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Scientific Design of the KAERI Integral Test Loop (ITL) Facility

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ABSTRACT

Scientific design of the facility for the integral effect test to simulate Korean PWR plants is presented in this study. After briefly describing the test objectives, preliminary test requirements and test matrices, the design requirements of the integral test loop (ITL) are introduced. Based on the design requirements, the ITL is designed according to the step-wise scaling (the modified volume scaling methodology) to satisfy the geometric, kinematic, dynamic and energetic similarities between the plant (KSNP) and the test facility. And finally the design description is presented for major components and systems of the ITL.

1. Introduction

Since the middle of 1980, Korea has started to localize the technologies for designing the NSSS (Nuclear Steam Supply System) of PWR, and a large number of computer codes were introduced and utilized for design and safety analysis. By these activities, technology for the design of Korean Standard Nuclear Plant (KSNP) was established, and the design of Korea Next Generation Reactor (KNGR) became possible using these accumulated technologies. However, establishment of the key technologies for verification and enhancement of the safety of Korean nuclear power plants is still necessary to become a reliable and independent NSSS supplier.

Until now, most of key technologies and experimental data for design certification and safety assessment for the existing plants and KSNP were obtained from foreign countries. To be free from foreign technologies and to develop a advanced nuclear power plant by ourselves, it is indispensable to have an integral test facility, which enables us to evaluate and verify the performance of components and systems as well as computer codes for our design of plants. Especially, it seems to be mandatory to verify the safety of new plants designed by ourselves for their export to foreign countries through integral effect tests. In addition, in order to design and to implement new safety concepts and safety systems for safety enhancement and economic competitiveness, new experimental data are necessary. For these reasons, an integral test loop (ITL) facility has been proposed to construct at KAERI under the national mid- and long-term R&D project, and its basic design has been completed.

From the international point of view, general needs for current LWRs can be summarized as follows [1] : First, extension of the capability of existing codes and the associated data base is needed for application beyond the current model and code development. Validation areas include startup and cool-down transients, low power and shutdown operating modes, accidents involving multiple system failures and operator mitigation efforts. Secondly, development and evaluation of accident management procedures. Thirdly, code uncertainties require improvement. Also capability is needed for analyzing transients in operating plant and future designs. For doing these, existing codes should be modified and/or new codes need to be developed. And for satisfying these needs, experimental facilities for integral and possibly separate effects tests are required. And at least, one facility capable of representing each of major reactor designs should be maintained to meet the long-term needs in thermal-hydraulics.

In this paper, the scientific design of the ITL, which is expected to be installed in near future at KAERI, is described. The test objectives, preliminary test requirements, design requirements of the ITL, and design characteristics of major systems and components as well as the instrumentation and control systems are specified briefly.

2. Test Objectives and Design Basis

The integral effect test, in general, is aimed at providing experimental data of overall thermal hydraulic response of plants under operational transients or anticipated accidental conditions of reference plants. In order to meet general or specific objectives of integral effect test (IET), the test facility should be designed so as to reveal various thermal-hydraulic phenomena, as closely as possible, to be exepcted to occur in real plants during operation or anticipated transients of interest.

The KAERI-ITL will be used for evaluating and verifying the safety of Korean PWR plants, for assessing the safety analysis codes as well as for experimentally resolving safety issues. [2] Major test objectives include the followings:

(1) Verification of Thermal-Hydraulic Safety Concerns

(2) Verification of Plant Design Optimization

(3) Developmental Assessment and Evaluation of T/H and Safety Codes

Since the integral effect test facility should be designed so as to simulate real plants during operation or anticipated transients, the design and operational characteristics of the reference plants (Korean Standard Nuclear Plant and Korean Next Generation Reactor) were analyzed in order to draw major components, systems, and functions to be satisfied or simulated in the test facility.

The test matrix is set up by considering major safety concerns of interest and the test objectives to confirm and enhance the safety of the plants. They are summarized in Table 1. [2] And the analysis and prioritization of the test matrix leads to the general design requirements of the test facility. Based on the general design requirements, the design criteria is set up for the basic and detailed design of the test facility. And finally the design requirements specific to the fluid system and measurement system of the test facility are established [2]. The design requirements is used as a guideline to the scaling analysis and scientific design of the test facility. The test matrix can be modified later in the stage of main testing by considering the needs of experiments and circumstances at that time.

General procedures applied to the ITL design is schematically shown in Fig. 1. The design basis determined by considering various aspects for the ITL design is summarized in Table 2.

3. Design Description of the ITL

The ITL is a full height, full pressure integral facility and is designed according to the modified volume scaling method [3]. It consists of two steps of the design approaches: the top-down approach and the bottom-up approach, as shown in Table 3 and Fig. 2. The first approach is done by applying the general volume scaling methodology, which results in determining major geometric and thermal-hydraulic data of the ITL to meet the geometric, kinematic, dynamic and energetic similarities of global thermal-hydraulic phenomena between the plants and test facility. The second approach is applied to meet the scaling requirements for important local phenomena to govern global behaviors in the system.

At the beginning stage of ITL scientific design, the design and operational characteristics of the reference plants (KSNP and KNGR) were analyzed in order to draw major components, systems, and functions to be satisfied or simulated in the test facility.

The ITL simulates the primary, secondary and safety systems of the KSNP, and new safety concepts such as SDVS (Safety Depressurization and

Venting System), IRWST (In-Containment Refueling Water Storage Tank), which will be adopted in the design of KNGR, will be installed as necessary.[4] The volume scale is 1/200 of the reference plant (KSNP) and the power of simulated core is 15 % of the scaled core power. The volume scale of the ITL is compared with other integral test facilities in Fig. 3. A formal scaling analysis has been performed to assure that it accurately model the details of the KSNP geometry including the primary system, the secondary system, and the safety systems. The interconnecting pipe routings are also duplicated.

All of the primary system components will be fabricated of stainless steel (SUS316) and are capable of prolonged operation at 18.7 MPa and 370 ^{o}C. The test facility should endure more than 200 tests without repair. Fig. 4 and Fig.s 7-10 show the schematics of the ITL. .

3.1 Primary and Secondary Systems

The primary system of the ITL includes the following components:

Reactor Vessel: It models the upper and lower reactor internals, the core barrel, the downcomer and the core. Connections for hot legs, cold legs and direct vessel injection (DVI) lines are provided and core bypass is also simulated. The reactor vessel contains 209 electrical heater rods with 0.382 in O.D. and a heated length of 150 inch. The heater rod should be operated up to 900 ^{o}C without damage. The maximum core power is 2.5 MW. The elevation of the center line of hot leg nozzle and the lower inner surface of the cold legs will be preserved. Fig. 5 shows a cutaway view of the reactor vessel.

The downcomer will be represented by a hybrid shape, as shown in Fig. 5 : The middle and upper parts will be a concentric annulus, and the lower part connected to the lower plenum of the reactor vessel will be two external pipes which enables us to measure mass flow rate. The upper part of the downcomer is connected to four DVI lines.

Primary System Piping: Loop piping models two primary loops, each of which consists of one hot leg, two intermediate legs, and two cold legs, as shown in Fig. 8. Break simulators can be installed on cold legs, and DVI lines etc. to simulate pipe breaks. The flow discharged from the QOV installed in the break simulator vents to the containment simulator. The containment simulator is used to determine break flow rates by measuring the liquid level.

The Froude Number, which is generally recognized as a good criterion with respect to preserving the flow regime transition, counter-current flow limitation and stratification in a horizontal pipe, is preserved for the hot legs, cold legs, and horizontal part of intermediate legs. The vertical parts of the intermediate legs, however, is scaled based on the volume scaling methodology to preserve the flooding phenomenon. Due to this design feature, the characteristics of calculated pressure drop under nominal operation condition shows that the pressure drop at the hot legs is small and that of the intermediate legs is excessive in comparison to those of the reference plant. Even though this kind of scaling distortion of local pressure drop may not be avoided, total pressure drop through the primary loop piping is preserved. Four primary coolant pumps, which is centrifugal pumps with canned motor type, will be installed. The pumps shall be geometrically similar to the reference reactor coolant pump (RCP) and be designed so that hydraulic head, pump pressure loss, and homologous curve are preserved. In addition, the flow coast-down characteristics will be simulated by pump speed controller.

Steam Generators: Each of two steam generators provides 1.4 MW heat transfer capability and its operating pressure and temperature are 10.0 MPa and 327.3 °C, respectively to meet the requirements for SGTR scenario. Each steam generator contains 41 U-tubes with the same internal and external diameters as in the reference steam generator. Since hydraulic diameter of the ideally scaled annulus is too small, the downcomer of steam generator is simulated by two external pipes, as shown in Fig. 6. Economizer and steam separator are provided, whereas steam dryer is not installed. The feed water system provides cooling water to steam generators and the flow rate and temperature of cooling water will be adjustable. Steam leaves the steam generators, as shwon in Fig. 10, through main steam system, which consists of isolation valves, safety and relief valves. The steam is condensed in a spray condenser sized enough to extract the maximum core power.

Pressurizer: The pressurizer is designed with a full height, 1/200 volume scale and is equipped with internal electrical heaters and spray system for pressure control. On its top, safety valves and safety depressurization system (SDS) piping are installed. The pressurizer surge line is designed so as to preserve Froude Number, CCFL criteria, off-take phenomenon, and L/D design limit.

3.2 Safety Systems

The ITL includes safety injection systems (SIS), SDS and containment system:

Safety Injection Systems: Safety injection systems consist of high pressure safety injection (HPSI) system and low pressure safety injection (LPSI), shutdown cooling system (SCS), IRWST. HPSI system consists of four pumps and four safety injection tanks (SIT). ITL is designed to inject cooling water not only into the cold legs as in KSNP, but also into other locations, such as the reactor vessel downcomer as in KNGR, the hot legs, etc. LPSI system consists of two pumps, and valves and pipings. Two HPSI pumps will be used to simulate the KSNP, whereas four HPSI pumps will be used when simulating the KNGR. Two LPSI pumps will be used as a part of the SCS. The performance curve of each injection pump is programmed into a controller to regulate the injection flow rate as a function of system pressure.

Four SITs is volume scaled and is pressurized by nitrogen gas. The injection lines is designed to preserve the characteristics of pressure drop and scaled volume. The source of cooling water is the IRWST. During recirculation operation mode, the suction of each pump is automatically aligned into the containment simulator. The IRWST is designed to provide water at least 30 minutes of all safety injection pumps prior to reaching a specified water level. A sparger will be installed inside of the IRWST to condensate the steam-water mixture from the SDS.

Safety Depressurization System (SDS): Safety depressurization system is to depressurize the RCS in the event of a LOCA or a transient, to allow the safety injection water to the reactor vessel to prevent the core uncovery. The system also has a capability to reduce the RCS pressure to operate the SCS. The system consists of a depressurization valve, a sparger, and valves and piping. The fluid from the pressurizer is vented to a sparger, through the depressurization valve, either in the containment simulator for the simulation of the KSNP or in the IRWST for the KNGR simulation. The size and pattern of the sparger holes are preserved and the number of sparger holes are volume scaled.

Containment Simulator: The containment simulator is designed to simulate the containment of the plant. There is a cooling and spray system in the simulator so that the pressure of the simulator can be maintained below a specified level to simulate the pressure behavior of the containment during a LOCA. The simulator also provides a mean to measure the mass flow rate of the effluent from the RCS or secondary system.

3.3 Break Simulator

It is possible to simulate a break with various sizes at several locations using specific devices (break simulators). The simulator consists of a venturi, a turbine flow meter, a gamma densitometer, temperature and pressure sensors, and valves and piping. Small and intermediate breaks can be achieved on the cold legs, hot legs, upper head and lower plenum of the reactor vessel, pressurizer, steam generator, and secondary systems such as feed water line and steam line. Steam generator tube ruptures will be simulated by external piping, which links the steam generator plenum and steam generator secondary side.

The break simulator is used to simulate the breaks of the piping and vessel and is equipped with instruments spool to measure two-phase flow from breaks or SDS. The volumetric two-phase flow rate is measured by a venturi and a turbine flow meter at the break simulator and the average density of a two-phase mixture is measured by a gamma densitometer in the break simulator. The quick opening valve simulates a break and the effluent is vented to the containment simulator. The variation of liquid level in the containment simulator is also used to calculate the two-phase mass flow rates through a break.

The design features of the ITL described above has been primarily checked by performing the preliminary analysis of scaling distortions to be occurred [3,4] as well as the scoping analysis using the RELAP5 and MARS codes [5,6] for typical SBLOCA and MSLB scenarios, and they show reasonable agreements of prediction bewteen ITL and KSNP cases, which reveals the technical feasibility of the current ITL design.

3.4 Instrumentation

Instrumentation is provided to obtain detailed information on thermal-hydraulic phenomena in the primary and secondary side during a transient. Sufficient instrumentation will be installed based on the design criteria of robustness, reliability and overlapping. About 1,500 channels are continuously recorded by the Data Acquisition System (DAS).

The ITL includes the following types of instrumentation. Thermocouples are used to measure the temperature of coolant and surface of the fuel pins, piping and vessels. Special grade thermocouples will be used and connected to the DAS. Pressure transducers are used to measure the static pressures within various tanks, vessels and pipes. Differential pressure transducers are used to measure the liquid levels in various tanks, vessels and pipes. They are also used to determine pressure drop in system piping, and across fittings and components. Turbine flow meters and venturis are used to measure single and mixture flow rates. Void fractions will be calculated by gamma densitometers under forced flow conditions and by DP under stationary or low flow condition. And heat flux meters are used to measure the heat loss from individual tanks and components.

3.5 DAS and Controls

The DAS includes all the equipments necessary to receive, transmit, process, and record the voltage or current signal outputs from the individual sensors. This includes amplifiers, signal conditioners, transmitters, interconnecting wiring, A/D converters, interfacing boards, switching panels, computers, displays and other recording devices as needed to access the instruments. The DAS is capable of storing and maintaining all data retrieved and recorded during a single test.

The ITL will include a control panel capable of modeling all of the important safety logic of the reference plant. All control actions, such as valve opening and closure, pumps starts, and safety signals, will be monitored and recorded using a software package. The package provides a time history of all control actions that occur during a test.

4. Preliminary Test Plan

Preliminary test plan is set up and they are divided into three phases:

Phase-I: During this phase, the design characteristics of the ITL will be confirmed. The characteristics of liquid inventory of each component and system, and the pressure drop will be quantified to confirm the design of the facility and to quantify the scaling distortion to be expected. Characteristics of the heat loss and heat storage will also be examined. And finally several natural circulation tests will be performed to finally check the overall characteristics of the facility.

Phase-II: The key test matrices, most of which are the design basis accidents, will be tested. They include SBLOCA with either cold leg injection or DVI, steam generator tube rupture (SGTR), steam line break (SLB) and feedwater line break (FLB). In addition, simulation of some of safety concerns such as low power shutdown (LPS) and total loss of feedwater (TLOFW) accidents, will be tested.

Phase-III: During this phase, testing for developing strategy for accident management will be performed. They include a simulation of multiple failures, beyond design base event (bDBE), bDBE coupled with advance design feature (ADF) or passive design feature (PDF). Characteristics of new safety concepts such as passive secondary cooling system (PSCS) and secondary system feed-bleed will be investigated to examine the validity of new concepts. Other testing for safety issues will be also performed as required.

5. Conclusions

The ITL is a state-of-the-art integral effect test facility designed to develop a data base suitable for the assessment of thermal-hydraulic/safety analysis codes that will be used to evaluate or verify the performance of components and systems of Korean PWRs. The design requirements are obtained through the analysis of the design and operational characteristics of the reference plants (KSNP) and KNGR. The preliminary test matrix is set up by considering major safety concerns of interest and the test objectives to confirm and enhance the safety of the plants.

The facility is scientifically designed according to the test requirements and test matrix to satisfy geometric and thermal-hydraulic similarities between the reference plant and the test facility.

In this paper, the design procedures, scaling method, design concept and technical specifications of major components and systems of the ITL are briefly described.

References

[1] OECD, “CSNI Integral Test Facility Validation Test matrix for the Assessment of Thermal-Hydraulic Codes for LWR LOCA and Transients”, OECD/GD(97)12 (1996)

[2] C.-H. Song et al., "Test Requirements for the Integral Test Loop to Simulate Korean PWR Plants", KAERI/TR-1771/2001, KAERI (2001)

[3] C.-H. Song et al., "Scaling Analysis of the Integral Test Loop to Simulate Korean PWR Plants", Technical Report, KAERI (2001)

[4] C.-H. Song et al., "Basic Design of the Integral Test Loop to Simulate Korean PWR Plants", Technical Report, KAERI (2001)

[5] K.H. Bae, C.-H. Song & M.K. Chung, "Preliminary Scoping Analysis of the Integral Test Loop for SBLOCA by RELAP5", Internal Document, KAERI (1998)

[6] W.J. Lee et al., "Scoping Analysis of the Integral Test Loop for SBLOCA and MSLB by MARS", Internal Document, KAERI (2000)

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Table 1. Summary of the Preliminary Test Matrix

Classification		Test Name	No. of Test
Phase-Ⅰ	Group-1	Natural Circulation(NC)	5
	Group-2	SBLOCA (1) DBA: Interface Common Header Break (ECCS + SCS etc.) (2) ECCS capacity with power up (3) ECCS Optimization (4) Multiple Failure & operator recovery	11
	Group-3	SLB	2
		SGTR	2
	Group-4	LBLOCA (at the end of the Core-1)	3
Phase-Ⅱ	Group-5	FLB	2
	Group-6	TLOFW	2
	Group-7	Shutdown LOCA	2
	Group-8	MID-Loop	2
	Group-9	LOFA	2
	Group-10	SBO	1
	Group-11	ATWS	1

Table 2. Summary of the Design Basis for the ITL

Reference Plant		KSNP	Basis
		KNGR	Additional
Height Ratio		1/1	
Volume Ratio		1/200	
Max. Core Power		15 % of Scaled Full Power	2.5 MW
Max. Operating Condition	1ry Sys.	18.7 MPa, 370 ℃	
	2ry System	10.0 MPa, 327.3 ℃	

Table 3. Comparison of Scaling Methodologies

Scaling Item	Volume Scaling	Modified Volume Scaling	Linear Scaling	3-Level Scaling
1) Global (System)	Applied	Applied	Applied	Applied
2) Boundary/Inventory	N/A	Applied	N/A	Applied
3) Local Phenomena	N/A		N/A	Applied

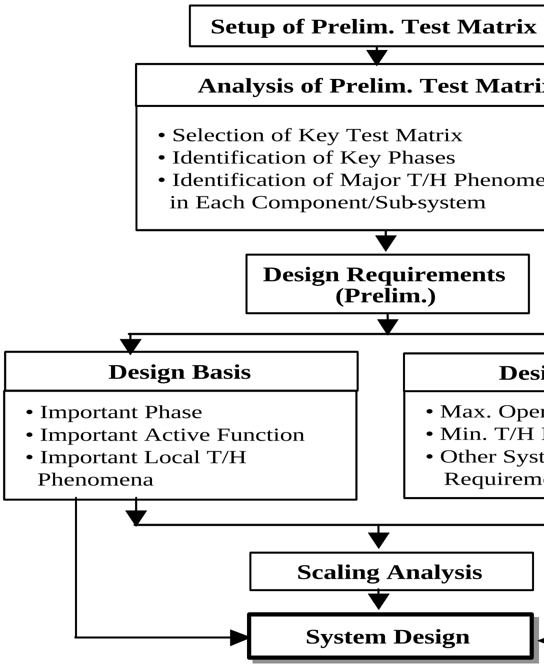

Fig. 1 Diagram to Show General Procedures of the ITL Design

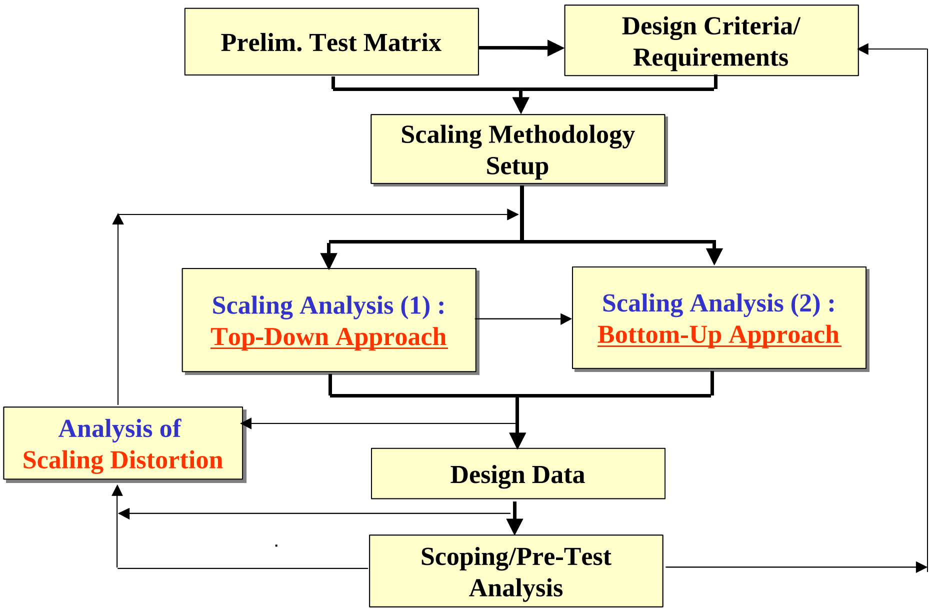

Fig. 2 Diagram to Show the Procedures of Scaling Analysis

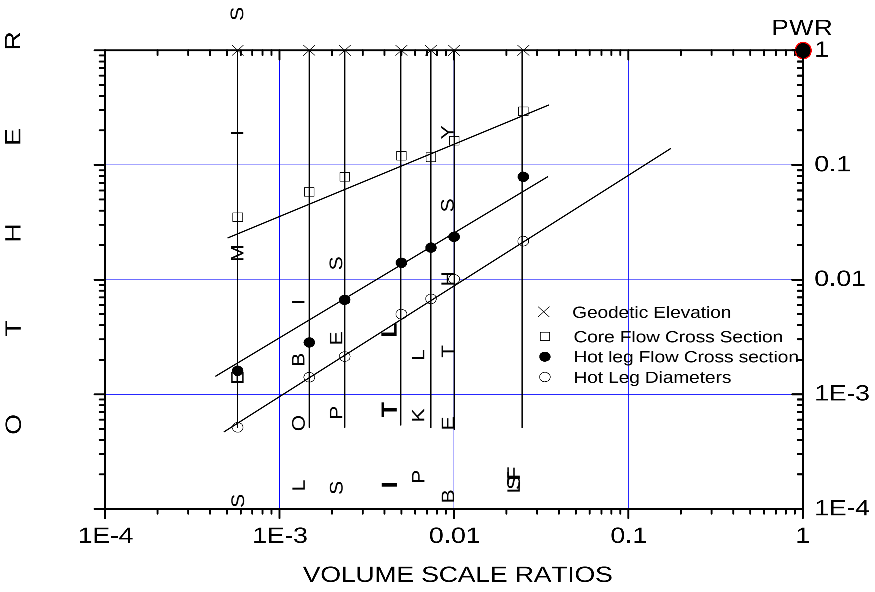

Fig. 3 Comparison of the Volume Scale of the KAERI-ITL with Other Test Facilities

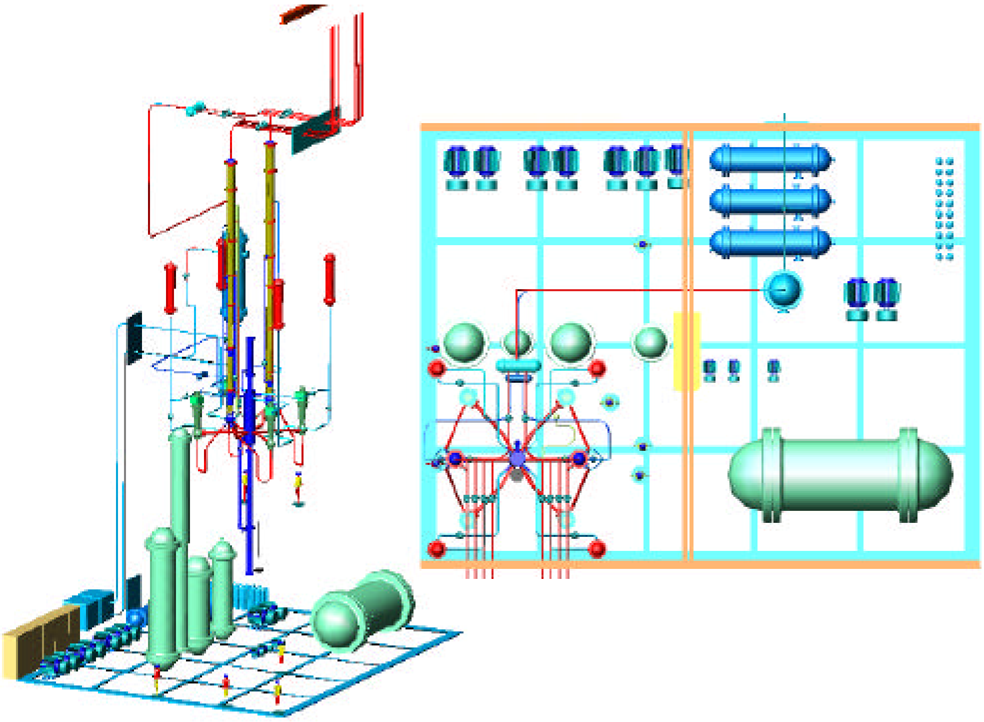

Fig. 4 General Arrangement of the ITL

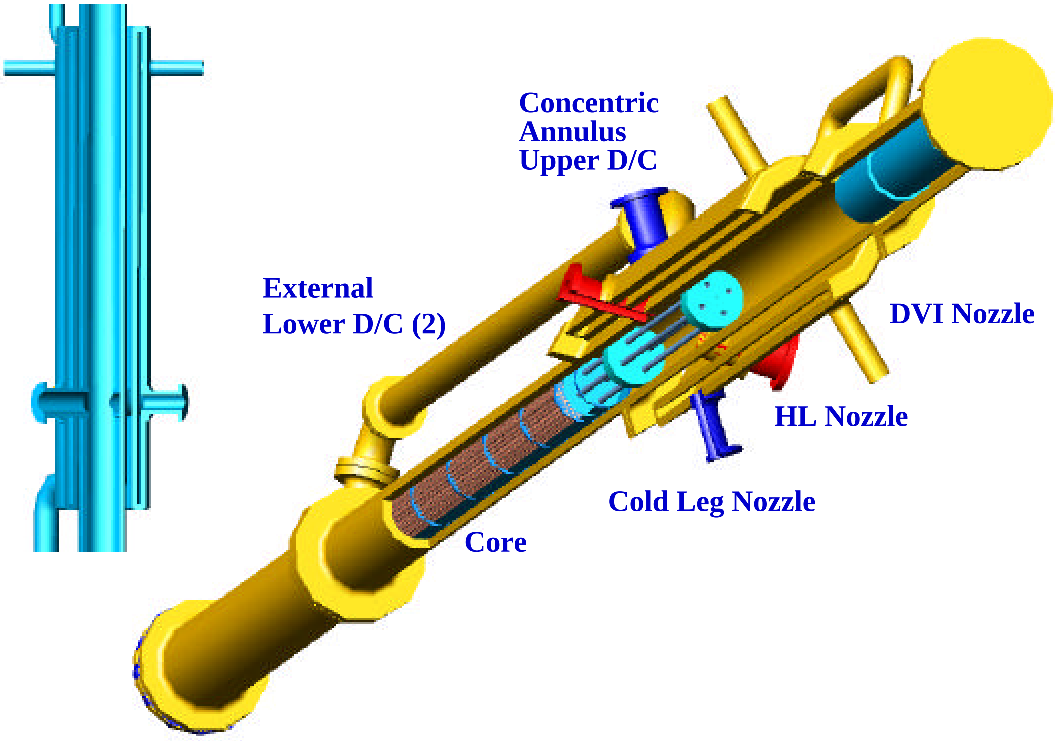

Fig. 5 Reactor Vessel and Downcomer

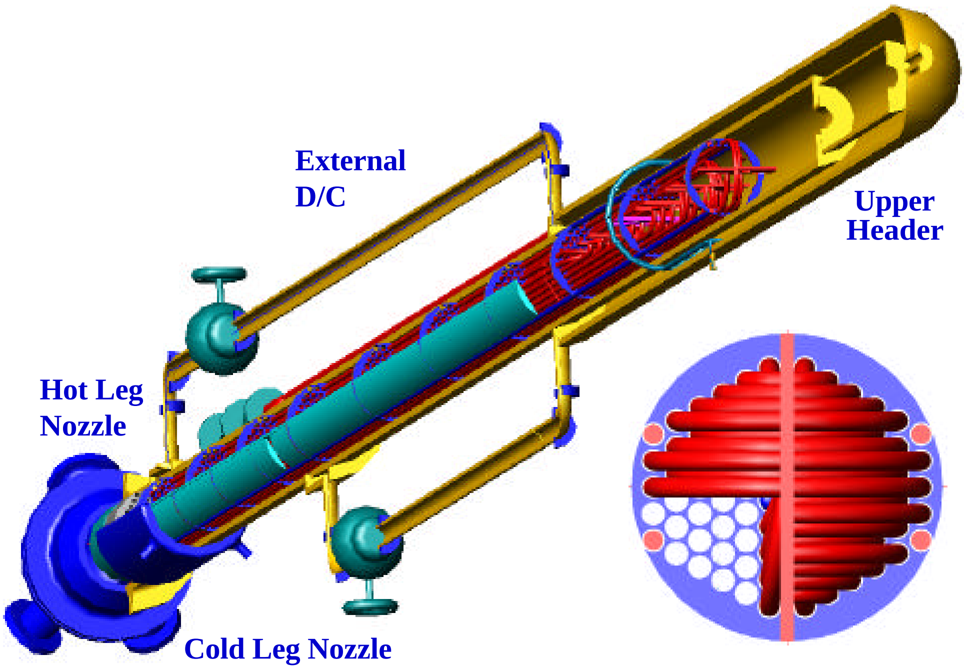

Fig. 6 Steam generator

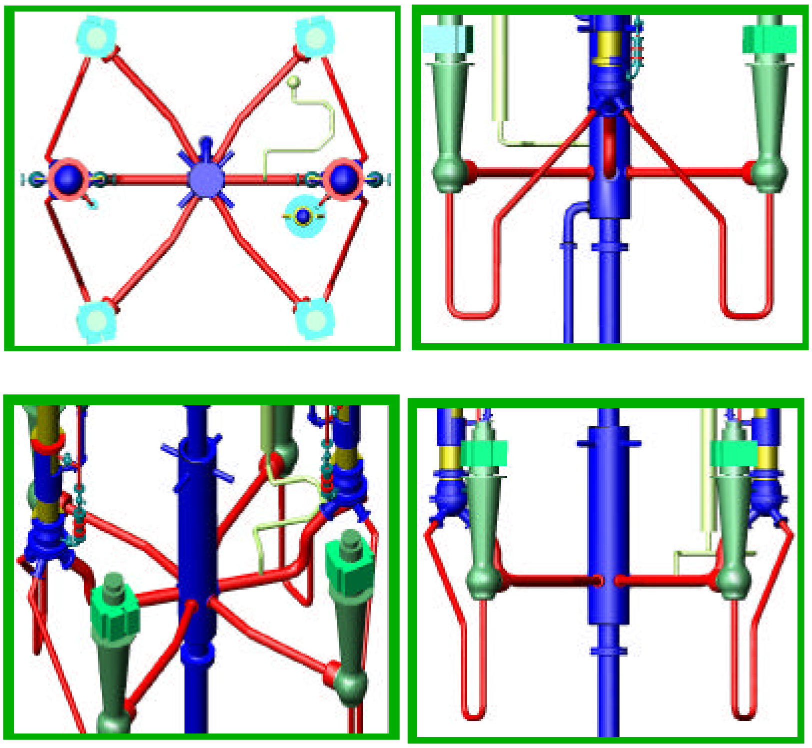

Fig. 7 General Arrangement of the Primary System

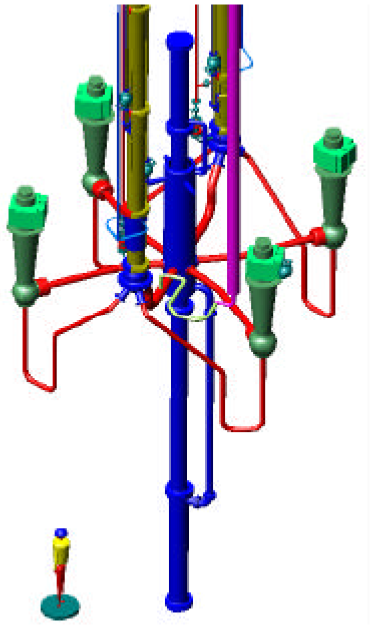

Fig. 8 Overall View of the Primary System

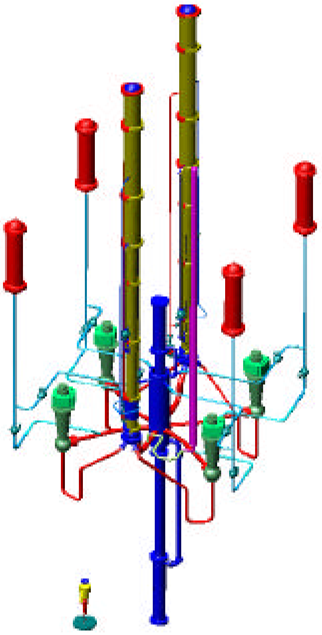

Fig. 9 Overall View of the Primary and Safety Systems

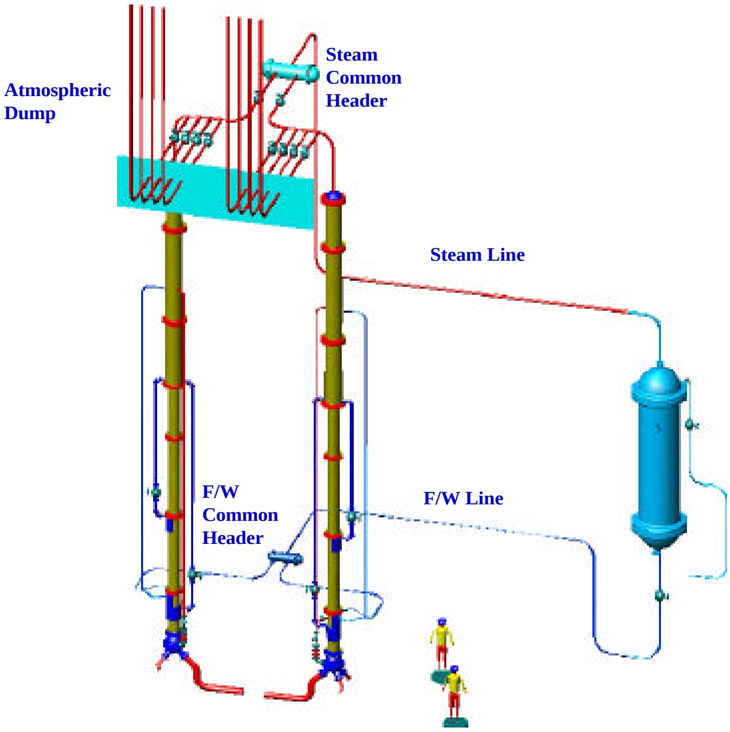

Fig. 10 Overall View of the Secondary System