Technical Description for the Secondary System of the ATLAS Facility

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1. Introduction

A thermal-hydraulic integral effect test (IET) facility, a Advanced Thermal-hydraulic test Loop for Accident Simulation (ATLAS), has been constructed in the Korea Atomic Energy Research Institute (KAERI). The ATLAS has a 1/2 height, 1/288 volume, and full pressure simulation of a reference PWR –i.e. the APR1400 [1]. The secondary coolant system of the ATLAS is designed to simulate the steady state and transient responses of the steam and feed water flows and a primary-to-secondary heat transfer. The secondary system can be divided into four sub-systems such as the SG secondary side, the main steam system, the main and auxiliary feed water system, and the steam condensation and cooling system. The maximum 2.1 MWt heat removal capability of the secondary system meets the maximum power of the electrically heated core which will set the steady-state flow requirements at 10.7 % of the scaled reference PWR flow. The main focus of this paper is to present a technical description of the secondary system of the ATLAS facility.

2. Technical Descriptions

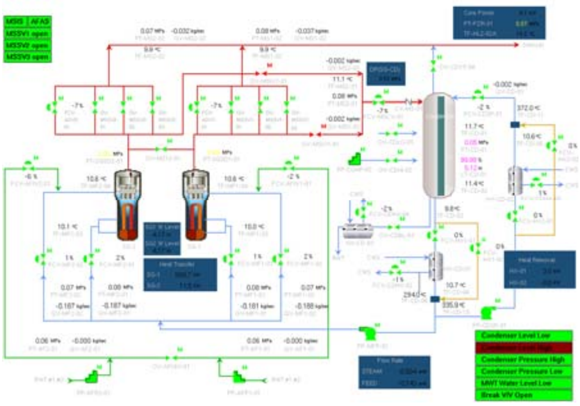

Fig. 1 Flow Diagram of ATLAS Secondary Coolant System

Figure 1 shows a flow diagram of the secondary system of the ATLAS. There are two SGs (SG-1 and SG-2) each with a maximum heat removal capacity of 9.82 MW, which is a 1/203.7 scaled capacity of that of the APR1400. The secondary system, except for the steam condensation and cooling sub-system, has a volumetric scaling ratio of 1/288 that of a reference plant. However, according to the scaling law [2], the feed and steam flow rate has been scaled at the ratio of 1/203.7.

2.1 Steam Generator

For the design of SG secondary side, several thermal-hydraulic phenomena have been considered. For example, for the case of a Loss-of Coolant Accident, a counter current flow in the inlet plenum, a condensation in the outlet plenum, a reflux condensation in the U-tube inside, a swelling and flashing in the downcomer, a subcooled boiling in the economizer, and a nucleate boiling and flashing in the riser section have been taken into account. From the consideration of identified phenomena for corresponding transients, several design criteria have been deduced and applied to the component design process. Important design criteria include a nucleate boiling heat transfer and a re-circulation ratio through a downcomer. Table 1 shows the major design specifications of the SG [3]. The two SGs have the same design specifications.

Table 1 Technical Specifications of SG

ITEMS	ATLAS	Scale (A_m/A_p)
Number of SGs	2	1
Max. Heat Transfer Rate / 1 SG (MW)	9.82	1/203.7
Number of U Tubes	175	1/71.8
Steam/Feedwater Flow Rate / 1 SG (kg/s)	5.56	1/203.7
Saturated Steam Pressure (MPa)	6.895	1
Saturated Steam Temperature (°C)	284.8	1
Primary Pressure (MPa)	15.2	1
SG Inlet Temperature (°C)	324	1
SG Outlet Temperature (°C)	291	1
U Tube Inner Diameter (mm)	12	0.71
U Tube Outer Diameter (mm)	14	0.74
Averaged U Tube Length (m)	9.46	0.474
U Tube Pitch (mm) (Hydraulic Diameter)	20 (18)	0.787 (1.0)
Feedwater Temperature (°C)	232.2	1
Recirculation Ratio	3.9	-
Econnmizer Flow (0 ~ 20 % power)	0	1
Downcomer Flow (0 ~ 20 % power)	0~20	1
Econnmizer Flow (20 ~ 100 % power)	10~90	1

Each SG consists of a vessel, 175 u-tube and a tube sheet, an inlet and outlet plenum, a steam separator, a dryer, and other internals such as a flow distribution plate, an economizer, an evaporator, and a steam drum. The total height from the tube sheet to the dryer is 8.05 m. The vessel consists of a lower shroud, a upper shroud, and a top head. The main steam line nozzle is located at the top of the SG vessel. The one downcomer feed water inlet nozzle is connected at the middle of the vessel and two economizer feed water nozzles are located at 0.48 m above top of the tube sheet.

The main flow in the SG starts with the feed water nozzle, and flows through the flow distribution plate to the evaporator, and then through the separator to the downcomer where the re-circulated water mixes with the injected feed water. The downcomer consists of an upper annular region and two external pipes (I.D. = 87.33 mm). To avoid an increased friction loss and preserve a flow similarity, the external downcomer concept is adopted in the SG design. Manual flow control valve was installed on each external downcomer pipe to regulate the re-circulation ratio. To compensate for a heat loss through the outer wall of the SG, insulating material and a heat tracing system have been installed at the SG vessel.

2.2 Steam and Feed Water System

The main steam system includes the steam supply line, various functional valves and instruments. Unlike the reference PWR, the steam line was designed as a single piping arrangement per SG. The main steam line connects the SG to the direct condenser through a steam header. One ADV, three MSSVs, one MSIV, a main steam flow control valve (MSCV), a check valve and instruments are furnished in the main steam line in order to simulate various system responses. A connecting flange for the break simulator, however, is only provided in SG-1. The rated flow rate of the MSSVs and ADV is scaled from a typical rated flow of the reference PWR. The operating set points of the ATLAS MSSVs are the same as those of the reference PWR [4].

Main feed system consists of a feed water line from the main feed water pump to the SG feed water nozzle, functional valves such as a MFIV and various types of instruments. The important functional requirement of the main feed water system is to provide a continuous feed water flow to the secondary side of the SGs at a specified pressure, temperature and flow rate. Thus, the controllability of the injected feed water by the main feed water pump and flow control valves determines the performance of the system. When the MSIS is actuated the main steam and feed water lines can be isolated by the isolation valves (MSIVs and MFIVs). Main feed water pump (MFP) is a canned type centrifugal pump. The total differential head (TDH) of the MFP is designed up to 1.5MPa to overcome a pressure loss of the entire flow channel and a pressure unbalance between the SG and the direct condenser (DC).

The auxiliary feed water system is automatically actuated by the AFAS. During normal and initial heat-up operating conditions, the system is isolated from the main feed water system by the AFIV. The AFAS can be actuated by the SG low water level, and the setting point is 23.5% of a wide range SG water level. The auxiliary feed water system can provide a continuous feed water to the secondary side of the SG through the downcomer feed water nozzle at a specified pressure, temperature and flow rate. The flow range of the auxiliary feed water is 0.57 ~ 0.91m^3/hr.

2.3 Steam Condensation and Cooling system

Steam generated from the SGs flows into the DC through the main steam line and is condensed by re-circulated spray water. Then the condensed hot water flows through the condenser heat exchanger whose function is to cool the hot water to a specified temperature. The steam condensation and cooling system consists of condenser heat exchangers-I and -II, a cooling tower, a spray re-circulation pump, DC and other auxiliary sub-systems such as a low-pressure and high-pressure injection, an auto-bleed and vent system to control the water level and pressure of the DC. The feed water temperature can be controlled by the heat exchanger bypass flow rate using FCV-HX1-01 (or -02) and FCV-HX2-01 (or -02) shown in Fig.1. Table 2 shows the technical specifications of the DC.

Table 2 Technical Specifications of SG

ITEMS	Units	ATLAS
Design pressure	MPa	10
Design temperature	^oC	310
I.D. of DC	m	1.2
Effective total height of DC	m	5
Effective total volume	m^3	5.65
I.D. of steam inlet nozzle	m	0.0493
Inlet steam temperature	^oC	289.4
Rated steam flow rate	kg/s	1.05
I.D. of condensed water outlet nozzle	m	0.0972
Outlet water temperature	^oC	286.7
I.D. of recirculated water inlet nozzle	m	0.0737
Recirculated water temperatue	^oC	221
Recirculated water flow rate	kg/s	5.2

3. Conclusions

The function of the secondary system is not only to discharge the energy to a surrounding atmosphere but also to simulate the reference PWR primary-secondary interactions for most simulated accident or operational transient scenarios. In the ATLAS the SG and main steam and feed water system of the reference PWR (APR1400) are simulated as closely as possible including the control and trip logics. However, the turbine generator system of the APR1400 was replaced by a steam condensation and cooling system.

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