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Thermal Hydraulic Test Program for Evaluating or Verifying the Performance of New Design Features in KNGR

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Abstract

Experimental program for thermal-hydraulic evaluation or verification of new design features in the KNGR is presented for some selected items. This program is in progress under the framework of the national mid- and long-term projects on nuclear R&D. It includes the LBLOCA DVI ECCS performance evaluation test, fluidic device performance verification test, sparger performance evaluation test and the CEDM (control element drive mechanism) performance evaluation test. In this paper, the test program is presented, which includes the overview, test objectives, experimental method and test schedule for each test item.

1. Introduction

Development of the Korean Next Generation Reactor (KNGR), an evolutionary type of pressurized water reactor (PWR), is in progress under the phase-III program. It has a capacity of 4,000 MWth with 2x4 loop arrangement of the reactor coolant system (RCS) and 60 years of design lifetime. New design features of the KNGR include, among others, four trains of the safety injection system (SIS), the In-containment Refueling Water Storage Tank (IRWST) and the Safety Depressurization and Venting System (SDVS) [1].

Borated water is discharged through four independent trains of SIS directly into the downcomer of the reactor pressure vessel (RPV), and incorporation of the direct vessel injection (DVI) mode eliminates complicated piping interconnection and is believed to ensure more SI water to reach the reactor core. The SIS per train consists of a high-pressure safety injection (HPSI) pump and a Safety Injection Tank (SIT) with a passive flow controller called the fluidic device. The IRWST is employed for ensuring the suction of the SIS, which simplifies operation and increases reliability, and it can operate along with the SDVS to enable to depressurize the RCS by the bleed-feed operation to cope with the total loss of feedwater (TLOFW) event.

Since these new design features are required to evaluate and verify their performance for ensuring their contribution to the safety enhancement, so it was decided by the government to implement relevant experimental activities on evaluation or verification for some selected items into the national nuclear midand long-term R&D projects. And it was launched at the beginning of 1999. They include the LBLOCA DVI ECCS performance evaluation test, the fluidic device performance verification test, the sparger performance evaluation test and the CEDM (control element drive mechanism) performance evaluation test.

In this paper, presented is the experimental program for thermal-hydraulic evaluation or verification of new design features incorporated in the KNGR, which is in progress. For each test item, the overview, test objectives, experimental method and test schedule are presented.

2. LBLOCA DVI ECCS Test

2.1 Overview

KNGR adopts the direct vessel injection (DVI) mode of the SIS, and DVI Nozzles are located in the upper part of the reactor pressure vessel (RPV) downcomer. Due to this design feature, it seems that thermal hydraulic phenomena in RPV downcomer may be different from the cold leg injection (CLI) mode and is believed to govern the reflood phase behavior in case of LBLOCA. Therefore, experimental data for the DVI mode is needed to understand what happens in RPV downcomer during LBLOCA reflood phase. And it will be of great use for evaluating or improving relevant thermal hydraulic models and correlations in safety analysis codes, which are currently applicable to the CLI mode of the SIS.

The objective of the DVI ECCS test is to provide experimental data for evaluating or validating relevant thermal hydraulic models and correlations in best estimate codes, and to produce backup data for KNGR licensing, if required. The test will be carried out focusing on thermal hydraulic phenomena in RPV downcomer during the reflood phase of a postulated double-ended guillotine break of the cold leg.

Even though there are some experimental data on flow behaviors in downcomer with DVI mode using the UPTF facility, there still needs to have additional experimental data on the KNGR configuration. The reason for the need can be explained by excerpting the statements from Mayinger (1997) based on the experimental observation in UPTF on the thermal hydraulic phenomena in RPV downcomer during LBLOCA [2]. He summarized the observations such that thermal hydraulic situation in downcomer is a function of the positions of the broken and intact cold legs, and steam production in core, and the situation differs from reactor to reactor depending on the position of the CL nozzles as well as of SI injection nozzles around the downcomer annulus. Due to these distinct features, he concluded that there is no general scaling law which can model these geometry-dependent phenomena.

In the present test on the LBLOCA DVI ECCS, a series of separate effect test for the thermal hydraulic phenomena in RPV downcomer will be done, which cover a wide range of initial and boundary conditions and the test period from the early reflood to the late reflood phase (~ 500 sec). Testing will be mainly focused on steady-state conditions, and some transient tests will be done under quasi-steady state steam injection condition.

2.2 Test Facility

Design Concept

Test facility consists of a test section, 4 cold leg nozzles (3 intact legs and 1 broken leg), a boiler as a steam supply source and a containment simulator. The test section simulates the downcomer and core barrel region separately. Downcomer is simulated as a annulus, which is separated from the core barrel but connected to it through a pipe. This design feature allows an easiness of instruments access to the downcomer region and minimization of the scaling distortion of wall stored energy release to the annulus region, which usually occurs in small-scale test facilities. Boiler supplies superheated steam, which should be in fact produced in the core region and discharged into the downcomer through the cold legs, to the test section directly through the intact cold legs, as shown in Fig. 1.

Major thermal hydraulic parameters to be considered in the test include ECC flow rate, characteristics of steam injected through CL nozzles, steam flow, and the degree of superheating, differences in flow between each CL nozzle. And geometric parameters to be considered include relative elevation, length and angle between DVI and CL nozzles, existence of hot leg nozzles in downcomer (blockage effect). However, stored energy release through wall, ratio of volume between water inventory and solid wall, rate of stored energy release will not be simulated in the test facility.

Scaling Methodology

The test facility is designed based on the design criteria of prototypic fluid, pressure and temperature conditions. Volume scaling law is applied to determine major geometric and thermal-hydraulic design parameters based on a full height simulation with the area scale of 1/24.3, and the maximum operating condition results in the velocity scale of 1/1, time scale of 1/1, and power-to-volume scale of 1/1. Using this scaling method, it seems to be inevitable to have conventional drawbacks to be appeared in small-scale test facilities, such as a large aspect ratio, increased surface area and reduced diameter (curvature effect and short response time).

Therefore, based on the experimental observation from preliminary air-water conditions [3], new scaling approach, which is called the modified linear scaling law [4], has been developed in order to determine the test conditions, which are appropriate for the reduced test facility. The motivation of this new scaling method came from our observation, from 1/7-Scale UPTF counterpart hydraulic test (air-water) [3], such that the Wallis type parameter is appropriate to adopt for predicting the direct ECC bypass flow and new scaling law is needed to analyze highly geometry-dependent experimental data. The 'modified linear scaling' law shows the following features : a time- and velocity-reduced linear scaling, a prediction capability of multi-dimensional flow behavior in downcomer, preservation of aspect ratio with the prototype. This method is believed to apply to the flow phenomena in downcomer such as the direct ECC bypass, direct contact condensation of steam with ECC water, and void height. [4]

2.3 Measurement

Since the thermal-hydraulic phenomena in downcomer seem to be so complicated due to the interaction between the steam discharged from the intact cold legs and the liquid film of ECC water supplied from the DVI nozzles, it is necessary to observe what really happens in the downcomer annulus region. And this lead to do some preliminary air-water experiments in cylindrical and slab geometries [3, 5, 6, 7]. From these pre-tests, it was observed that there are multi-dimensional flow behaviors formed in the downcomer annulus region, and the ECC water penetration into the lower plenum will be closely related to the direct ECC bypass, the sweep-out of accumulated water in lower downcomer and the distribution of liquid film.

Based on these observations, the location of the instrumentation for the test section was determined, and experimental data to be obtained include the temperature and density distributions in downcomer, water level in downcomer and ECC Bypass. Many thermocouple sensors will be installed in the downcomer region, and pressure and differential pressure distribution will also be measured. In addition, two sets of Gamma densitometer will be used for measuring the density distribution in downcomer. [8] The break flow discharged through the broken cold leg to the containment simulator will be determined by measuring the steam and liquid flow after separating the break flow in the steam-water separator.

2.4 Test Schedule and Matrix

The basic and detailed designs as well as the manufacturing of the steam-water test facility were completed and the installation of the facility will be done in the middle of the November this year. After pre-test run scheduled to start at the end of this year, the main testing will be followed in the spring of next year. The test matrix of main testing will be determined in detail by considering the proposal from thermal hydraulic experts in the country.

It is expected that the experimental results be used to evaluate relevant best-estimate thermal hydraulic codes and also to resolve any licensing issues, if required, relevant to the DVI mode of the KNGR SIS by providing backup data.

3. Fluidic Device Test

3.1 Overview

The KNGR employs the fluidic device as one of the passive design features. The purpose of this passive safety component is to get effective use of SIT water by achieving the goals to minimize ECCS bypass during blowdown, and to prevent spillage of excess ECCS water during refill and reflood.

During the phase-II of the KNGR development program, a scaled-down model test has been carried out by KAERI using the facility of AEA Technology of UK [9, 10]. In the phase-III of the KNGR development program, a full-scale fluidic device performance test will be carried out at KAERI under the framework of the national R&D projects. For testing the full-scale fluidic device, the test facility is newly being constructed. This section briefly describes the test requirement, the design of both the fluidic device and test loop, as well as the test schedule.

The full-scale SIT design parameters and SIT performance requirements are summarized in the Reference [11]. The initial SIT pressure is 610 psig and the initial gas volume is 806 ft^3. The SIT water volume is 160 ft^3 and the amount of water volume before the stand pipe is uncovered is 800 ft^3. The peak flow rate through the fluidic device is 1,723 lbm/s and the target value of the flow turndown ratio is 3:1.

3.2 Test Facility

Fluidic Device

The design data of the full-scale fluidic device which can satisfy the turndown ratio of 3:1 are derived from the analysis of the scaled-down model test results. [9] The fluidic device consists of a lower plate, a middle plate, a partition plate, a closure plate and insert plates. All components of the fluidic device are designed and constructed according to the ASME VIII Div-1 code. The standpipe, 16 inch sch. 10s and 3,106 mm in height, is flange-jointed to the closure plate of the fluidic device and is also connected to the supply port inside the SIT. Four control ports, of which the flow area is the same as that of the supply port, are installed on the closure plate.

Test Loop

The main components of the test loop are a SIT (TK-1001) as shown in Fig. 2, a stock tank, a centrifugal pump, and an air compressing system. The P&I diagram of the test loop is shown in Fig. 3. The fluidic device is installed in lower part of the SIT. The SIT(TK-1001) is designed according to the prototypic design parameters and fabricated to the ASME VIII Div.-1 pressure vessel regulations. The vessel is 11.99 m in height with 2.74m I.D. and 60 mm in wall thickness. The lower part of the SIT is flange-jointed to the main body of SIT. This flange connection between the lower part and the main body of the SIT provides an easy access of disassemble and assemble of the SIT when the fluidic device within the lower part of the SIT is required to change. Two manholes of 24 inch diameter are installed at the top and lower parts of the SIT to allow maintenance and inspection inside the SIT.

The stock tank (TK-1002) is a concrete tank with a dimension of 4 m in length, 5.5 m in width and 4.4 m in height. The stock tank volume is 97 m^3, and this accommodates the water discharged from the SIT safely without any pressure effect. The centrifugal pump (PU-1001) has a capacity of 60 m^3/hr and will supply water from the stock tank to the SIT. The air compressing system is a three stage, reciprocating, and lubricating type and will supply air to pressurize the SIT to a required pressure condition after it has been filled with water. The air pressure inside the SIT will be continuously monitored and will be automatically cut off when the required pressure is set.

Major measuring parameters to be obtained during the test include the followings : gas pressure in the SIT, water level in the SIT, water level in the stand pipe, discharge flow rate, pressure drop through the fluidic device at downstream of the fluidic device. These measuring parameters are continuously monitored during the test and stored on the data acquisition system.

3.3 Test Schedule

The detailed design of the test facility as well as the fluidic device has been completed and the construction of the test facility is now in progress. The construction will be finished on December 2000. And the pretest run will start, and the main performance test will be followed successively.

4. Unit Cell Sparger Test

4.1 Overview

In the event of transients or SBLOCA coincident with steam generator secondary side heat removal unavailable, the four Pilot Operated Safety Relief Valves (POSRV) provide RCS overpressure protection [12]. To cope with these situations, the KNGR incorporates the SDVS to provide the feed and bleed capability along with the SIS to maintain the integrity of the RCS and the core. The actuation of the POSRVs result in a time varying high energy flow of air, steam or two-phase mixture from the pressurizer discharged to the IRWST through spargers. The discharge of these fluids induces complicated thermal hydraulic phenomena such as water jet, air clearing, steam condensation etc, and these phenomena impose relevant hydrodynamic forces on IRWST structure and SDVS system. Therefore, the IRWST structure should be designed so as to withstand the hydrodynamic loads for maintaining the structural integrity and safety functions of the engineered safety features (ESF) systems.

Following the actuation of the POSRVs, the water in spargers is discharged and air inside the SDVS piping and spargers enters through spargers into the IRWST in the form of high pressure bubbles. These bubbles expand and compress due to the momentum of the water and over-expansion of the bubbles. The oscillation of the bubbles produces oscillatory load on the submerged portion of the IRWST boundary wall and its internal structures. Following the water and air clearing from the SDVS line, steam or steam/water mixture is discharged through the sparger in the IRWST and condensed therein. The steam condensation phenomenon produces a high frequency, low magnitude oscillatory loading on the IRWST boundary wall [12, 13].

After closure of the POSRVs at the end of the blowdown, water from the condensation pool rises in a column through the discharge pipe (reflooding phenomenon) due to the condensation of steam there. This phenomenon may produce a big load on the discharge pipe and its supports due to water hammering. The presence of a vacuum valve that allows air to be sucked in can reduce the final level of a water column inside the spargers and therefore, the possibility of occurrence of the water hammering will be greatly reduced.

Among these phenomena, air clearing phenomenon is most important for the integrity of the IRWST [12, 13]. The analytical method for air clearing load due to the actuation of the POSRVs is not well understood and established, and experimental data for PWR conditions are very rare or unavailable. In addition, the effect of vacuum breaker size on the water level in the discharge pipe is not well understood.

For these reasons, the unit cell sparger test has been determined to do at KAERI. The main objective of the sparger test is to produce thermal hydraulic load data for development and verification of calculation model for air clearing and reflooding phenomena.

4.2 Experimental Method

A total of 30 blowdown tests will be conducted by discharging high pressure, high temperature steam from a blowdown vessel to a quench tank (IRWST simulator) through a sparger. [14] The test will be performed at the Blowdown and Condensation (B&C) Loop installed at the KAERI [15], with some modifications. The test facility, as schematically shown in Fig. 4, consists of a blowdown vessel (pressurizer simulator) equipped with an electric heater, a quench tank, a unit cell sparger, an air compressor, a depressurization valve and an isolation valve, and associated sensors and devices to measure flow rate, temperature and pressure, and a data acquisition system.

The blowdown vessel simulates a pressurizer and contains high pressure, high temperature steam and water. Design pressure and temperature of the vessel are 17.8 MPa and 370 °C, respectively and the internal volume is 0.85 m^3. The diameter and height of the quench tank is 3 m and 4 m, respectively, and the top of the tank is open to the atmosphere. A prototype sparger that will be used in the KNGR is installed at the center of the quench tank. Air in the pipe between the depressurization and isolation valves will be pressurized using an air compressor to increase air mass in the discharge pipe. The minimum valve stroke time of two valves is 0.7 sec and can be adjusted.

Important parameters for the air clearing phenomenon are air mass in the discharge pipe, pipe wall temperature, water temperature in quench tank, and steam mass flow rate discharged [13, 16, 17]. Major parameters for the experiment include the air mass in the discharge pipe, pipe wall temperature, collection tank water temperature, and steam mass flow rate. In addition, the effect of valve opening time and water level in the quench tank, and vacuum break size will be examined. The mass flow rate of steam and air, pressure and temperature at the discharge pipe, dynamic pressure at the bottom and wall of the collection tank will be measured. The air bubble internal pressure will be measured and the behavior of the bubble will be observed through wall mounted glass windows. For the vacuum breaker tests, in addition, water level in the sparger and discharge pipe will be measured.

The blowdown vessel will be initially filled with de-mineralized water and heated with the internal heater up to the initial condition. The pipe volume between two valves will be pressurized by the air compressor up to the desired pressure to get the initial air mass in the discharge pipe. Then the isolation valve and depressurization valve will be opened sequentially to simulate the actuation of the POSRVs in the KNGR SDVS. The valve opening sequence will be determined from the pre-test calculation using the RELAP5 code. The blowdown of the pressurizer will be continued for 10 sec. Then, the depressurization valve will be closed and the performance of the vacuum breaker will be measured. In this manner, a series of experiments will be performed for various combinations of test parameters.

4.3 Test Schedule

The test facility uses the B&C Loop. [15] To match the initial test conditions, however, some modification of the loop was necessary. So the piping configuration was changed, and valves and an air compressor were added to the exsiting B&C Loop. The modification and installation of components have been actually completed. The measurement system and data acquisition system will be installed and the test procedure will be developed. The shakedown test is scheduled to complete at the end of this year. And main tests will be followed successively.

4.4 Interface with Industry

The amplitude of the air clearing load depends on sparger design characteristics such as type of sparger and sparger hole pattern [16, 17]. Since this unit cell sparger test uses a prototype sparger for the KNGR, and the air mass in the pipe of the test facility and steam pressure and temperature are prototypic, so the test results will be the prototypic. Therefore, these data could be used to verify the performance of the SDVS design tools. In addition, the vacuum test results can be used for model development of SDVS piping configuration and for the design of piping supports.

5. CEDM Test

5.1 Overview

Design bases for the KNGR plant have been changed from the KSNP to accommodate needs from utility and to improve its safety. The electric power rating of KNGR increased from that of KSNP resulting in the higher heat generation of rate from CEDM's. CEA travel distance of KNGR is expected to be 2,040 km which is about 68 times more than the YGN/UCN requirement, when mode K load following operation and 60 year life are applied to the design. Thus it is required to perform a CEDM test to verify the endurance capability and air cooling capacity of the present CEDM design.

For evaluating the CEDM performance, KAERI has chosen four types of CEDM performance testing items for KNGR based on System 80 experience: travel test, drop test, power measurement, and air cooling test. [18] The objective of the travel test is for the verification of operability, life and travel requirements, the drop test is to verify latch release time characteristics of CEA drop. The power measurement and air cooling test are aimed to verify the electric power requirements and air cooling requirements during CEDM operation, respectively.

The KAERI had constructed a test loop named the CEDM test facility at the Engineering Complex Building in KAERI under the financial support of the KEPCO/KEPRI within the framework of the KNGR(II) development program, and completed a commissioning test for these purposes last year under the framework of the national R&D projects funded by the government. The test loop can simulate reactor operating conditions such as pressure, temperature and water chemistry of PWR primary system. A CEDM unit manufactured by Hanjung has been installed in the loop and some preliminary CEDM test data have been obtained.

This section describes the design features of the CEDM test facility constructed in KAERI, and details the types of CEDM testing which are in progress in the KAERI CEDM loop.

5.2 Test Facility

The CEDM test facility is a high temperature, high pressure, water circulation loop used for testing a CEDM motor under simulated reactor operating conditions. This test facility is designed to provide a flow rate of 1.3 kg/s at a maximum temperature of 320 ^{o}C and a maximum pressure of 15.6 MPa. The design value of nominal heat-up and cool-down rates is 50 ^{o}C per hour. The loop is comprised of a test vessel, a circulation pump, three heater banks, a pressurizer, a charging pump, and loop control system, as shown in Fig. 5.

Pressurizer provides the desired loop pressure and a cushion of steam in the system, which prevents large system pressure excursion due to expansion and contraction of the water in the loop as its temperature changes. A charging pump is used to make up water lost from the loop during normal operation and to provide a means of leak test in the loop. The circulation pump is a canned type centrifugal pump and circulates coolant through the test vessel. The electric heat banks raise coolant temperature up to the test conditions. A PLC system controls loop operating conditions as well as records the test parameters such as temperature, flow rates, pressure and water chemistry. A computer system controls the CEDM-CS which provides required electric power to the CEDM coils, and the system is also used to obtain and records the coil current trace and the weight drop curve as a function of time [19].

The test vessel is installed just below the CEDM assembly to accommodate the drive shaft of the CEDM and the test weight. At the bottom of the test vessel a hydraulic damper is located. As the weight enters into the hydraulic damper, the water escapes through the radial holes into the test vessel. The holes are sized to limit the flow, by which the dropping test weight is decelerated while dropping down.

5.3 Test Matrix and Measurements

CEDM performance verification test is to be carried out at the CEDM test facility in KAERI. Water chemistry in the test loop should be tightly controlled to meet operating condition of reactor make-up water. Prior to testing, the parts of the test CEDM motor assembly are thoroughly inspected, and dimensions are measured. A new extension shaft is installed into the test station to be used for the test. The test weight equivalent to the weight of a four finger CEA and CEA extension shaft is used in the test. The CEDM is operated with a nominal speed of 30 inch per minute as provided by the CEDM control system (CEDM-CS). [18]

Test matrix for the CEDM performance verification test consists of four different testing items as follows:

Air Cooling Test : Air cooling test is to be performed in order to measure the heat rejection rate of the CEDM at various air cooling flow rate and temperature. The thermocouples embedded in the coil assembly read the coil temperature at various operating conditions. And the temperature at the inlet and outlet of the coil assembly as well as the flow rate through the coil assembly are measured.

Drop Test : More than 400 full height gravity-driven drop tests are to be performed from fully withdrawn hold mode at simulated reactor operating conditions. Latch release time is measured and recorded. The times required for the test weight to commence dropping and the position of the test weight as a function of time until the drop is completed are measured. The total elapsed time from interruption of power to the CEDM coil to the time at which the test weight reaches 90 % of its fully falling down position should not exceed a certain acceptance criteria.

Travel Test : The CEDM motor is to be tested for a minimum of 9,144 m of travel length. At the completion of the test run, the CEDM is disassembled and inspected for excessive wear of moving parts, and dimensional inspection data are recorded. And the travel test is resumed until the CEDM becomes disabled.

Power Measurement Test : Operating currents at the four coils and total electric power at insertion, withdrawal and stop modes are measured and recorded.

5.4 Preliminary Testing

A CEDM system manufactured by Hanjung was installed to the KAERI CEDM test loop and tested at simulated reactor operating conditions. The purpose of these testing is to tune up the test loop and the CEDM-CS designed by KAERI [19], and establish test procedure for the CEDM performance verification test. Fig. 6 shows a typical result of CEDM coil trace obtained at 30 ipm of driving speed at 320 ^{o}C of temperature and 15.6 MPa of pressure simulating the reactor operating condition. The coil trace shows normal movement of the drive shaft with 97 kg of the test weight upwards. Fig. 7 shows the drop curve of the test weight, which meets the acceptance test criteria of the drop time.

6. Summary

KNGR incorporates many advanced design features to enhance its safety. New design features integrated with the Engineering Safety Feature (ESF) systems represent significant advances and is a major contributor to the reduced core damage frequency and improved severe accident performance for the KNGR. For design items which are not adopted in existing plants, there are needs to do evaluation and verification works for ensuring their performance.

Experimental program for thermal-hydraulic evaluation or verification of new design features in KNGR is presented for some selected items in this paper. It includes the LBLOCA DVI ECCS performance evaluation test, fluidic device performance verification test, sparger performance evaluation test and the CEDM performance evaluation test. In this paper, the test program is presented for each test item, which includes the overview, test objectives, experimental method and test schedule.

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Reference

[1] Standard Safety Analysis Report for Korean Next Generation Reactor, KEPCO, 1999

[2] F. Mayinger, “Status of Thermo-hydraulic Research in Nuclear Safety and New Challenges”, Proc. of the ICONE-8, pp. 1508-1518, Kyoto, 1997.

[3] 윤병조 등, “차세대원자로 대형냉각재 손실사고 발생시 재관수기간동안 강수부내 수력현상에 관한 실험적 고찰“, 한국원자력학회 춘계학술대회 논문집, 2000.

[4] 윤병조 등, “LBLOCA 재관수과정에서 DVI 방식의 안전주입수 직접우회 현상을 위한 척도해석 방법론 개발”, 한국원자력학회 추계학술대회 논문집, 2000.

[5] 윤병조 등, “LBLOCA 재관수 기간동안 비상노심 냉각수의 직접우회 현상에 관한 물-공기 실험 : UPTF Test 21-D 비교실험”, 한국원자력학회 추계학술대회 논문집, 2000.

[6] 윤병조, 권태순, 송철화, “DVI 실험장치의 척도해석”, 내부 기술보고서, 한국원자력 연구소, 2000.

[7] T.S. Kwon et al. “ECC Water Spreading Width for Flat Plate”, Proc. KNS Autumn Meeting, Oct. 2000.

[8] 주인철 등, “DVI 실험장치 강수관 내부에서의 기포율 측정을 위한 감마선 밀도계의 적용”, 한국원자력학회 추계학술대회 논문집, 2000.

[9] B. H. Cho et al., ‘Development of Fluidic Device in SIT for Korean Next Generation Reactor (I)’, KAERI Report, KAERI/TR-1363/99, 1999.

[10] J.-K. Park et al., “Development of Fluidic Device in SIT for KNGR Design (II)“, the 14th KAIF/ KNS Conference, April 1999.

[11] 조봉현, “차세대원자로(III) Fluidic Device 실규격 성능실험 실험요건”, 한국원자력연구소, 1999.

[12] KOPEC, “IRWST Thermal Hydraulic Load Analysis Report,” N-001-END461-201, Feb. 1999.

[13] C.K. Park et al., “A Study on the Characteristics of the Jet Type Condensation,” Proc. the Korean Nuclear Society Spring Meeting, Korea, 1999.

[14] C.K. Park, C.-H. Song, & J.K. Park, “Test Matrix of the KNGR Sparger Performance Test,” 53121-SPGR-TR002, Rev. 00, Project Internal Report, KAERI, 2000. 7.

[15] C.K. Park, et al. “Construction of the Blowdown and Condensation Loop”, KAERI/TR-941/98, KAERI, 1998.

[16] H.Y. Kim et al., “Methodology on the Sparger Development for Korean Next Generation Reactor”, KAERI/TR-1337, KAERI, 1999.

[17] USNRC, “Suppression Pool Temperature Limits for BWR Containments,” NUREG- 0783, Nov. 1981.

[18] S. Choi, K B. Park & J.-K. Park, "Test Requirement of CEDM Performance Test for Korea Next Generation Reactor", KNGR-ME-TR250-01, Rev.2, KAERI, 1999.6.

[19] S. Hur et al., “Development of CEDM Control System for CEDM Performance Test”, Proc. Korean Nuclear Society Spring Meeting, Pohang, Korea, May 1999.

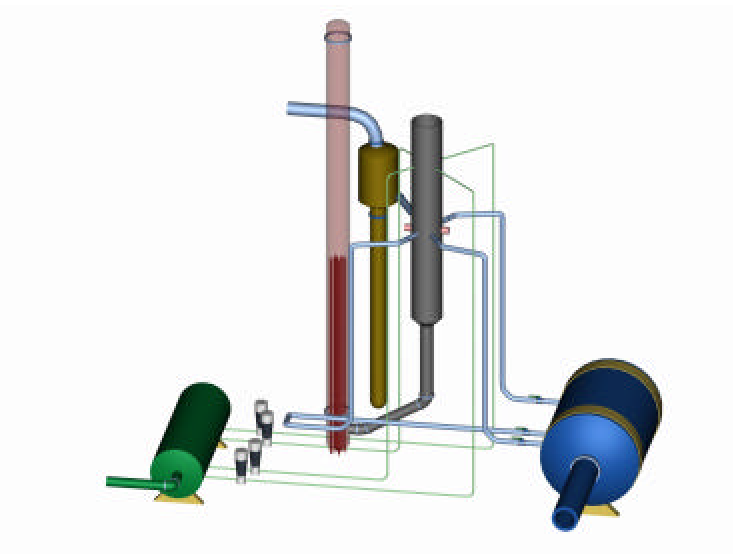


Fig. 1 Steam-Water DVI Test Facility

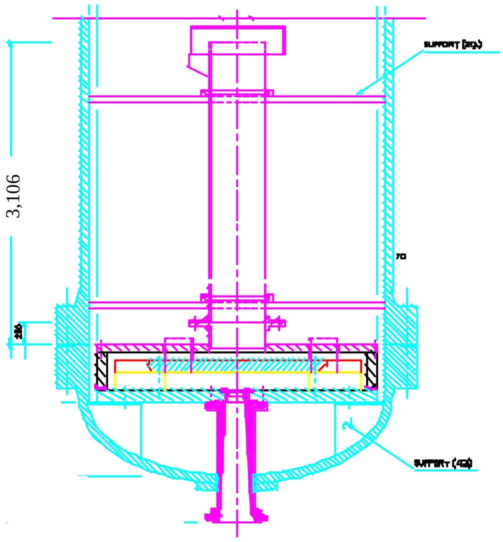


Fig. 2 Drawing of SIT with Fluidic Device

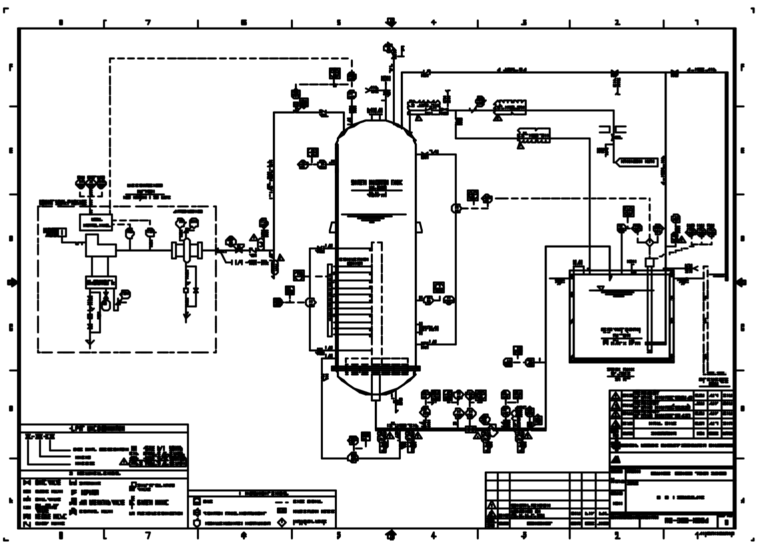


Fig. 3 P&I Diagram of the Fluidic Device Test Loop

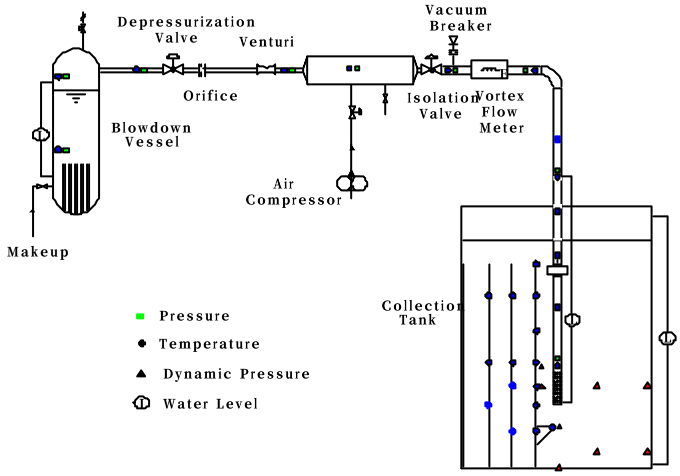


Fig. 4 Schematic Diagram of Unit Cell Sparger Test Facility

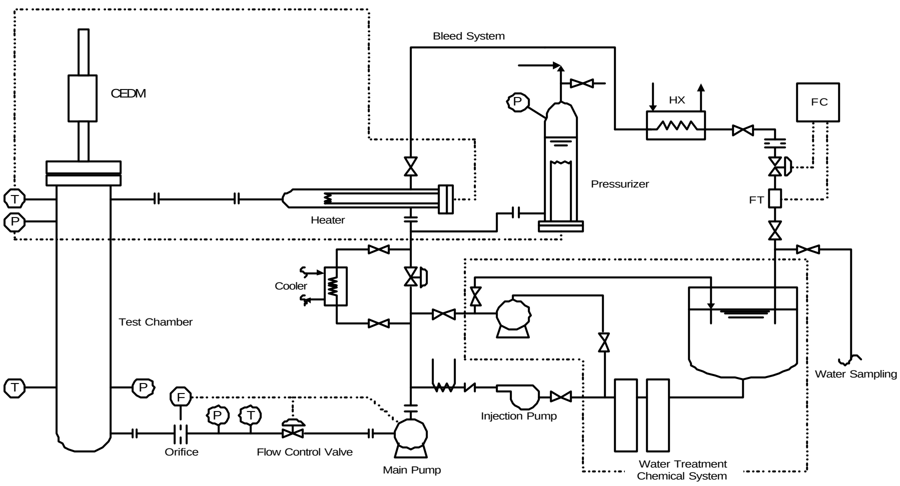
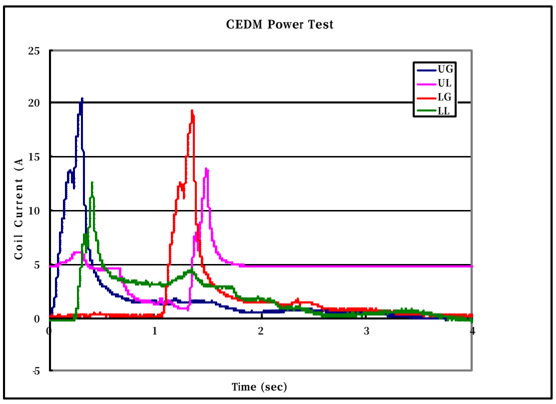


Fig. 5 KAERI CEDM Test Facility



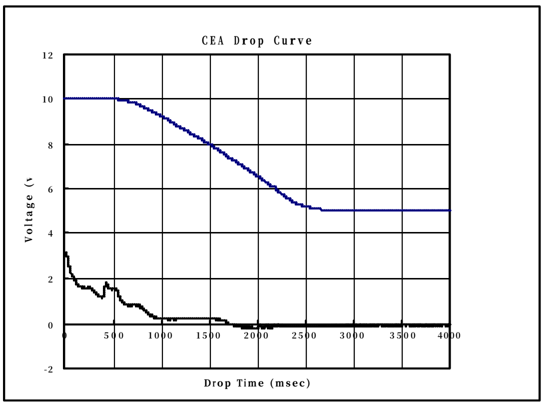


Fig. 6 CEDM Coil Current Trace

Fig. 7 Drop Curve of the Test Weight