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# Blowdown and Condensation (B&C) Loop for Development of Reactor Depressurization System

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## Abstract

High pressure, high temperature steam/water blowdown test loop has been constructed. The loop simulates a pressurizer, depressurization system and In-Containment Refueling Water Storage Tank (IRWST) with full pressure and temperature conditions, and will be used to generate data for development of an optimal sparger as well as for design of safety/automatic depressurization system. In addition, experiments for reactor safety and pressurizer thermal hydraulics are scheduled. In this paper, general description of the Blowdown and Condensation (B&C) Loop will be given together with the test program.

## 1. Introduction

Timely depressurization of RCS is important when a large amount of core cooling water injection is needed from low driving pressure water sources, such as accumulators, low pressure safety injection system, etc. As a result, after the TMI-2 accident, depressurization system has been proposed as one of the important safety systems among others for safety improvement. For example, ABB-CE proposes a Rapid Depressurization System (RDS) for the System 80+™, Westinghouse proposes an Automatic Depressurization System (ADS) for the AP-600 plant, and KEPCO incorporates Safety Depressurization System (SDS) for Korean Nuclear Next Generation Reactor [1].

The actuation of depressurization system induces several transient and steady-state phenomena in the subsequent piping, and in the tank: the related dynamic load intensities strongly depend upon the reactor and water tank thermodynamic conditions, valve actuation mode, piping and support configuration, and steam/water discharge device (sparger) [2]. These phenomena have been intensively studied in the past, essentially for BWR. However, for application of this function to PWR, more data are required for a wide range of physical parameters, such as reactor pressure, discharge steam/water mass flow rate, water tank thermodynamics and geometrical characteristics.

In addition, depending on the function and system configuration, subsequent range of reactor pressure, mass flow rate, valve operation, and sparger and tank geometry can be different. Therefore, for design and for licensing, it is required an in-depth experimental and analytical effort to define design loads on surrounding structures and to demonstrate safety performance of system components in all expected conditions.

While dynamic loads due to valve operation and fluid flow in piping may be assessed using appropriate computer codes (i.e., RELAP [3], TRAC [4], etc.), dynamic force and response due to steam condensation in the water tank need to be characterized by test data. These loads are expected to act on the In-Containment Refueling Water Storage Tank (IRWST) wall and submerged structures in the IRWST, including the submerged discharge pipe, sparger, and heat exchangers or other spargers.

The overall objectives of the B&C Loop are to obtain sufficient information to support ADS/SDS design, and to develop an optimal sparger for SDS/ADS for future nuclear power plant. In addition, several specific objectives for this facility include: to collect sufficient thermal hydraulic performance data to support development and verification of analytical model of the ADS/SDS to be used in safety analyses of events for the ADS/SDS actuation, to obtain information on dynamic behavior of pressurizer, and to collect data on two-phase flow including critical flow.

## 2. Description of Blowdown and Condensation (B&C) Loop

The loop is designed to simulate the pressurizer, IRWST, and depressurization system of PWR. The operating conditions for the pressurizer and piping to the quench tank (IRWST) are the same as those of typical PWR. Mass fluxes through the depressurization piping will be matched to those of a typical PWR depressurization system by installing an appropriate test section and an orifice upstream of the depressurization valve. In addition, the location of sparger can be adjusted using the sliding pedestal, which makes it possible to study the effect of distance between the sparger and the IRWST wall or internal component in the IRWST.

The schematic diagram of B&C Loop is shown in Figure 1. Its main components are a pressurizer, pneumatic valves, a quench tank, a steam generator, nitrogen tanks, and piping and instrumentation. The loop consists basically of 4 systems, such as depressurization system, quench tank, steam generator, and nitrogen supply system.

Depressurization system

The depressurization system consists of a pressurizer, depressurization valves, a quick opening valve (QOV), and test sections and piping. The operating conditions for part of this system (up to and including depressurization valves and QOV) are 16.0 MPa, 350 °C. The pressurizer provides an isolable source of saturated steam/water at pressure and temperature typical of PWR conditions to achieve prototypic volumetric mass flux through the depressurization system. The volume of the pressurizer is 0.85 $m^3$, and internal diameter and height are 0.6 m, and 3.0 m, respectively. Two flanges are attached at the upper and lower portions of the vessel, to provide flow paths for steam and water, respectively (Figure 1). The steam and water lines use 2 inch Schedule 160S piping up to QOV and dwpressurization valves. In general, steam is discharged to the quench tank through the steam line, via depressurization valve(s) and sparger. However, to investigate the sparger performance for two-phase mixture discharge condition, water can be discharged through the water line, via depressurization valve(s) and sparger.

Two types of valves are used to simulate the depressurization valves. The valve installed near the pressurizer is an electro-pneumatic operated Pressure Control Valve (PCV), which can operate in several different operating modes: (1) fixed opening area with adjustable opening time (1 - 999 s), (2) manual control mode in which the valve opens one step whenever a button is pushed. (3) pressure control mode. This valve will be used when a loop seal is required to simulate. The depressurization valves installed downstream of the depressurization test sections are used to simulate SDS/ADS valve(s). These valves can be operated in (1) and (2) modes as mentioned above. To measure mass flow rate through depressurization valve(s), one venturi type flow meter per each line is installed.

The discharge pipe consists of 2.5 inch Schedule 80S pipe, and 2 inch Schedule 40S pipe connects the discharge line to the sparger inlet. One inch vacuum breaker is provided in the discharge piping and is located above the quench tank level to prevent water from rising in the discharge piping when flow through the depressurization valve is terminated.

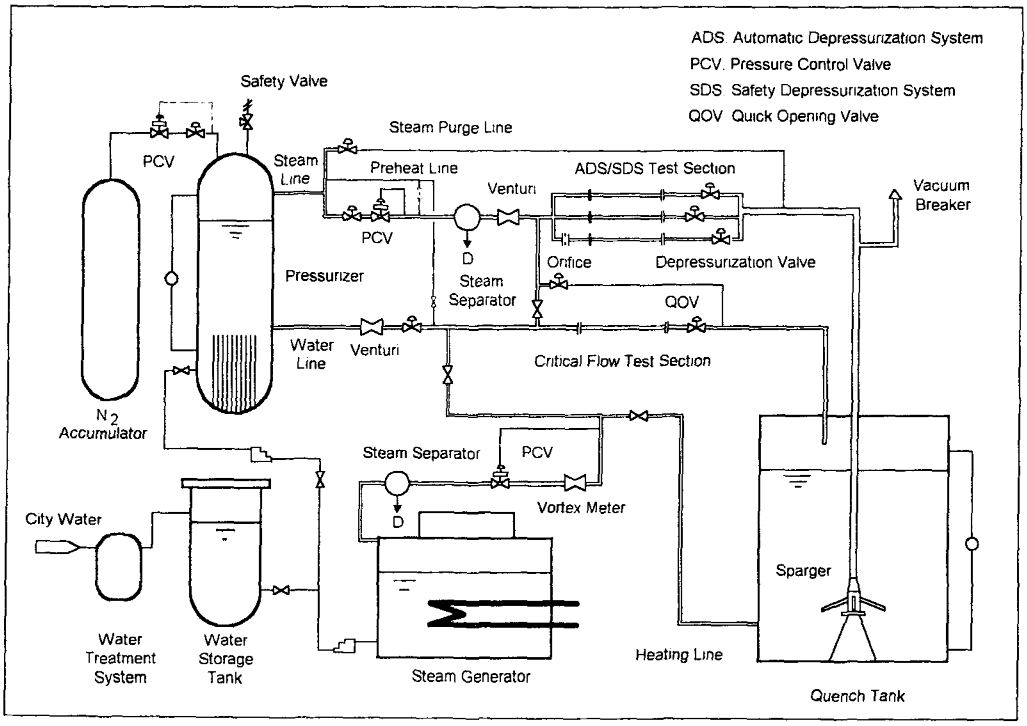


Figure 1. Schematic Diagram of the Blowdown and Condensation (B&C) Loop

<u>Quench Tank</u>

The quench tank contains the sparger and instrument support columns. The tank is cylindrical in shape and has rigid wall, and the surface of the tank is insulated using silica-gel. The volume of the tank is 28 $m^3$, and the diameter and height are 3 m and 4 m, respectively. The tank is covered with several pieces of detachable roofs. The roofs will be uncovered to provide vent during a test. The tank has 4 windows for visual observation and recording of condensation phenomena. The steam from the steam generator is fed to the spray ring installed at the bottom of the tank to heat the water up to 100 °C to match the initial test condition for quench tank water temperature.

Normally sparger will be installed at the center of the tank. However, to investigate the effect of the distance from the wall to the sparger, sparger can be installed at specific locations with respect to the tank wall. For this purpose, special type of pedestal has been installed at the bottom of the tank to fix sparger. One of the specific objective of this loop is to obtain data on sparger generated pressure forcing functions and resulting loads within the quench tank. For this purpose, instrument support columns are installed. Instruments a3re installed at specific locations of these columns to measure the pressure impulses as a function of distance from the sparger, and to measure the quench tank water heat-up and recirculation patterns (Figure 2)

Several configurations of sparger will be examined to quantify the effect of sparger shapes (I, T, Y, X types), and shapes, sizes, and distribution of holes on the sparger performance.

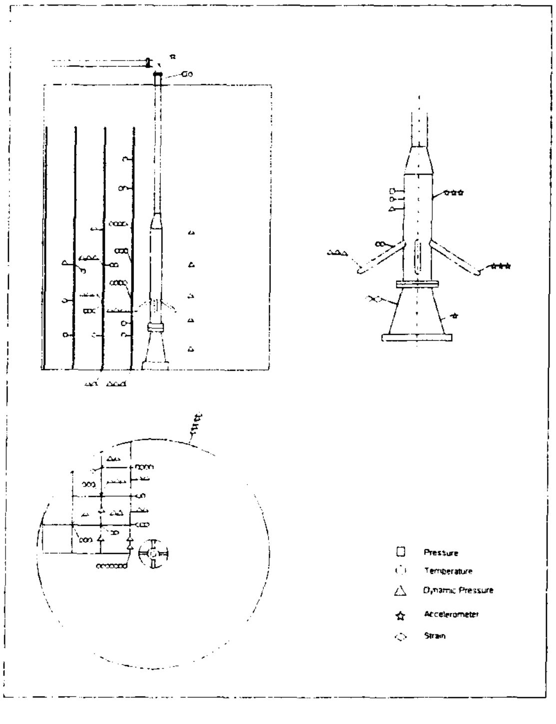


Figure 2. Location of Some Instrumentation in the Quench Tank, the Discharge Line, and the Sparger

<u>Steam Generator</u>

Steam generator provides low pressure steam for sparger test and for heating of quench tank water. The maximum operating pressure of this equipment is 1.0 MPa and it has 300 kW internal heater for steam production. In addition, the volume of steam drum is large enough to constantly provide approximate 0.3 kg/s of steam for short duration (5 minutes) while maintaining initial system pressure. A vortex flow meter is provided to measure the steam flow rate and a pressure control valve is installed to maintain constant pressure downstream of pressure control valve for steady-state sparger test.

Nitrogen Supply System

Hot water may be discharged to the quench tank through the water line and QOV in order to simulate critical flow phenomena or small break LOCA. For steady-state two-phase critical flow test, nitrogen is supplied from the nitrogen supply system to maintain constant pressure in the pressurizer. This system consists of high pressure nitrogen gas accumulator (0.7 $m^3$ and 12.0 MPa operating pressure), and a pressure control valve and an isolation valve. During a critical flow test, the pressurizer pressure is maintained constant by the pressure control valve.

Piping and Instrumentation

To provide de-aerated, de-mineralized water to the pressurizer and the steam generator, water treatment system and a water storage tank have been installed. The water treatment system provides de-mineralized water (conductivity less than 0.2 micro-mho/cm) and an electric heater removes air and non-condensable gas in water by boiling water in the water storage tank.

For critical flow test, various test sections can be installed upstream of the QOV. The maximum length of critical flow test section is 1.5 m, and the QOV can be opened within 0.3 second.

Total of 160 instrument channels has been provided for pressure, temperature, acceleration, and strain measurements. Pressure measurements in piping and components include 25 static pressure, 25 dynamic pressure, and 10 differential pressure sensors. In addition, 3 differential pressure sensors are used for level measurement (2 for pressurizer and 1 for quench tank). Flow rates through venturis are measured by differential pressure transducers and steam flow rate from the steam generator is measured by a vortex flow meter.

Temperatures at 80 different locations including pressurizer, piping, sparger, and quench tank are extensively measured. In addition, 8 channels of acceleration, 2 channels of strain, and one channel of void fraction (at test section) will be measured. High resolution video camera and VCR will be used to monitor the sparger performance and to visualize the condensation phenomena.

HP-VXI controller (V743/100) is used for data acquisition. Total of 144 channels can be connected to this controller. A high speed recorder will be used to record dynamic pressures and acceleration data. A low speed recorder will be used to monitor and to record several important temperatures and strain signals before and during a test.

## 3. Test Program

The B&C Loop is basically a steam/water test bench for components. The loop will be used for following tests:

(1) Steady-State Condensation Test: This test is aimed to get sufficient data for selection of basic sparger configurations such as size, shape, and distribution of holes, sparger shape, etc. Attention will be concentrated to chugging and interfacial oscillation condensation phenomena. For these tests, steam generator provides maximum 0.3 kg/s of steam to the sparger via depressurization valve(s). Test parameters include mass flux, quench tank water temperature, sparger submergence, and sparger shape.

(2) Transient Sparger Test: Several types of spargers designed according to the data through the steady-state sparger test will be tested using high pressure, high temperature steam from the pressurizer. In addition, high pressure, saturated water will be discharged through the depressurization valve to

investigate the condensation characteristics of two-phase mixture. Void fraction in the test section will be measured by a X-ray densitometer. For these tests, attention will be focused on the initial loading to quench tank and discharge piping. Accordingly, depressurization valve opening time will be an important test parameter. The data collected in these tests will be used to design a prototype of optimal sparger. The prototype will be extensively tested to fix final sparger design for anticipated pressure and temperature conditions during accidents.

(3) Depressurization Test: This test will be conducted to obtain data to support SDS/ADS component design. The effect of piping and valve sizes and of valve opening time on fluid temperature, pressure and pressure drop versus mass flow rate through valve(s) and piping(s) will be investigated. In addition, loop seal will be provided , if necessary, upstream of the depressurization valve(s) to characterize piping, sparger, and quench tank loads due to acceleration and discharge of water.

(4) Two-phase Flow Test: This test will be performed to develop two-phase critical flow and two-phase pressure drop models. Critical flow with subcooling for high pressure (8.0 MPa) as well as low pressure (1.0 MPa) critical flow with two-phase inlet conditions will be investigated. For latter case, water from the pressurizer and steam from the steam generator will be mixed at the mixer and discharged through the quick opening valve. With the same configuration, two-phase pressure drop test may be performed.

(5) Other Tests: Behavior of pressurizer during a LOCA or valve stuck-open will be investigated using depressurization valve(s) or QOV. In addition, high pressure, high temperature valves (i.e., safety and relief valves) may be tested to qualify valves for commercial use.

## 4. Test Schedule

Construction of the B&C loop has been completed at the end of 1995. Evaluation of system components and data acquisition system is now under way. Steady-state sparger test will be completed by July 1995. Tests for verification of optimal sparger design is planned to terminate in July 1996. Depressurization tests for SDS/ADS design will be performed for next 6 months. Two-phase tests will follow after the termination of these tests.

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