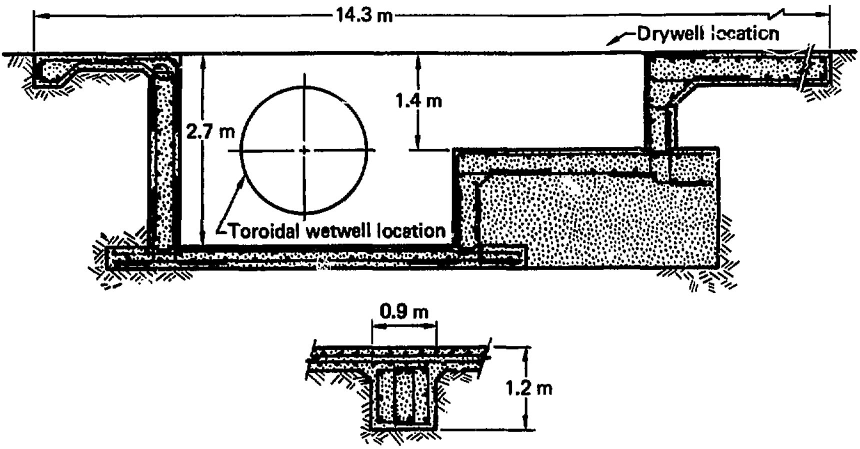

Fig. 9. Cross section of test facility pit and concrete beam below toroidal wetwell main supports.

to, or less than 0.2 mm (0.01 in.). Figure 10 is a three-dimensional deflection plot for the pit floor produced by digital computer. The figure shows relative static deflection with all expected peak loads applied simultaneously. Since the deflections are less than 0.2 mm (0.01 in.), the floor on which the toroidal wetwells are mounted offers an essentially rigid base. In fact, the deflections were so small, they could not be measured with state-of-the-art instruments.

Cast-in-concrete studs are provided on the reinforced concrete grade level slab surrounding the pit for two 27-kN (6,000-lbm) capacity jib cranes. The cranes were installed for removal of toroidal wetwell end plates and for lifting equipment into and out of the test pit. Additional steel pads were cast into the grade level concrete slab for mounting the flash boiler. These pads are similar to the wetwell mounting pads and also have a vertical uplift capacity of 110 kN (25,000 lbf). The nitrogen line and associated support brackets are also mounted on the grade level slab. The nitrogen storage vessels are mounted on grade level just off the test pad.

Following installation of the drywell and wetwells, a corrugated sheet metal roof was installed over the test pit. All features of the facility such as safety ladders and handrails around the pit meet LLL hazards control requirements.

Design specifications for the test pad are listed in Table 2.

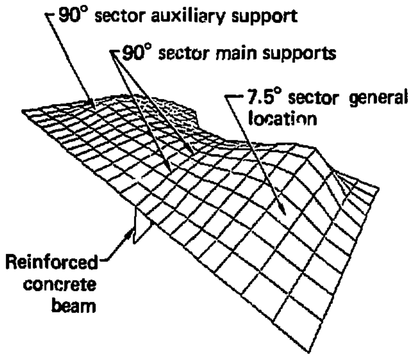

Fig. 10. Calculated three-dimensional deflection plot of the pit floor.

Design Specifications and Parameters

Table 2. Test pad specifications and parameters.

Item	Specification
Overall pad dimensions	13.4 m × 14.3 m (44 ft × 47 ft)
Construction	Reinforced concrete
Concrete compressive strength	211 kg per cm^2 (3000 lb/in.^{2}) @ 28 d
Reinforcing bar	
Type	Deformed steel bar
Minimum yield strength	413,640 kPa (60,000 psi)
ASTM specification	A615 or A616
Pit	
Size	5.0 m × 8.8 m (16.5 ft × 29 ft)
Depth below grade	2.7 m (9 ft)
Drywell step, depth below grade	1.4 m (4.5 ft)
Floor thickness	0.3 m (1 ft)
Floor reinforcing beam	
Size	0.9 m × 0.9 m (3 ft × 3 ft)
Location	Below 90° wetwell main supports
Grade level slab	
Thickness	
Under jib cranes and flash boiler	0.46 m (18 in.) minimum
Other	0.20 m (8 in.) minimum
Equipment mounting pads	
Type	Steel plate and rebar
Installation	Cast in concrete
Vertical uplift capacity	110 kN (25,000 lbf)
Cranes	
Type	Jib
Quantity	2
Capacity, each	27 kN (6,000 lbf)
Major LLL drawings	
Concrete work	AAA 76-105656-OC
Finish grading plan	PLC76-099-052E
Mechanical details	PLM76-099-030D AAA76-114047-OO
Electrical plot plan, details	PLE76-099-061D

Construction

The site work in preparation for test pad construction was carried out by a commercial contractor. On-site inspection of all construction work was performed by LLL Plant Engineering personnel.

4. DRYWELL

Introduction

The drywell design has a volume scaled to properly supply the 90° and 7.5° toroidal wetwells. Capability is provided for evacuation to subatmospheric pressure, for instrumentation, and for personnel access. Jet deflectors are installed on the entrances to the vent pipes in a fashion simulating the full-scale prototype plant. During all tests, nitrogen in the drywell is simultaneously discharged through the three vent lines to the 7.5° and the two 45° toroidal wetwell sectors.

Description

The drywell vessel is a right-circular cylinder with a 1.67-m (66-in.) outside diameter and approximately 5.4 m (18 ft) long. The vessel is mounted with its longitudinal axis vertical on a reinforced concrete shelf approximately 1.4 m (54 in.) above the floor of the test pit. The vessel is secured by 32-mm (1.25-in.) diameter anchor bolts (36) cast in a reinforced concrete pad. The vessel was designed and fabricated in accordance with ASME Section VIII, Rules for Construction of Pressure Vessels, Division I [5] and is code-stamped.

The main connections made to the drywell vessel are for the nitrogen inlet line, vent pipes to the 90° and 7.5° toroidal wetwells, vacuum pumping port, and the steam line as shown in Figs. 11 and 12. A 0.60-m (24-in.) flange with a hinged blank-off plate is mounted on the side of the vessel for access. All nozzles were designed to withstand hypothetical thrust and bending moments. The loads corresponding to main nozzles of interest are shown in the drywell specifications.

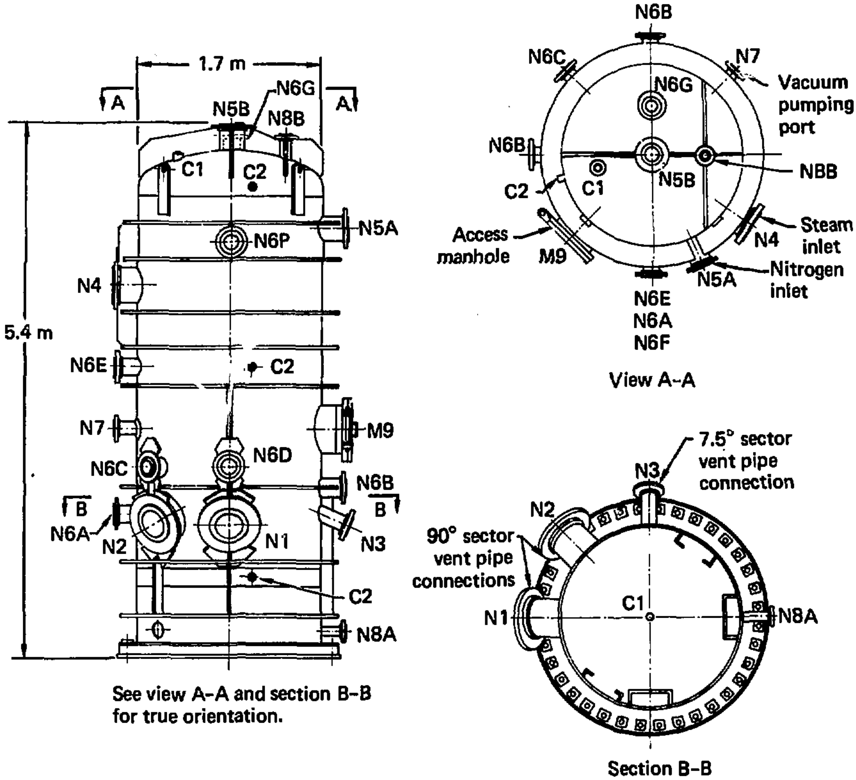

Fig. 11. Drywell design for the 1/5-scale pressure suppression experiment.

Fig. 12. Drywell without thermal insulation.

Fabrication

Fabrication tolerances on the vessel were nominally 0.6 m (0.25 in.) with the exception of the location of nozzles for vent lines to the 90° and 7.5° toroidal wetwell sectors. The three nozzles are 45° apart in the plan view, and the central axis of all nozzles leaving the drywell vessel is sloped down 22.5° from a horizontal plane. The location and orientation of the two vent pipe nozzles for the 90° torus were critical since any angular or positional error would be increased in direct proportion to the distance between the drywell nozzle and the corresponding nozzles on the wetwell. Gross misalignment would make installation of vent pipes difficult if not impossible. The nozzles were to be located within 3.2 mm (0.125 in.) of true position on the completed vessel. To expect this type of tolerance on a welded assembly was extremely optimistic. As a precautionary measure, bevel plate assemblies were designed for installation at the drywell end of the vent pipe assembly. These assemblies could compensate for up to 3° of misalignment.

After the fabrication was completed, the drywell volume was determined experimentally. The method of measurement utilized a calibrated volume that was filled with high-pressure helium. The calibrated volume was then connected to the drywell and the pressures equalized. Measurements of initial and final pressures and temperatures enabled calculation of the drywell volume.[10]

Installation

The drywell vessel was the first piece of fabricated hardware to be received for the pressure suppression experiment. The drywell was installed and grouted in place prior to positioning the toroidal wetwells, associated supports, and vent pipes. The drywell had to be accurately positioned to allow vent and toroidal wetwell sections to bolt up properly with toroidal wetwell support stands over the steel foundation plates installed in the concrete floor.

With the aid of contract millwrights, the following steps were taken to ensure the drywell would be properly positioned:

- The relative height of all eight floor plates was established using an optical level.
- The height of the drywell was calculated based on the geometry of the drywell, toroidal wetwells, and supports and the highest pad in the floor.
- Centerlines for the 7.5° and 90° toroidal wetwells and flash boiler were laid out from the center of the drywell location and scribed in the concrete floor.

The drywell was positioned on the pad, shimmed, and rotated until the best compromise position was reached. Following are steps taken and positional accuracies for the drywell vessel:

- Elevation of the 90° wetwell vent pipe flanges above a reference floor plate was adjusted to within 6.3 mm (0.250 in.).
- The vessel was rotated until the bisector of the angle between the 90° toroidal wetwell vent pipe flanges, the centerline of the steam line flange, and centerline of the 7.5° toroidal wetwell were within 4.1 mm (0.160 in.) of the scribed centerline in the concrete.
- The vessel was shimmed until a line established between the centerline of the 90° toroidal wetwell flanges was horizontal to within 1.5 mm (0.060 in.).
- The vessel had to be tilted so the flange face angle on the 90° torus vent flanges with respect to the vertical plane was as close to 22.5° as possible. One flange is within 0.10° of 22.5°; however, the second flange was misaligned when welded into the vessel. Its angle with the vertical plane was 23.2°. The bevel plates used between the drywell and vent pipes compensated for this misalignment, and no difficulties arose during the subsequent torus-vent pipe assembly.

After final checks of vessel position, the nuts were installed on anchor studs and tightened. The space between the shimmed vessel and the concrete slab was grouted with metallic grouting compound.

Calculations were performed to determine insulation requirements for the drywell vessel. Criteria were to limit the temperature change after heaters were turned off to 11° C (20° F) in one-half hour from a temperature of 420° K (300° F). The calculations indicate heat loss through 38 mm (1.5 in.) of 67 kg/m^3 (4.2 lbm/ft^3) fiberglass to be approximately 190 W/m^2 (60 $Btu/hr/ft^2$).

The insulation was installed using stick pins cemented to the vessel in advance of actual insulation installation as shown in Fig. 12. The insulation is then pushed over the pins and retained by a small self-locking metal plate pushed onto each pin. The insulation was covered with fiberglass mesh and coated with weather-resistant mastic.

Design Specifications and Parameters

Design specifications and parameters for the drywell are listed in Table 3. Also included is the major specification drawing number. The drawing is available for a limited time through LLL.

Table 3. Drywell design specifications and parameters.

Item		Specification
Outside diameter		1.67 m (66 in.)
Overall height		5.43 m (214 in.)
Volume		9.88 m^3 (349 ft^3)
Design pressure		758 to 101 kPa (110 to -14.7 psig)
Design temperature		420°K (300°F)
Test pressure		1.1 MPa (165 psig)
Shell material		Steel - SA-516-70
Nozzle design loads		
Nozzle	Thrust	Bending moment
90° torus vent	93 kN (21,000 lbf)	41 kN·m (360,000 in lbf)
7.5° torus vent	13 kN (3,000 lbf)	0.7 kN·m (6,000 in lbf)
Steam line	160 kN (35,000 lbf)	20 kN·m (180,000 in lbf)
All others	9 kN (2,000 lbf)	0.7 kN·m (6,000 in lbf)
Rupture disk rating		689 kPa (100 psig)
Gaskets		Flexitallic type G
Vessel weight		7030 kg (15,500 lbm)
Code stamp		ASME U
Installation location accuracy		
Elevation		Within 6.3 mm (0.25 in.)
Rotation		Within 4.1 mm (0.16 in.)
90° vent flanges		
Adjoining centerline horizontal		Within 1.5 mm (0.06 in.)
Flange face angle		Within 0.7°
Insulation		
Type		Fiberglass board
Density		67 kg/m^3 (4.2 lb/ft^3)
Thickness		38 mm (1.5 in.)
Theoretical heat loss		190 W/m^2 (60 Btu/hr/ft^2)
Coating		Fiberglass and mastic
Grout		
Type		Metallic
Manufacturer		The Burke Company
Compressive strength		
Setting time	Compressive strength	
6 h	8.3 MPa (1,200 lb/in.)	
1 d	37.9 MPa (5,500 lb/in.)	
3 d	54.4 MPa (7,900 lb/in.)	
7 d	75.8 MPa (11,000 lb/in.)	
28 d	83.0 MPa (12,000 lb/in.)	
LLL drywell vessel specification drawing		AAA-76-107979-OB

5. NITROGEN STORAGE SYSTEM

Introduction

The nitrogen storage system consists of six storage bottles, a manifold, and a high-pressure pipeline that allows nitrogen flow from the storage bottles to the drywell. An isolation valve, rupture disk assembly, and flow nozzle are installed in the pipeline. A schematic and a photograph of the nitrogen supply system are shown in Figs. 13 and 14.

The length of pipeline extending into the drywell vessel, which is perforated, acts as a diffuser during blowdown (Fig. 15). The pipe from nitrogen storage vessels to the drywell vessel is supported on pipe stands at intervals along the pipeline. The pipe support nearest the drywell is designed to not only support the weight of the line, but also prevent upward motion from reaction forces during blowdown.

Description

High-pressure nitrogen for blowdowns is contained in a cluster of modified 0.41-m (16-in.) o.d. Titan I gas storage bottles. One of the original seven bottles in the cluster was removed, the manifold system modified, and new flanges and fittings added. Each of the remaining six bottles has a small shutoff valve used for pressurization, a pressure gage, and a thread-in type rupture disk assembly mounted on a short section of pipe welded in the inlet manifold of the vessel. A 63-mm (2.5-in.), raised-face flange (for mating to the new manifold) was welded to the inlet of each vessel. The discharge restriction in each vessel is 38 mm (1.5 in.) i.d.

The useable volume inside the bottles was reduced by adding coal tar epoxy prior to assembly. The total useable volume of the six cylinders is approximately 1.3 m^3 (46 ft^3). The useable volume of individual cylinder bottles ranged from 0.08 m^3 to 0.44 m^3 (2.8 ft^3 to 15.5 ft^3).

A pipe section containing a shutoff valve is connected to each of the six bottles. All six pipe section assemblies are connected to a larger 15.3-cm (6-in.) diameter manifold. This larger manifold is bolted to the main nitrogen line isolation valve. To prepare for a particular test, a combination of bottles is selected. The resultant total volume is pressurized to a predetermined value up to 6.9 MPa (1000 psia) so that the desired drywell pressurization rate is achieved. The unpressurized vessel valves remained closed from the manifold.

The pipeline between the isolation valve and the drywell vessel contains pipe spools, a double rupture disk assembly, and a standard ASME flow nozzle. The spools are sections of pipe with weld neck flanges on either end. Each spool has fittings welded to it to accommodate the necessary instrumentation. The double rupture disk assembly is made up of three separate heavy wall rings. The assembly with appropriate face seals on both ends is installed between two raised face flanges. Studs are used to compress the assembly. The mating surfaces at the center section of the assembly are shaped and finished to provide a metal-to-metal seal on the rupture disks. The rupture disks used are the nonfragmenting, cross-scored type. The rupture disk pressure rating is selected to meet experiment requirements.

The diffuser extending into the drywell is fabricated from 100-mm (4-in.) pipe with a tee section of 100-mm (4-in.) pipe welded normal to the pipe axis across the end. The weldment contains 100 holes of 25-mm (1-in.) diameter for a total open area of approximately 0.051 m^2 (79 $in.^2$) (Fig. 15).

Design Specifications and Parameters

Specifications for the nitrogen storage system are listed in Table 4.

Table 4. Nitrogen storage system design specifications and parameters.

Item			Specification
Nitrogen storage bottles (6 each)			
Volume	Quan.	Vol. each m^3 (ft^3)	Total vol. m^3 (ft^3)
	1	0.44 (15.5)	0.44 (15.5)
	1	0.25 (8.8)	0.25 (8.8)
	3	0.17 (6)	0.51 (18)
	1	0.08 (2.8)	0.08 (2.8)
Total	6		1.28 (45.1)
Outlet flange			
Size		63 mm (2-1/2 in.)	
Rating		4 MPa (600 lb/in.^{2})	
Discharge restriction i.d.		38 mm (1.5 in.)	
Rupture disk assembly			
Type		Fike – 1/2 - 30 SM	
Size		13 mm (1.2 in.)	
Rating		8.7 MPa (1250 psig)	
Fill valve			
Type		Dragon 10M057	
Size		13 mm (1/2 in.)	
Rating		40 MPa (6000 psig)	
Pressure gage range		14 MPa (2000 psig)	
Maximum allowable working pressure		9.8 MPa (1400 psig)	
Operating temperature		260 to 370°K (0 to 200°F)	
Test pressure		15 MPa (2100 psig)	
Vessel valve spool			
Valve			
Type		Socket weld ball valve	
Size		51 mm (2 in.)	
Manufacturer		Apollo – Cat. No. 73-208	
Design pressure		9.8 MPa (1400 psig)	
Design temperature		270 to 320°K (20 to 120°F)	
Test pressure			
Flange to flange, valve open		15 MPa (2100 psig)	
Closed valve, test both directions		7 MPa (1000 psig)	
Nitrogen manifold			
Design pressure		9.8 MPa (1400 psig)	
Design temperature		270 to 320°K (20 to 120°F)	
Test pressure		15 MPa (2100 psig)	

Table 4. (continued)

Item	Specification
Isolation valve	
Type	Grove B4 ball valve
Operator	Wrench-operated
Size	100 mm (4 in.)
Rating	4 MPa (600 lbf/in.^{2})
Rupture disk assembly	
Type	BS&B 2 disk assembly
Size	100 mm (4 in.)
Rating	4 MPa (600 lbf/in.^{2})
Part Nos. (BS&B numbers)	
Upstream	77UOC-034
Center	77UOC-035
Downstream	77UOC-036
Rupture disks	
Type	Nonfragmenting
Pressure	Dependent on experiment requirements
Flow nozzle bore	48.59 mm (1.913 in.)
Gaskets	
Type	Parker Gask-O-Seal
Rating	4 MPa (600 lbf/in.^{2})
Pipe spools	
Pipe nom. size	100 mm (4 in.)
Grade	A106 Gr B
Schedule	X-Strong
Flanges	
Type	Raised face weld neck[a]
Rating	4 MPa (600 lbf/in.^{2})
Design pressure	9.8 MPa (1400 psig)
Design temperature	270 to 320°K (20 to 120°F)
Test pressure	15 MPa (2100 psig)
LLL installation drawing	AAA-76-114047-OO

[a]Raised face slip on orifice flange at orifice location.

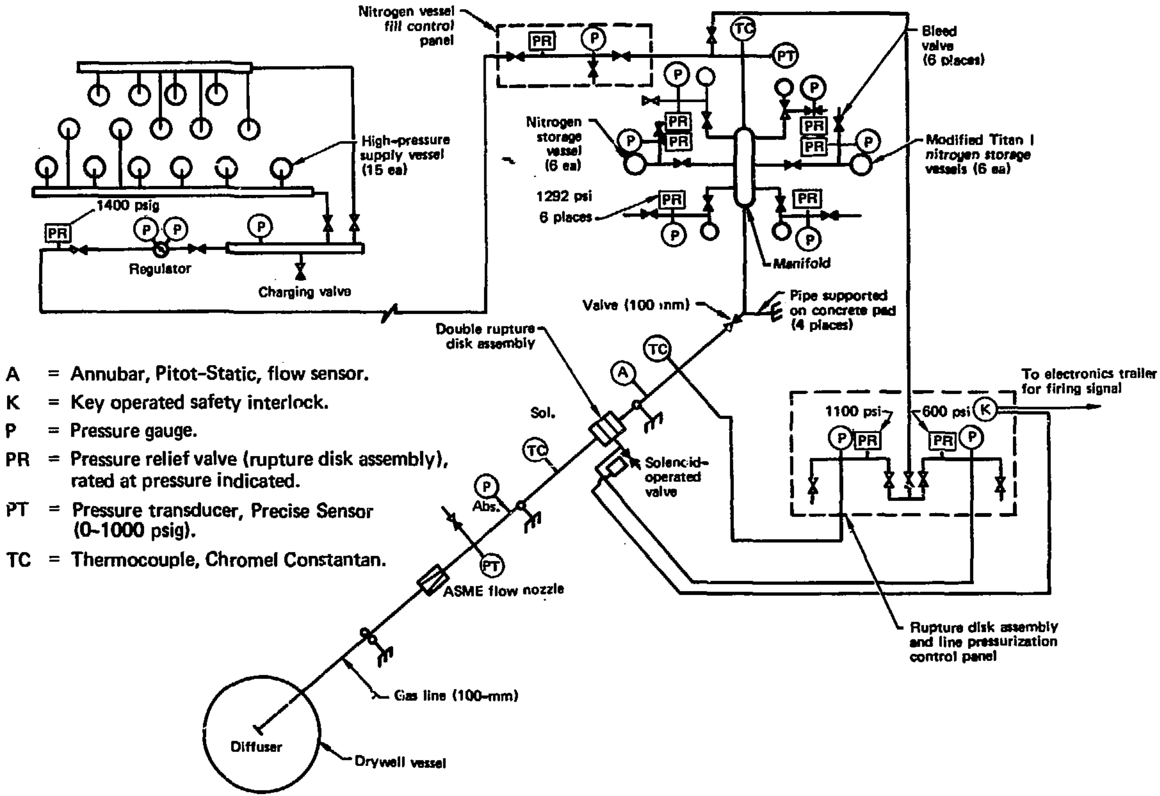

Fig. 13. Nitrogen supply system schematic.

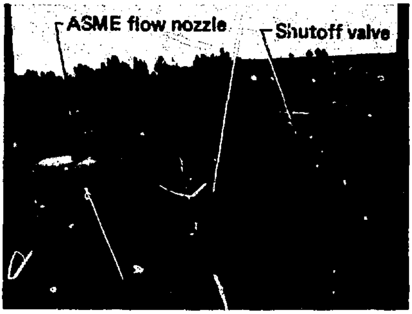

Fig. 14. Nitrogen supply system.

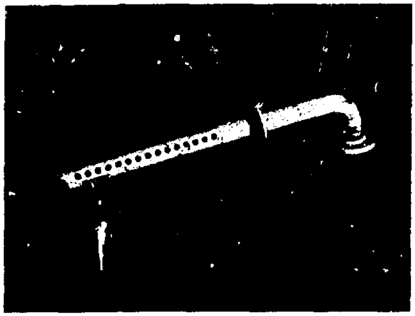

Fig. 15. Nitrogen line diffuser (extends inside drywell vessel).

Fabrication of System Components

Modification of existing storage bottles and fabrication and subassembly of nitrogen system components was accomplished by personnel at LLL. The nitrogen storage bottles were thoroughly inspected by an LLL pressure inspector prior to modification. Internal inspection was by borescope. All welds associated with vessel modifications were inspected using fluorescent penetrant techniques. The modified vessels were pressure tested to 1.5 times the maximum allowable working pressure and labeled for maximum allowable working pressure and temperature as well as the test pressure.

All welds on the manifold and pipe spools were inspected using magnetic particle techniques per ASME Boiler and Pressure Vessel Code Section VIII Division I, Appendix VI.[5] No cracks were allowed. The pipe spools were also vacuum leak tested using a helium mass spectrometer having a sensitivity of 1×10^{-6} std cc per s of helium. The manifold and spools were pressure tested to 1.5 times the maximum allowable working pressure.

Installation

Assembly of the nitrogen storage system took place after the drywell was installed and grouted. The nitrogen line was assembled from the drywell vessel out toward the nitrogen storage vessels. Appropriate pipe supports were installed under the pipe as the sections were added. The manifold was added to the nitrogen storage vessels after the vessels had been moved to the PSE Facility. The manifold-vessel assembly was then attached to the isolation valve in the line. Anchoring the pipe supports to the concrete pad and connecting small fill and transfer lines as well as connections for the instrumentation completed the nitrogen system assembly.

6. TOROIDAL WETWELLS

Introduction

The 90° and 7.5° toroidal wetwells, including ringheaders and downcomers, are geometrically scaled models 1/5 the size of those at the Peachbottom Nuclear Power Plant. The 7.5° vessel is included so that two-dimensional and three-dimensional test results can be compared on a single test. The 7.5° vent pipe is not a model of the Peachbottom plant because it feeds only two downcomers; however, the flow resistance in the 7.5° vent pipe is duplicated. Vent pipes for both vessels are provided with flanges that permit installation of orifice plates to further restrict flow as required for scaling considerations.

The 90° wetwell is supported at three points: one on both sides of a center ring located between the two 45° sectors; and one below the left-end flange of the 90° assembly. These supports, in addition to four header support struts, contain load cells.

Figure 16 is a cross section through the 90° toroidal wetwell that shows the toroidal wetwell wall, vent pipe, and ringheader configuration and trunnion supports. Typical locations of camera and light ports are shown in the vessel wall. These ports are used to record bubble growth and the surface motion of the water during tests.

The 7.5° wetwell is supported by two structural legs bolted directly to the floor of the test pit. Load cells are omitted in these supports because the weight of the 7.5° wetwell is so large that any load data would be unreliable. No load cell is used in the 7.5° header support since the header is bolted directly to the vessel end plate. Vertical loads can be determined by integrating the pressure data over the surface area of the 7.5° sector vessel wall.

The final equilibrium pressure of the wetwell system during the air test series was less than 280 kPa (40 psig). The design pressure for the wetwells was 350 kPa (50 psig), and the vessels are protected from overpressure by 310- to 350-kPa (45- to 50-psig) rupture disks. The design of the vessels met or exceeded criteria for design according to the ASME Boiler and Pressure Vessel Code Section VIII, Division I for unfired pressure vessels.[5] Vessels and vent pipe spools were pressure tested to 520 kPa (75 psig).

Description

The 90° wetwell is designed as a rigid structure and consists of two 45° sectors. Each sector consists of three cylindrical sections joined by meter joints. Figure 17 is a plan and elevation view of the left sector as viewed from the drywell. Each cylindrical section for the sector is rolled from 19-mm (0.75-in.) thick plate. The flanges on either end of the sector were made from 76-mm (3-in.) plate. All steel used in the vessel is ASTM A537 C1-A.

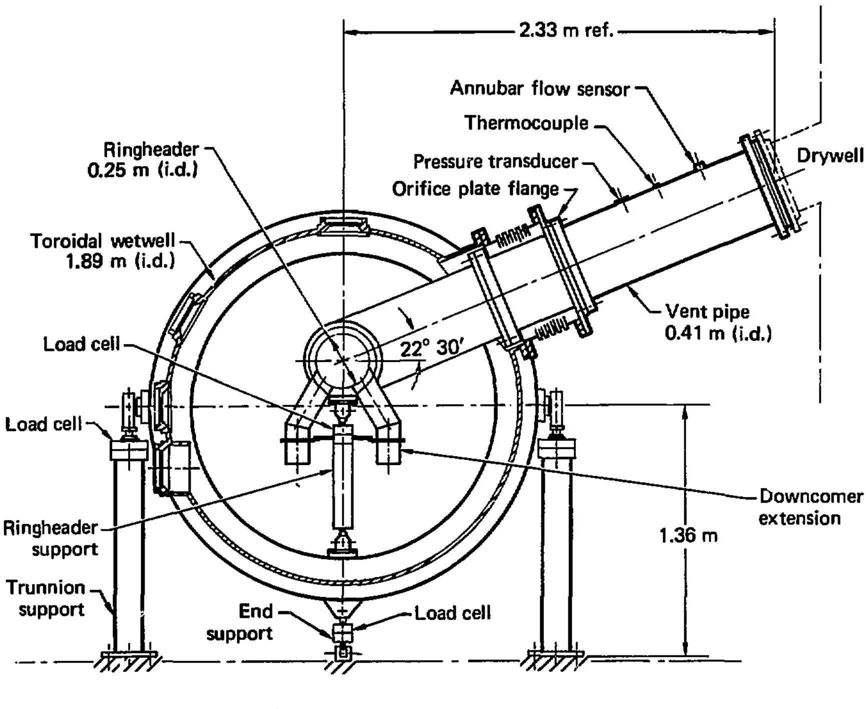

Fig. 16. Cross section of 1/5-scale 90° toroidal wetwell.

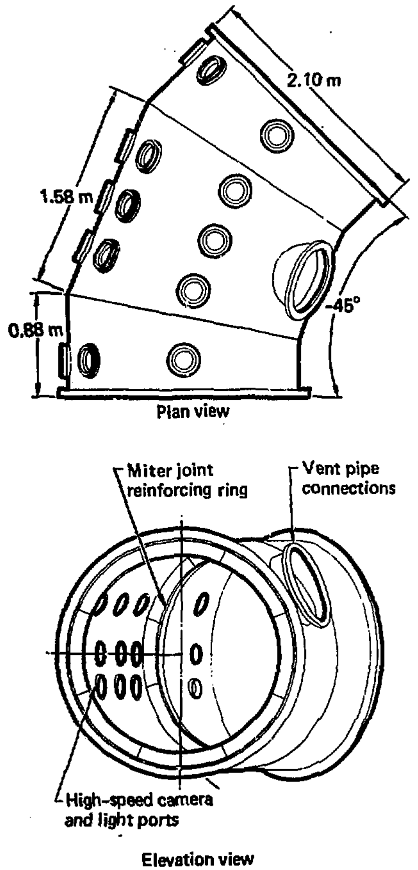

Fig. 17. Toroidal wetwell design for the 1/5-scale pressure suppression experiment.

Penetrations are provided in the vessel wall for vent pipe connection, camera and light ports, and instrumentation ports. Vessel penetration reinforcement requirements were determined for the maximum size of opening which is the 0.61-m (24-in.) diameter port for the vent pipe in each sector. ASME Boiler Code criteria for the radius and wall thickness indicated that no reinforcement was required.

There are more penetrations in the left sector than in the right sector. The left sector contains 20 camera and light ports in five vertical rows of four each per row. The right sector contains one row of four ports. Camera port stress calculations are based on 25-mm (1-in.) borosilicate lenses using flat plate theory. The vessel was pressure tested with the windows with appropriate gaskets in place.

Numerous holes with pipe threads are provided for pool swell probes, pressure transducers, thermocouples, and feedthroughs for header instrumentation leads. [3]

The pressure transducers are mounted on an adapter that can be threaded into the vessel wall. Extra holes are plugged with standard 51-mm (2-in.) pipe caps. This philosophy offers flexibility in positioning transducers because the adapters can be moved easily from one location to another by removing one of the pipe caps.

The two 45° sectors are bolted together to form the 90° toroidal wetwell. A heavy 76-mm (3-in.) thick metal center ring is inserted between the mating flanges of the two sectors. This center ring includes pins that fit into the spherical bearings in the trunnion support brackets. The center ring can also accommodate a blank-off plate in the event that test data are required from separate 45° sectors. The center ring is fabricated from ASTM A537 grade A steel.

Blank-off plates are installed on both ends of the 90° torus. The plate in the left end (facing from drywell) contains additional camera and light ports for photographing bubble formation during a test. This plate also contains a vacuum pumpout port and a rupture disk assembly. The plate on the opposite end of the torus is a blank except for a port at the top for the rupture disk assembly. The plates are fabricated from 76-mm (3-in.) thick ASTM A537 grade A steel.

Each 45° sector of the toroidal wetwell contains a header assembly containing 12 downcomers. The headers are joined at the center of the toroidal wetwell by a spiral wrap seal of rubber and thin stainless steel sheet. Each header is a welded assembly made up of two cylindrical sections and a tee section. The cylindrical sections are formed of two separate pieces of 305-mm (12-in.) o.d., 6-mm (0.25-in.) wall, ASTM A519 steel tubing joined by a mitre joint. The downcomers are 127-mm (5-in.) o.d., 2.4-mm (0.095-in.) wall, ASTM A513 steel tubing fabricated to the required geometry. The tee section is fabricated from rolled 6-mm (0.250-in.) thick ASTM A36 plate. A transition piece is provided on each side which in turn mates with the smaller diameter cylindrical sections. A flange is welded to the leg of the tee for attachment to the intermediate vent pipe spool. The header has a number of instrumentation transducer ports similar to those in the toroidal wetwell. Instrument leads from the transducers on the header are enclosed in copper tubes that are routed through fittings in torus wall.

Each 45° header feeds 12 downcomers and is supported on 2 struts with universal joints on both ends. Each strut contains a ± 110-kN (25-K lbf) capability load cell. The overall length of each strut can be adjusted by means of a 50-mm (2-in.) diameter adjusting screw. The screw has right- and left-hand threads that mate with threads in the upper and lower sections of the support strut. The adjustment is provided to allow accurate positioning of the ring header in the toroidal wetwell. The adjustment feature is also used to calibrate the strain gages mounted on the drywell end of the vent pipe. The struts are bolted to mounting pads welded to the toroidal wetwell and ring header.

Downcomer extensions were fabricated with flanges to mate with downcomer flanges on the header assemblies. Two sets of extensions were fabricated with different overall length allowing downcomer submergence to be changed by merely changing the downcomer extensions.

The vent pipes connecting the header assemblies to the drywell are composed of an intermediate spool that bolts to the header and a longer spool that mates with the intermediate spool and drywell nozzle flanges. A set of two bevel plates, which can accommodate up to 3° of misalignment, is installed between the long spool and drywell flange. The plates are captive inside the array of flange bolts. The seal between the vent pipe and wetwell is made via a bellows assembly just as in the full scale plant. The vent pipe spools are rolled and welded cylindrical sections with machined flanges at both ends. The intermediate spool is fabricated from ASTM steel grades A36 and A537. The long spool is fabricated with ASTM A537 steel flanges and HY80 steel shell material. The bevel plates are fabricated from ASTM A36 steel.

The intermediate spool flange that mates with the long spool has a counterbore machined in the face to accept an orifice plate. The orifice plate is captive between the two flanges. Each flange has an "O" ring that seals against the orifice plate. An orifice plate must be present to have a system seal at that joint. If no orifice is desired, a ring with an inside diameter equal to the pipe inside diameter is installed. The orifice plates are fabricated from 300 series stainless steel. Instrumentation ports are provided in the long spool to measure pressure, temperature, and mass flow rate (Fig. 16).

Volumes and inside surface areas of the components in the vent pipe, ringheader, and downcomer assembly are shown in Tables 5 and 6 for the 7.5° and 45° sector. Values for a 90° sector would be double those of the 45° sector.

The main support for the assembled 90° chamber is provided by two solid columns bolted to steel plates in the floor. The supports are designed complete with load cells to minimize deflection while handling total vertical forces up to ±900 kN (200,000 lbf). This design value for total vertical force was at least twice as great as the value expected. The total mass of the toroidal wetwell, half-filled with water, is approximately 20,000 kg (44,000 lbm). Each main support consists of a steel column, a load cell, and a bearing block that houses a large diameter spherical bearing. The bore of the bearing slips over the pin retained in each side of the center ring between the two 45° vessels. The vessel and trunnion support columns are stabilized by the following auxiliary supports:

- Vessel end support.
- Horizontal wall brace.
- Diagonal struts.

The end support is mounted below the left end (looking from the drywell) flange of the assembled 90° torus. The support is designed with universal joint ends and uses the same specification load cell as used in the header support struts. The vessel end of the strut is attached to a block bolted to the face of the vessel blank-off plate. The lower end of the strut is bolted to one of the steel plates cast in the pit floor.

The wall brace is a strut extending horizontally from the trunnion bearing block nearest the drywell to a steel plate cast in the wall of the pit below the drywell. The strut accommodates the blow-off load due to the vent pipe penetration through the bellows and prevents the toroidal wetwell from moving radially outward. The strut does not contain a load cell. The strut overall length is adjustable at assembly, and installation is by bolts at both ends.

The diagonal struts attach to the upper end of the main support columns and extend diagonally to clevis bolted to steel plates cast in the pit floor. The struts do not contain load cells.

Materials used in the design of the support system were selected to satisfy either fracture safe requirements or minimum deflection requirements. The header support and end support universal joints and threaded load-carrying components were fabricated from HY130 steel with mounting adapter plates fabricated from HY80 steel. The wall brace was fabricated from ASTM A537 grade A with HY130 universal joint components. The trunnion

Table 5. Volumes of the vent pipe, ringheader, and downcomer assembly.

Sector	Total volume	Total volume (above nominal water level)	Volume upstream of orifice	Volume downstream of orifice (above nominal water level)	Ratio: Volume upstream of orifice / Volume downstream of orifice (above nominal water level)
7.5°	0.0757 m^3 (2.67 ft^3) (4,620 $in.^3$)	0.0695 m^3 (2.45 ft^3) (4,240 $in.^3$)	0.0217 m^3 (0.770 ft^3) (1,330 $in.^3$)	0.048 m^3 (1.69 ft^3) (2,920 $in.^3$)	0.454
45°	0.575 m^3 (20.3 ft^3) (35,100 $in.^3$)	0.537 m^3 (19.0 ft^3) (32,800 $in.^3$)	0.154 m^3 (5.45 ft^3) (9,420 $in.^3$)	0.383 m^3 (13.5 ft^3) (23,300 $in.^3$)	0.404

Table 6. Internal surface areas of the vent pipe, ringheader, and downcomer assembly.

Sector	Total internal surface area	Total internal surface area (above nominal water level)	Internal surface area upstream of orifice	Internal surface area downstream of orifice (above nominal water level)	Ratio: Internal surface area upstream of orifice / Internal surface area downstream of orifice above nominal water level)
7.5°	1.85 m^2 (19.9 ft^2) (2,870 $in.^2$)	1.65 m^2 (17.7 ft^2) (2,550 $in.^2$)	0.677 m^2 (7.29 ft^2) (1,050 $in.^2$)	0.968 m^2 (10.4 ft^2) (1,500 $in.^2$)	0.70
45°	7.31 m^2 (78.7 ft^2) (11,300 $in.^2$)	6.07 m^2 (65.3 ft^2) (9,410 $in.^2$)	1.50 m^2 (16.2 ft^2) (2,330 $in.^2$)	4.57 m^2 (49.2 ft^2) (7,100 $in.^2$)	0.329

support bearing block was fabricated from ASTM A537 grade A. Pins and threaded load-carrying components for the main supports were fabricated from HY130. Each main support column was fabricated from 15-cm (6-in.) diameter ASTM A36 steel bar with an ASTM A537 base plate attached by welding. The diagonal braces were fabricated from ASTM A36 steel.

The 7.5° wetwell represents a 7.5° sector of the 90° wetwell but with parallel flanges. The vessel is fabricated using the same materials and techniques used on the 45° sectors. The vessel contains a header bolted directly to the end blank-off plate nearest the drywell. The header has two downcomers. Instrumentation ports are provided in the vessel wall similar to those in each 45° torus. Ports are provided for pool swell probes, pressure transducers thermocouples, and feedthroughs for header instrumentation leads. The blank-off plate on the side of the vessel away from the drywell contains camera and light ports as well as a vacuum pumping port. The blank-off plates are similar to the plates used on the 90° vessel; i.e., 76-mm (3-in.) thick ASTM A537 grade A steel.

The vent pipe for the 7.5° sector is an assembly of three spools fabricated from 130-mm (5-in.), schedule 40, stainless steel (300 series) pipe. The vent pipe connects to the drywell nozzle sloped 22.5° from horizontal. The end of the vent pipe bolts to the face of the wetwell blank-off plate in line with the header mounted on the inside of the blank-off plate. The spool bolted to the drywell has fittings welded to it to accommodate the necessary instrumentation transducers. Flanges on the spools are standard, raised-face, slip-on type. The spool attached to the blank-off plate has a mitre joint to provide a flange parallel to vent pipe flanges when bolted to the wetwell blank-off plate. This spool is joined to the two-piece vent by a stainless steel bellows assembly. All spools and the bellows assembly were pressure tested to 517 kPa (75 psig) at room temperature for 1 h. Volumes and surface areas of the vent pipe assembly are shown in Tables 5 and 6.

The mating flanges of the first two spools of the 7.5° wetwell vent pipe are orifice flanges. The vent pipe is supported at the location of the orifice flange by a stand bolted to the pit floor. The support has a saddle attached to it that supports both pipe ends when the flanges are separated during an orifice change. The orifice is fabricated from 300 series stainless steel.

The 7.5° wetwell is bolted solidly to the steel plates cast in the pit floor. There are no load cells in the 7.5° wetwell support system. The supports are welded structural shapes bolted to plates welded on the sides of the wetwell vessel.

Specifications for wetwells are listed in Table 7.

Design Specifications and Parameters

Specifications for wetwells are listed in Table 7.

Fabrication

The wetwells were fabricated from ASTM A537 grade A steel plate, which is a low-alloy, high-strength steel requiring special low-hydrogen welding technology. Fabrication was in accordance with Section VIII of the ASME unfired pressure vessel code.[5] Welding was done by qualified welders using procedures and equipment required to produce fracture-safe weldments in accordance with EG&G specifications.[11] All welds were radiographically inspected over a minimum of 10 percent of each seam. Inspection of longitudinal welds exceeded requirements of ASME Boiler Code. The acceptance criteria for weld quality is established in welding specifications for fracture safe weldments.[11]

Tight tolerances for the large wetwell weldments were required for accuracy of system configuration scaling. Final welded assemblies were very close to nominal dimensions and within tolerances specified. An example of accuracy of welded assembly is the 45° included-angle for the wetwell sectors. The true position of the flange faces, one to the other, was within 1.5 mm (0.060 in.).

Table 7. Toroidal wetwell design specifications and parameters.

Item	Specification
90° toroidal wetwell	
General	
Air volume	7.56 m^3 (267 ft^3)
Water volume	6.93 m^3 (245 ft^3)
Maximum internal pressure	450 kPa (65 psia)
Minimum internal pressure	3.5 kPa (0.5 psia)
Maximum temperature	420° K (300° F)
Major diameter	6.80 m (22.3 ft)
Major inside diameter	1.9 m (6.2 ft)
Wall thickness	19 mm (0.75 in.)
Material	ASTM A537
Hydrostatic test pressure	520 kPa (75 psig)
Rupture disk assembly	350 kPa (50 psig)
Manufacturer	Fike
Catalog No.	73-123
Size	100 mm (4 in.)
Material	Carbon steel
Flange rating	1 MPa (150 psig)
Pressure rating	350 kPa (50 psig)
End plates	
Diameter	2.10 m (82.5 in.)
Thickness	76 mm (3 in.)
Material	ASTM A537
Center ring	
Outside diameter	2.10 m (82.5 in.)
Inside diameter	1.77 m (69.5 in.)
Thickness	70 mm (2.750 in.)
Material	ASTM A537
Approximate weight (dry)	10,500 kg (23,100 lbm)
45° sector (left)	3,000 kg (6,600 lbm)
45° sector (right)	3,000 kg (6,6000 lbm)
Center ring	430 kg (950 lbm)
End plate	2,000 kg (4,500 lbm)
End plate	2,000 kg (4,500 lbm)
Vent pipe - long spool	
Outside diameter	42.4 m (16.70 in.)
Wall thickness	6 mm (0.25 in.)
Overall length	1.16 m (45.72 in.)
Material	
Shell	HY80
Flanges	ASTM A537
Hydrostatic test pressure	520 kPa (75 psig)
Approximate mass	160 kg (360 lbm)
Vent pipe - intermediate spool	
Outside diameter	0.418 m (16.45 in.)
Wall thickness	3.2 mm (0.125 in.)
Overall length	0.451 m (17.75 in.)

Table 7. (continued)

Item	Specification
Material	
Shell	ASTM A36
Header flange	ASTM A36
Vent flange	ASTM A537
Hydrostatic test pressure	520 kPa (75 psig)
Approximate mass	130 kg (285 lbm)
Vent pipe bellows	
Inside diameter	0.56 m (22 in.)
Outside diameter	0.62 m (24.25 in.)
Material	Stainless steel
Internal operating pressure	350 kPa (50 psig)
Minimum cycle life	500
Axial spring rate	44 to 88 kN/m (250 to 500 lbf/in.)
Operating temperature	420° K (300° F) max
Axial movement - compression	110 mm (4.5 in.) max
Axial movement - tension	38 mm (1.5 in.) max
Environment	Steam
Lateral deflection	9.4 mm (0.37 in.) min
Hydrostatic test pressure	520 kPa (75 psig)
Approximate mass	111 kg (245 lbm)
Vent pipe orifice	
Outside diameter	0.465 m (18.4 in.)
Inside diameter (two sizes used)	
I.D.	Approximate weight
0.241 m (9.5 in.)	7.7 kg (17 lbm)
0.269 m (10.58 in.)	6.8 kg (15 lbm)
Thickness	6.4 mm (0.255 in.)
Material	300 series stainless steel
Header	
Inside diameter	0.295 m (11.60 in.)
Wall thickness	6.4 mm (0.25 in.)
Downcomers	
Outside diameter	0.127 m (5.0 in.)
Wall thickness	2.4 mm (0.095 in.)
Distance centerline to vent flange	0.876 m (34.5 in.)
Material	ASTM A36
Downcomer extensions	
Outside diameter	0.127 m (5.0 in.)
Wall thickness	2.4 mm (0.095 in.)
Length	Adjusted at assembly
Major EG&G drawings	
Toroidal wetwell	
Test section, 45° left	LJ 106119
Test section, 45° right	LJ 106342
Center ring	LD 106147
End plate	LE 106131
End plate, basic	LE 106687

Table 7. (continued)

Item	Specification
Vent pipe	
Vent pipe spool, long	LE 106873
Vent pipe spool, intermediate	LE 106326
Bellows assembly	LE 106150
Orifice plate	LC 106893
Bevel plate	LD 106664
Bevel plate	LD 106829
Header	
Header assembly, primary	LJ 106466
Header assembly, secondary	LJ 106469
Tee	LE 106325
Extension, downcomer	LD 106639

7.5° toroidal wetwell

Item	Specification
General	
Air volume	0.63 m^3 (22 ft^3)
Water volume	0.58 m^3 (21 ft^3)
Maximum internal pressure	450 kPa (65 psia)
Minimum internal pressure	3.5 kPa (0.5 psia)
Maximum temperature	420° K (300° F)
Inside diameter	1.9 m (6.2 ft)
Wall thickness	19 mm (0.75 in.)
Material	ASTM A537
Hydrostatic test pressure	520 kPa (75 psig)
Rupture disk assembly	Same as 90° torus
Rupture disk pressure rating	350 kPa (50 psig)
End plates	Same as 90° torus
Approximate mass	4,940 kg (10,900 lbm)
7.5° Chamber	860 kg (1,900 lbm)
End plate	2,000 kg (4,500 lbm)
End plate	2,000 kg (4,500 lbm)
Vent pipe	
Outside diameter	0.14 m (5.56 in.)
Wall thickness	Schedule 40 pipe
Material	304 stainless steel
Hydrostatic test pressure	520 kPa (75 psig)
Overall length and approximate weight	

Spool	Length	Weight
Instrumented	1.68 m (66.23 in.)	59 kg (130 lbm)
Short	0.5 m (20.00 in.)	34 kg (75 lbm)
Elbow	0.6 m (21.75 in.)	27 kg (60 lbm)

Item	Specification
Bellows	
Inside diameter	0.15 m (5.875 in.)
Outside diameter	0.17 m (6.88 in.)
Material	Stainless steel
Internal operating pressure	350 kPa (50 psig)
Minimum cycle life	500
Axial spring rate	18 to 36 kN/m (100 to 200 lbf/in.)

Table 7. (continued)

Item	Specification
Operating temperature	420° K (300° F) max
Axial movement - compression	64 mm (2.50 in.) min
Axial movement - extension	35 mm (1.37 in.) min
Environment	Steam
Lateral deflection	13 mm (0.50 in.) min
Special features	Stainless steel liner
Hydrostatic pressure test	520 kPa (75 psig)
Approximate mass	10 kg (22 lbm)
Orifice plates	
Outside diameter	0.18 m (7.120 in.)
Inside diameter (two sizes used)	
I.D.	Approximate mass
0.09 m (3.625 in.)	0.5 kg (1.1 lbm)
0.13 m (5.047 in.)	0.36 kg (0.8 lbm)
Thickness	3 mm (0.135 in.)
Material	300 series stainless steel
Header	
Outside diameter	0.3 m (12.00 in.)
Wall thickness	6 mm (0.25 in.)
Downcomers	
Outside diameter	0.13 m (5 in.)
Wall thickness	3 mm (0.109 in.)
Overall length	0.46 m (18.03 in.)
Material	ASTM A36
Downcomer extension	
Outside diameter	0.13 m (5 in.)
Wall thickness	3 mm (0.109 in.)
Overall length	Adjusted at assembly
"O" rings (all)	Ethylene propylene
Major EG&G drawings	
Toroidal wetwell	LJ 106726
Vent pipe	
Pipe spool, instrumented	LE 107106
Pipe spool, short	LD 107105
Bellows	LE 106913
Elbow	LD 106868
Orifice plate	LC 107104
Header assembly	LE 106848

The completed wetwells were hydrostatically tested to 520 kPa (75 psig).

The vent pipe spools were fabricated to the same specifications as the wetwells, including 520 kPa (75 psig) hydrostatic pressure test.

Fabrication of headers followed standard weld fabrication techniques. Each welded assembly was subjected to a rough vacuum test of 7 kPa (1 psi) differential pressure. The maximum permissible leakage rate was 3.5 kPa (0.5 psi) within 0.5 h.

Machining of all component parts for the wetwells followed standard industrial practices.

Installation

The 90° wetwell was assembled on grade level beside the test pad prior to being installed in the pit. The asembly consisted of both 45° wetwells, headers, intermediate vent pipe spools, bellows, and long spools.

Prior to installation of the headers in the wetwells, the relative location of downcomer flanges with respect to the header horizontal axis had to be determined. The end of all downcomer extensions was required to be within 1.5 mm (0.060 in.) of the theoretical horizontal plane and a specified dimension below the water level in the torus. When the header weldments were received, they were set on a surface plate, and variations in length of the downcomers relative to the longest downcomer were noted. The required length of downcomer extensions was then calculated and the extensions shortened and marked to correspond to appropriate downcomers.

The left header and header support struts were installed in the left 45° vessel. The bellows with shipping tie bars still in place and the intermediate spool piece were installed. The header was positioned in the center of the torus and held in place by nylon straps. Shims were installed between the bellows outer flange and the mating flange of the intermediate spool and bolts installed to hold the vent pipe rigidly in place. The right header and vent system was assembled using the same procedure.

After installing the center ring on the left 45° sector, the left and right 45° sectors were joined.

The assembled 90° toroidal wetwell assembly was then lowered into the pit and adjusted until the vent pipe flanges lined up with mating flanges on the drywell. The bevel plates and flange bolts were installed. The bolts were left loose to permit movement of the torus assembly during final alignment operations. The position of the 90° sector was adjusted to achieve the following:

- A horizontal centerline through the trunnion pins.
- A vertical plane through the trunnion pins coincident with reference line scribed in the concrete floor from center of the drywell.
- Bevel plates adjustment to have a parallel fit of all flange surfaces in the vent pipe-drywell flange joint.

When the torus was positioned it was cribbed in place, the shims in vent pipes removed, bellows tie bars removed, and bolts through vent pipe flanges tightened. Planer jacks were used in the cribbing to allow cribbing to be removed without jacking up the vessel once supports were installed.

The trunnion supports and all auxiliary supports were then assembled and installed, and the cribbing was removed. Grout was then put in place under the trunnion support base plates. With all supports in place the vessel is positioned within 3.3 mm (0.13 in.) of nominal.

The position of the header was adjusted in the torus by using the adjusting screws in the header support struts. Prior to moving the header, the bolts in the vent pipe-drywell flange were loosened to allow the header assembly to move freely. After any such movement, the bevel plates have to be readjusted and the flange bolts tightened and torqued. After the headers were positioned, the seal between the right and left header was installed. Tie rods were then installed to react against thrust loads, which would tend to separate the headers.

The downcomer extensions were then installed. The ends of all downcomer extensions were within 1.5 mm (0.060 in.) of the nominal plane. Prior to installing vessel end plates, the vent pipe strain gages were calibrated using the header strut adjusting screws. The end plates were then installed in preparation for the first air test.

During the air test series, it was necessary to make orifice changes. The orifice plates in the 90° vent pipes were changes without removing the vent pipes. This was accomplished by removing bolts in the long spool flange at the intermediate spool and compressing the bellows assembly using threaded rod. The orifice plate could then be removed and replaced.

The 7.5° wetwell was installed in much the same sequence as the 90° wetwell. However, the installation was much easier since no load cells were installed in the support system for either the vessel or header. The vessel was positioned, supports installed, and grouted. The header was then bolted in place and vent pipe installed. Assembly was completed with installation of downcomer extensions and the rear vessel blank-off plate. Prior to testing, all bolts on the vessels and vent systems of both wetwells were torqued to the proper levels.

7. FLASH BOILER

Introduction

The flash boiler for the second phase of testing is presently being fabricated by Hopper, Inc., Bakersfield, California. The boiler was designed and is being fabricated under Section I of the ASME Boiler and Pressure Vessel Code.[6] The completed vessel will be a code-stamped, power-electric boiler.

Description

The flash boiler will be a right-circular cylinder with a 1.3-m (51-in.) outside diameter and 50-mm (2-in.) wall and formed semi-ellipsoidal heads. Total vessel volume will be 4.5 m^3 (160 ft). The top head contains a 0.61-m (2-ft) manhole and blank-off flange. The vessel will be vertically mounted on a skirt and base plate. The overall height of the vessel is 5.56 m (219 in.). The vessel will be mounted on the reinforced concrete slab near the drywell and fastened to steel plates cast in the concrete pad.

The vessel will be connected to the drywell by a steam line containing a steam stop valve, rupture disk assembly, orifice plate and diagnostic instrumentation. The steam line extends into the flash boiler through a large blank-off flange. The pipe makes an elbow bend and extends to the space above the initial charge of water where it is open to saturated steam flow. The last section of pipe may be removed to expose the opening to saturated water rather than saturated steam.

In normal operation water will be introduced into the boiler to a depth of 1.2 m (4 ft). The water will then be heated to a maximum of 570° K (560° F) and 8.1 MPa (1160 psig), with 18 cal rod heaters installed in the bottom head of the boiler. Each cal rod heater has a capacity of 15 kW. Depending on the experiment, a rupture disk in the steam line may be ruptured by a procedure similar to that described for the nitrogen system, or a valve may be opened gradually. Approximately one-third of the water can be flashed to steam and used to charge the drywell-wetwell system.

Other nozzles and piping are provided for filling the vessel with water for forced air cooling, drains, level gages, relief valve, and miscellaneous controls and instrumentation. All nozzles on the vessel are designed to withstand anticipated reaction forces and moments at stress levels below the allowable stresses specified in Section I of the ASME Pressure Vessel Code.

Design Specifications and Parameters

Table 8 lists the specifications for the flash boiler.

Fabrication

Fabrication and inspection of the flash boiler will be in compliance with the ASME *Boiler and* Pressure Vessel Code, Section I, Power Boilers.[6]

Table 8. Flash boiler design specifications and parameters.

Item	Specification
Outside diameter	1.3 m (51 in.)
Wall thickness	50 mm (2 in.)
Volume of vessel	4.5 m^3 (160 ft^3)
Overall height	5.56 m (219 in.)
Maximum operating hydrostatic head	48 kPa (7 psig)
Design pressure, internal	8.1 MPa (1160 psig)
Design pressure, external	101 kPa (14.7 psig)
Design temperature	570° K (560° F)
Flange facings	ANSL 16.5 raised face
Nozzle type	Long weld neck
Gasket type	Flexitallic type G
Code stamp	ASME Section I (powered electric boiler)
LLL drawing	AAA-77-100691-OA

8. AUXILIARY EQUIPMENT

Three auxiliary systems were necessary for operation of the facility: electrical, vacuum pumping, and water circulation. This section includes a brief description of each system.

Electrical System

The electrical substation provides 500 kVA of electrical energy to charge the flash boiler (when installed), operate a 25-kW motor generator unit, and supply utility power to the test pad. The motor generator, in turn, supplies energy for the instrumentation and recording equipment. Isolation of the instrumentation by the motor generator unit minimizes the electrical noise level and improves the accuracy of the recorded data.

Vacuum Pumping System

The vacuum pump system (Fig. 18) consists of two 0.3-m^3/s (53-cfm) vacuum pumps and interconnecting piping for evacuating the drywell and both wetwells collectively or individually. A small vent line with valves at both ends ties the two wetwells together to allow equalization of pressure when the system is brought up to atmospheric pressure. Venting one wetwell at a time may cause water from the other wetwell to be drawn into the drywell if pressure in the wetwells is not equalized during this procedure.

Pipe spools and fittings are fabricated from aluminum pipe with plain flanges. Joint seals are made with gask-o-seals or other captive drop-in "O" ring assemblies. Pumpdown time to 21 kPa (3 psia) for the entire system is approximately 20 min.

Water Circulation System

The water circulation system (Fig. 19) consists of two 5.7-m^3 (1,500-gal) water storage tanks, associated piping and valves, and a circulation pump to drain and fill the wetwells. Supply and discharge manifolds for the wetwells are located in the pit. Lines to and from the two wetwells run in parallel from the manifolds, and each line has a gate valve at the manifold.

Water being pumped into the wetwells is filtered through a strainer in an inline tubular filter assembly. Once the water is in the wetwells, the clarity of the water is maintained for photographic purposes by using a diatomaceous earth filter unit piped across the two manifolds. The filter unit is used on one wetwell at a time to limit transfer of water from one wetwell sector to another during filtering operations.

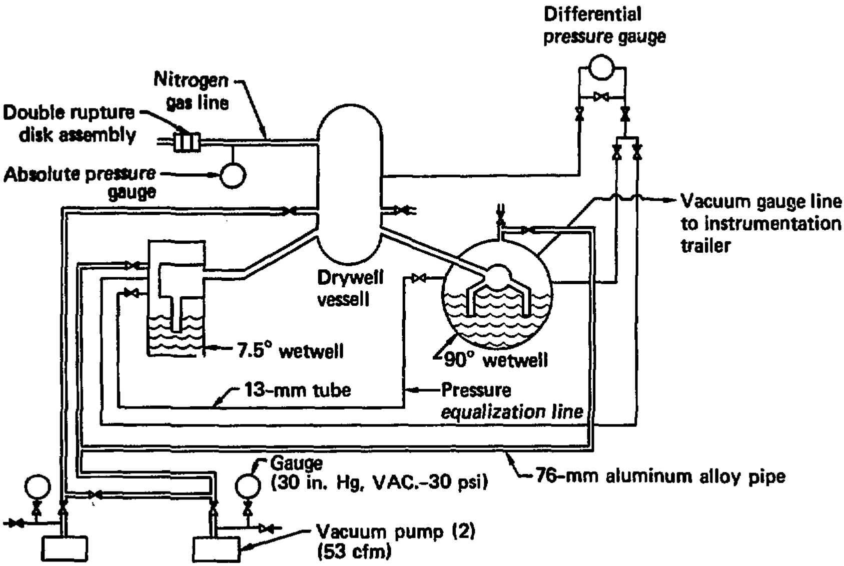

Fig. 18. Vacuum pumping system schematic.

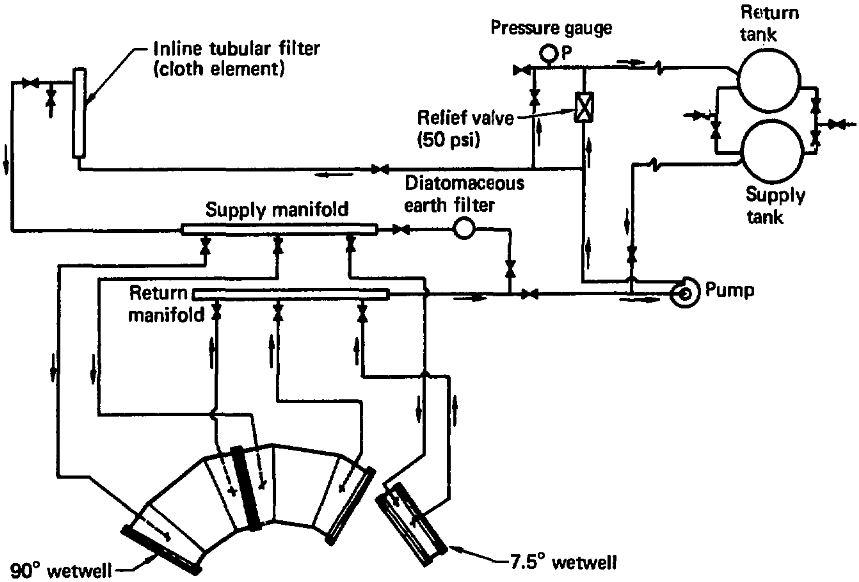

Fig. 19. Water system schematic.

9. FACILITY OPERATION

Introduction

The philosophy utilized for conducting tests was to predict general characteristics in advance. Predictions were made using the CONTEMPT-LT computer code[12, 13] and an LLL gas flow code developed specifically for the 1/5-scale pressure suppression test.[14]

Prior to conducting tests at the facility, several aspects of the equipment operation had to be investigated, a test matrix developed, and operating procedures established. The following is a description of the more important tests, steps leading to testing with dry nitrogen, and a discussion of test results.

Test Matrix Development

An air test matrix was developed by the Nuclear Regulatory Commission[15] in conjunction with LLL. Test conditions were varied one by one so that sensitivity of the vertical loads to various parameters could be examined. The final test matrix is included as Table 9.

Drywell Pressurization Test

A drywell pressurization test was conducted on February 1, 1977, with the vent line flanges blocked off and before the toroidal wetwells were installed.[16] The purposes of the test were to verify that the desired drywell pressure-time history profile could be obtained with installed equipment; and that the predicted response of the drywell was accurate.

Several weeks after completion of the drywell pressurization test, the Nuclear Regulatory Commission relayed a new drywell pressure-time signature in which the initial drywell pressurization rate was about 50 percent higher than previously desired. Additional calculations were performed that indicated the new pressure-time signature could be obtained with installed equipment by changing the particular nitrogen storage bottles selected for a specific test and the corresponding initial pressure. Because of the close agreement between calculated and experiment values previously observed, no further drywell pressurization tests were performed. Rather, minor adjustments were made after the first air tests on the complete facility.

A series of four test runs was completed during the drywell pressurization test with predicted initial drywell pressurization rates of 96.5, 128, 159, and 179 kPa/s (14.0, 18.6, 23.0, and 26.0 psi/s). Each test run consisted of charging various combinations of bottles with nitrogen under high pressure, evacuating the drywell to 1/5 atmosphere, and opening a valve between the two to allow quick pressurization of the drywell. A schematic of the equipment used is shown in Fig. 20. The pressure-time histories of all four test runs were in excellent agreement with predicted results made through a computer model developed at LLL[14] and the CONTEMPT-LT computer code.[13]

Because of the close agreement between predicted and experimental results, all desired pressure-time signatures could be obtained by pressurizing various combinations of the nitrogen storage bottles to a desired pressure. A flow nozzle placed in the nitrogen line between the storage bottles and the drywell to add additional flexibility was not needed. A constant size nozzle with a 4.86-cm (1.913-in.) throat diameter was used in all testing performed with the completed 1/5-scale pressure suppression facility.

Analysis of the data from the 1/5-scale air test matrix[1] (Table 9) shows the agreement between the desired drywell pressure-time signature and that actually achieved was excellent.

Ringheader Strut Support Test

After the 90° sector toroidal wetwell was connected to the drywell, a load-displacement test was conducted on the four ringheader-toroidal wetwell internal support struts. The load-displacement test was performed to ensure that forces existing due to expected vent pipe displacement under operating conditions were insignificant.

On March 3, 1977, equipment was installed to measure strain on the vent lines, the load in each of the four ringheader strut supports, and the change in length of the ringheader strut supports. The strain gages were located at the top and at the bottom of the vent lines near where the vent lines attach to the drywell (strain gages 21 and 22).[3] The length of the ringheader strut supports was varied by means of adjustment screws with right- and left-hand threads.

Results of this test are shown in Fig. 21 where total load on the ringheader strut supports and vent

Table 9. Final air test matrix.

Test No.	Initial wetwell pressure kPa (psia)	Initial drywell pressure kPa (psia)	Initial drywell over-pressure m H_2O (in)	Downcomer submer-gence m (in)	Torus water level m (in)	Initial drywell pressuri-zation rate kPa/s (psi/s)	Imposed symmetry	Measure-ment on 7.5° sector	Remarks	Test date	Quick-look report No.
1.0[a]	20.3 (2.95)	20.3 (2.95)	0	--	--	108 (15.6)	-	-	No water; without orifice	March 4, 1977	QLR No. 1, UCID-17446-1
1.0[b]	20.3 (2.95)	20.3 (2.95)	0	--	--	121 (17.5)	-	-	No water; with orifice	March 8, 1977	
1.1	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	-	-		March 18, 1977	
1.2	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	-	-	Check out repeatability, 3-D effects	March 25, 1977	QLR No. 2, UCID-17446-2
1.3	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	-	yes		March 30, 1977	
1.3.1	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	-	yes			
1.4	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	141 (20.5)	-	yes			
1.5	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	233 (33.8)	-	yes	Drywell pressurization rate	April 26, 1977	QLR No. 4, UCID-17446-4
1.6	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	263 (38.2)	-	yes			
2.1	20.3 (2.95)	( )	0.12 (4.8)	0.24 (9.6)	Nom.	188 (27.3)	-	yes			
2.2	20.3 (2.95)	( )	0.18 (7.2)	0.24 (9.6)	Nom.	188 (27.3)	-	yes	Drywell overpressure	April 26, 1977	QLR No. 3, UCID-17446-3
2.3	20.3 (2.95)	( )	0.18 (7.2)	0.24 (9.6)	Nom.	188 (27.3)	-	yes			
2.4	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	-	yes	Repeatability		
2.5	20.3 (2.95)	20.3 (2.95)	0	0.340 (13.4)	0.10 (3.8)	188 (27.3)	-	yes		May 3, 1977	QLR No. 5, UCID-17446-5
2.6	20.3 (2.95)	20.3 (2.95)	0	0.15 (5.8)	-0.10 (-3.8)	188 (27.3)	-	yes	Downcomer submergence		
2.7	20.3 (2.95)	20.3 (2.95)	0	0.305 (12.0)	Nom.	188 (27.3)	-	yes		May 12, 1977	QLR No. 7, UCID-17446-7
2.8	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	0.061 (2.4)	188 (27.3)	-	yes			
2.9	20.3 (2.95)	20.3 (2.95)	0	0.305 (12.0)	Nom.	141 (20.5)	-	yes			
2.10	20.3 (2.95)	20.3 (2.95)	0	0.305 (12.0)	Nom.	233 (33.8)	-	yes	Drywell pressurization rate with increased submergence	May 12, 1977	QLR No. 7, UCID-17446-7
2.11	20.3 (2.95)	20.3 (2.95)	0	0.305 (12.0)	Nom.	263 (38.2)	-	yes			
3.1	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	-	yes	Variation of ṁh a/		
3.2	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	-	yes		May 3, 1977	QLR No. 5, UCID-17446-5
3.3[a]	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	(yes)[b]	yes			
3.3[b]	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	(yes)[b]	yes	Asymmetry with variation in ṁh		
3.4[a]	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	(yes)[b]	yes		May 3, 1977	QLR No. 6, UCID-17446-6
3.4[b]	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	(yes)[b]	yes			
3.5	20.3 (2.95)	20.3 (2.95)	0	0.24 (9.6)	Nom.	188 (27.3)	-	yes	Repeatability	May 3, 1977	QLR No. 5, UCID-17446-5

[a] Test 3.1 was conducted with orifice plates in the vent lines which were intermediate in size between a Moody-scaled orifice and no orifice. Test 3.2 was conducted with no orifices in the vent lines.

[b] The degree of asymmetry was obtained by varying the orifice size in the vent line. In tests 3.3(a), the right 45° sector vent line was blocked with a Moody-scaled orifice placed in the left 45° sector vent line. In test 3.3(b), the left 45° sector vent line was blocked and the right 45° sector vent line contained the Moody-scaled orifice. Tests 3.4(a) and 3.4(b) were similar except that no orifice was used in the open vent line.

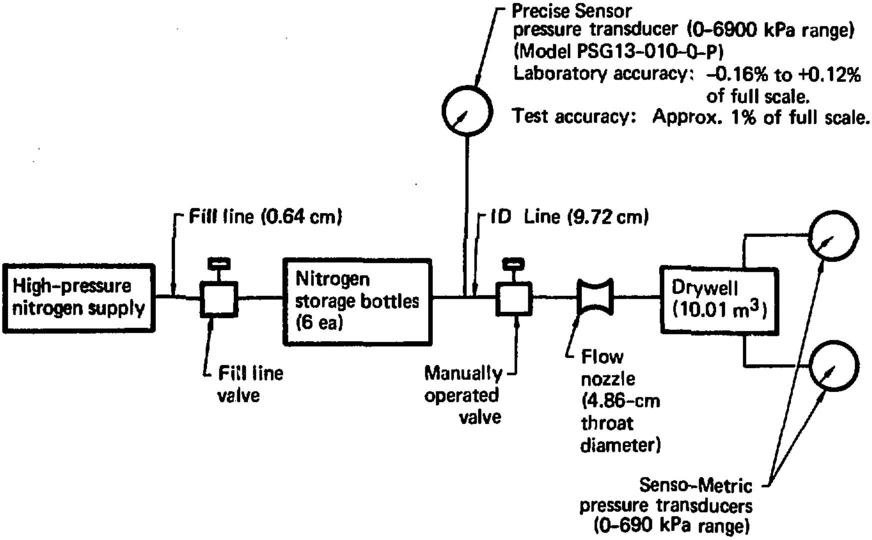

Fig. 20. Drywell pressurization test apparatus schematic.

line strain are plotted against ringheader deflection. The ringheader deflection is identical to the change in length of the ringheader strut supports. The test was conducted by rotating the adjustment screws until the load cells read near zero load. The change in strain measured on each vent line and in load measured in each of the four ringheader strut supports was recorded for discrete length changes in the ringheader strut supports. The discrete length changes were chosen as one complete turn of the adjustment screws and correspond to a 4.4-mm (0.17-in.) change in length.

Actual length changes under test conditions were less than 0.2 mm (0.004 in.) so that the maximum effect on measured values of load was only about 0.67 kN (150 lbf). This is negligible in comparison with measured total loads on the four ringheader strut supports (sum of load cells 2, 3, 6, and 7) of about 40 kN (9,000 lbf).

Test Operation

A checklist was utilized to conduct each test so that the probability of successful completion was increased. A copy of a typical checklist is included at the end of the section. The number of tests conducted was 27, and all tests were successful.

In the early morning hours of a test day, electronics personnel would arrive at the test site and begin electronic calibration of all instrumentation and readout systems. This calibration was a time consuming process normally taking three or four people about 8 h. During the mid-morning hours, mechanical technicians would arrive to check all systems other than electronics for correct operation. Near noon professional and supervisory personnel would arrive, and the process of completing the checklist was started.

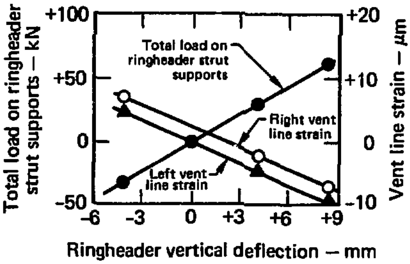

Fig. 21. Vent line — ringheader load calibration (1/5-scale).

The test director would call out the checklist items by number and description over a loudspeaker system. The appropriate personnel would respond by walkie-talkie when the item was completed. In general, items were completed as early as possible so that by 30 min prior to a test, all time consuming items were complete. At this time, evacuation of air from the toroidal wetwells and the drywell was started. When desired pressures were reached, a 5-min warning was announced.

Instrumentation readiness was then confirmed, valves positioned appropriately, and the test pad evacuated of personnel. At 1 min before a test, an automatic timing sequence was started that conducted all operations until completion of the test. For example, camera lights were turned on so that events could be captured before the film in the cameras was exhausted. The tape recorder used to record data was started. A solenoid valve used to initiate bleeding of gas between the two rupture disks in the nitrogen inlet line was opened. The rupture disks would burst, and the test conducted. After the test was complete, the cameras, lights, and tape recorder were turned off automatically. The test director would announce the test complete, and preparations would be started for the next test.

Once the initial test on a particular day was complete, additional tests could be performed at approximately 1-h intervals. After the last test of the day was complete, the facility was secured, and an electronic post-calibration completed.

Data tapes were packaged and transported to LLL's computing center for processing of the data from electronic signals into engineering units. All data was processed without filtering so that all noise and signal structure appeared in the engineering data. Further processing beyond this point was completed when several transducer data traces were combined into a desired result.

Tests Using Dry Nitrogen

Test operations consisted of a series of 27 air tests completed between March 4 and May 12, 1977. The first two tests were conducted without water in the toroidal wetwells so that the vent lines leading from the drywell to the toroidal wetwell could be examined. No orifices were present in the vent lines on Test 1.0a. Moody[2]-scaled orifice plates were placed in the vent lines on Test 1.0b.

Three nominal tests (1.1, 1.2, and 1.3) were conducted next to check repeatability and three-dimensional effects. These three tests were run separately with at least 5 days between tests. The time between tests was used to examine the data. Extensive effort was required to prepare the facility for a test. All systems had to be checked and the instrumentation electronics calibrated. In an effort to improve efficiency, the remainder of the tests were conducted in three groups. This reduced the effort per test necessary to prepare the facility for testing and for electronic calibration.

Tests 1.3.1, 1.4, 1.5, and 1.6 were conducted to determine the sensitivity of vertical loads to initial drywell pressurization rate. Tests 2.1, 2.2, and 2.3 were used to obtain effects of drywell overpressure. Drywell overpressure is obtained by evacuating the toroidal wetwells slightly below that of the drywell so that the water leg inside the downcomers is reduced.

Repeatability tests (2.4 and 3.5) were interspersed in the test matrix to assure the characteristics associated with the facility remained constant. Tests 2.5 and 2.6 were conducted with the initial water level in the toroidal wetwells either above or below the nominal position. Tests 2.7 through 2.11 repeated the variation of initial drywell pressurization rate and initial water level with extended downcomer length.

Test 3.1 was conducted with orifice plates in the vent lines that were intermediate in size between Moody-scaled orifices and no orifices. Test 3.2 was conducted without any orifices in the vent lines.

Tests 3.3(a) and 3.3(b) were used to examine asymmetry. In one test the left 45° sector vent line was blocked, and in the other test the right 45° sector vent line was blocked. The open vent lines contained Moody-scaled orifices. Instrumentation was concentrated on the left 45° sector so that with this pair of tests, the effects of asymmetry could be measured along the total length of the 90° sector. Tests 3.4(a) and 3.4(b) were a similar pair of tests except the open vent lines contained no orifice.

Predicted Response

CONTEMPT-LT[12, 13] was used to predict pressures in the drywell and in the air space of the toroidal wetwell as a function of time for all tests. Values of nitrogen flow rate and state into the drywell were predicted from an LLL computer code[14] developed specifically for this program. These values of inlet nitrogen flow rate and state were used as input to the CONTEMPT-LT computer runs.

Typical results are shown in Figs. 22 and 23 where drywell and toroidal wetwell air space pressures are plotted as a function of time. Actual data from a nominal case test (1.3.1)[1] agree with the

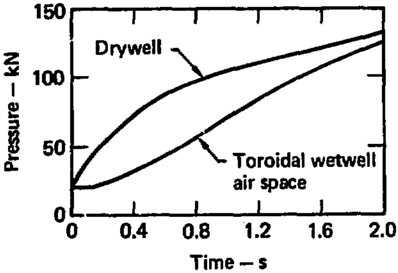

Fig. 22. Predicted pressure-time history for a nominal case test with vent line orifice plates (Test 1.3.1).

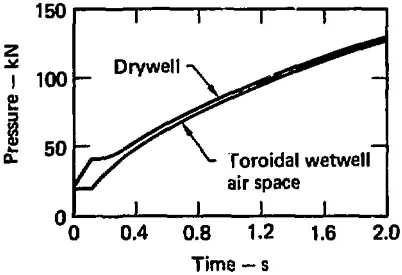

Fig. 23. Predicted pressure-time history for a test without vent line orifice plates (Test 3.2).

prediction of the drywell pressure-time history (Fig. 22). The toroidal wetwell air space pressure increases slightly faster than predicted. The delay in the pressurization of the toroidal wetwell air space is due to the water leg present inside the downcomers. No appreciable pressure increase occurs until the water leg is purged (vent clearing).

If the orifice plates are removed from the vent lines, the drywell pressure after vent clearing rises more slowly and contains a distinct change in slope (Fig. 23). The wetwell air space pressure increases more rapidly. These general phenomena are observed in actual experimental data.

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Pressure Suppression Experiment
Checkoff List

TEST NO. _______ TEST DATE _______________

TIME _______________

TEST PERSONNEL

Test Director (TD) ____________________________

Mechanical Technician (MT) ____________________________

Instrument Engineer (IE) ____________________________

Electronic Engineer (EE) ____________________________

Photography (P) ____________________________

Videotapes (VT) ____________________________

Ambient conditions

Temperature _________ Barometer _________

EXPERIMENT PARAMETERS

	Volume (ft^3)	15.4	3	6	6	6	9
N_2 *supply (check bottles used)*		☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7

N_2 supply pressure _______________

Water level _______________

Other _______________

Item	Time	Person responsible	Checkoff	Initials
1. Confirm that main air line manual valve is closed.(1)	-85 m	MT	☐	
2. Open proper N_2 manifold valves. Close those not used.(6) ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7	-85 m	MT	☐	
3. Commence pressurizing N_2 storage system.	-80 m	MT	☐	
4. Change film in cameras.	-75 m	P	☐	
5. Change orifice plates (when required).	-75 m	MT/EGG	☐	
6. Start water filter upon completion of torus/drywell venting.	-75 m	MT	☐	
7. Change rupture disks.	-75 m	MT	☐	
8. Turn off filter.	-45 m	MT	☐	
9. Set water level; close all water valves.	-45 m	TD/MT	☐	
10. Vent N_2 manifold transducer to atmosphere (first test only).	-45 m	MT	☐	
11. Check for correct operating solenoid valve (first test only).	-45 m	EE	☐	
12. Complete zero calibration (first test only).	-30 m	EE	☐	
13. Repressurize N_2 manifold (first test only).	-30 m	MT	☐	
14. Close torus equalization line valves. (2)	-30 m	MT	☐	
15. Pressurize rupture disk assembly and air line.	-30 m	MT	☐	

	Item	Time	Person responsible	Checkoff	Initials
15a.	Confirm vent pipe nuts on threaded rods are loose.	-30 m	MT	☐	
16.	Commence pump down.	-30 m	MT	☐	
17.	Complete pump down.	- 5 m	MT	☐	
18.	Five-minute warning.	- 5 m	TD	☐	
19.	Confirm readiness of instrumentation.	- 5 m	IE	☐	
20.	Confirm readiness of videotape recorders.	- 5 m	VT	☐	
21.	Close ball valves on vacuum lines. (3)	- 4 m	MT	☐	
22.	Record temperature and pressure	- 3 m			
	a. Main air line pressure _____		MT	☐	
	b. Torus presure _____		IE	☐	
	c. Drywell/torus ΔP _____		MT	☐	
	d. Torus temperature _____		MT	☐	
	e. N_2 pressure _____		MT	☐	
23.	Close and verify position of valves.	- 2 m			
	a. Torus/drywell ΔP (2)		MT	☐	
	b. Torus absolute pressure		IE	☐	
	c. Main air line pressure gage		MT	☐	
24.	Turn off vacuum pumps.	- 1 1/2 m	MT	☐	
25.	Confirm readiness of high-speed cameras, evacuate pit, and secure ladders.	- 1 1/2 m	P	☐	
26.	Clear pad except to MT and P.	- 1 1/2 m	TD	☐	
27.	Open main air line valve.	- 1 1/2 m	MT	☐	
28.	Activate key-operated, solenoid safety mechanism.	- 1 m	MT	☐	

	Item	Time	Person responsible	Checkoff	Initials
29.	Evacuate pad.	- 1 m	TD/MT	☐	
30.	Announce "ALL SYSTEMS GO"	- 1 m	TD/MT	☐	
31.	Start automatic timing sequence.	- 1 m	EE	☐	
32.	Announce "TEST COMPLETE, ON LIMITS FOR MT ONLY".	+10 sec	TD	☐	
33.	Remove safety key.	+40 sec	MT	☐	
34.	Close main air line valve.	+50 sec	MT	☐	
35.	Open main air line gage valve and record pressure.	+ 1 m	MT	☐	
36.	Open torus equalization line valves. (2)	+ 2 m	MT	☐	
37.	Commence venting torus/ drywell.	+ 3 m	MT	☐	
38.	Announce "ON LIMITS" for everybody.	+ 4 m	TD	☐	
39.	Announce estimated time for next test.	+ 5 m	TD	☐	

JAD