Program and Test Description of the Third Phase of OECD/NEA ATLAS International Joint Project

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1. Introduction

During the past three decades, a number of integral effect test (IET) facilities have been constructed and successfully operated around the world and they have been used to resolve the thermal-hydraulic safety issues and to validate the system-scale safety analysis codes. The overall system behaviors and the related phenomena during the accident transients can be investigated by performing a well-designed IET. In particular, an event that has an extremely low occurring frequency but results in high core damage frequency can be investigated by utilizing the IET from the viewpoint of the "defense in depth" concept. Within the context of the OECD/NEA ATLAS Phase 2 Project from October 2017 to December 2020, a series of tests were performed to resolve key thermal-hydraulic safety issues related to multiple high-risk failures and highlighted in particular from the Fukushima accident, by using the ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) facility [1, 2]. These tests provided a unique database for validation of system-scale safety analysis codes and contributed to an understanding of thermal-hydraulic phenomena during the multiple high-risk failures covering the design basis accidents (DBAs) and beyond DBAs (BDBAs).

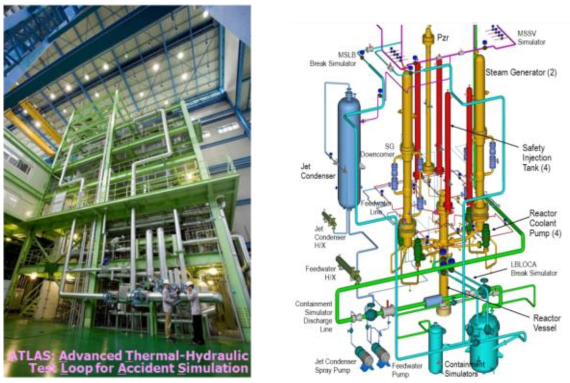

Fig.1. Photograph and schematic diagram of ATLAS

Notwithstanding the distinguished achievement of the OECD/NEA ATLAS Phase 2 Project, a general consensus between the Project partners was reached to continue the third phase of the project with an aim of enhancing the nuclear safety analysis technology and improving the best guidelines for accident managements. In the OECD/NEA ATLAS Phase 3 Project, a total of 10 tests by utilizing the ATLAS facility are proposed to be conducted in five different research topics.

2. Description of Tests

The OECD/NEA ATLAS Phase 3 Project consists of 10 tests that mainly include the following five groups of topics. These tests are all to be performed during the four years period from January 2021 to December 2024. Table 1 summarizes the overall test matrix of the OECD/NEA ATLAS Phase 3 Project.

Table I: Test matrix of OECD-ATLAS2 project

Topics	Number of tests	Remarks
C1-RCS-CTMT Integrated IET - SLB with ATLAS-CUBE - LOCA with ATLAS-CUBE	1 1	Interactive phenomena between RCS and containment (CTMT); Evaluation of multi-D phenomena inside the containment and cooling performance of spray system
C2-Passive Safety Systems - SBLOCA with PECCS - IBLOCA with PECCS - SLB with PAFS	1 1 1	Validation for performance of passive safety systems and related thermal-hydraulic phenomena
C3-Natural Circulation - Asymmetric Natural Circulation	1	Effect of asymmetric natural circulation on cooldown
C4-Design Extension Conditions - SBLOCA under SBO Condition - Total Loss of Heat Sink	1 1	Evaluation of the accident management strategy under the multiple failure condition; Effectiveness of PAFS on a shutdown operation
C5-Open Test - Counterpart Test, etc.	2	Addressing the scaling issue or resolution of safety issues
Total	**10**	

2.1 Test C1 series

Even though a series of tests were performed to resolve key thermal-hydraulic safety issues and to validate the system-scale safety analysis codes in the framework of the OECD/NEA ATLAS-2 project, there are still remaining working areas where we can improve safety analysis technology and eventually prevent the severe accident in any case.

One of the most interesting topics is a reactor coolant system (RCS)-containment integrated IET. In 2019, KAERI (Korea Atomic Energy Research Institute) constructed a containment simulation vessel named CUBE (Containment Utility for Best-estimate Evaluation) and connected it with the RCS of ATLAS as shown in Fig. 2. CUBE incorporated compartment structures, which could play a role of a passive heat sink of containment building during the accident transient.

The compartment structures of CUBE were designed in a similar shape with the prototype to preserve the flow path inside the containment as realistically as possible. As an active safety system of containment, the spray system was installed at the upper head of the containment simulation vessel.

By utilizing the ATLAS-CUBE facility, thermal-hydraulic interaction between the RCS and the containment building can be experimentally investigated. In particular, the evaluation of multi-dimensional phenomena inside the containment and cooling capability of the passive heat sink and spray system can be highlighted. RCS-containment integrated IET can contribute to enhancement of safety analysis technology.

Two tests will be performed on this topic by utilizing the ATLAS-CUBE facility. The target scenario for the C1.1 test is an SLB by simulating a guillotine break at the upstream of the main steam isolation valves (MSIVs). In order to investigate the cooling effect of spray system on the cool-down inside the containment, intentionally delayed activation or partial injection of spray system can be considered. Thermal stratification of the steam-gas mixture inside the containment will be evaluated according to a location of break and a role of the inner compartment as a passive heat sink.

In the C1.2 test, an IBLOCA at cold leg will be simulated. In order to simulate the maximum safety injection flow for a conservative condition in the containment, four safety injection pumps (SIPs) and four safety injection tanks (SITs) will be utilized. The spray system will be activated at a high-pressure signal of containment pressure. With an aim of investigating the effect of spray flow on the cool-down inside the containment, a single failure of the containment spray system can be assumed.

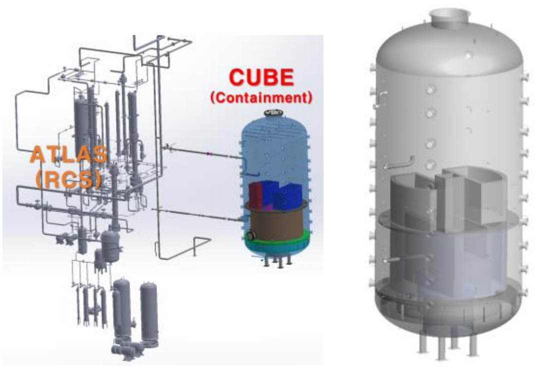

Fig.2. Schematic diagram of ATLAS-CUBE facility

2.2 Test C2 series

After the Fukushima accident, various passive safety systems have been proposed to improve the safety and reliability of an ultimate heat removal system without any operator action during DBA and BDBA transients. Performance and reliability of passive systems still need to be validated further due to the inherently low driving force, multi-dimensional flow or mixing, asymmetric behavior, flow oscillation and instability. Such complex thermal-hydraulic phenomena are also greatly affected by the detailed design of the system. So that, it is considered to be very challenging to the code developers and users. The one-dimensional simulation code needs to be validated with various experimental database before it is applied to the passive safety system. Therefore, it is expected that more experimental and validation works are necessary to improve our understanding of the physics and to improve simulation codes. Besides, three-dimensional analysis is highly recommended to be used in predicting the complex phenomena related to the passive safety system.

ATLAS incorporates several types of passive safety systems which include a passive auxiliary feedwater system (PAFS), a hybrid safety injection tank (H-SIT), and a passive emergency core cooling system (PECCS). Therefore, ATLAS can provide unique experimental data by utilizing the combination of these passive safety systems. PAFS connected to the steam generator (SG) of light water reactor (LWR) is intended to completely replace the conventional active auxiliary feedwater system to cope with DBA and BDBA transients as shown in Fig. 3. PAFS cools down the secondary side of a steam generator and eventually removes the decay heat from the reactor core by introducing a natural driving force mechanism; i.e., condensing, boiling, and natural circulation. H-SIT is a passive safety injection system that allows high-pressure core make-up over the operating pressures of LWR. H-SIT can be pressurized equally to the RCS through a pipe connection between the SIT and the pressurizer, along with nitrogen charging, in which case the coolant can be injected by gravitational head between the RCS and the H-SIT. As a similar concept to the H-SIT, PECCS can be pressurized equally to the RCS through a pipe connection between the SIT and a cold leg as shown in Fig. 4. It is worth investigating the thermal-hydraulic phenomena anticipated during the operation of these passive safety systems to produce clear knowledge of the actual phenomena and to provide the best guideline for accident management.

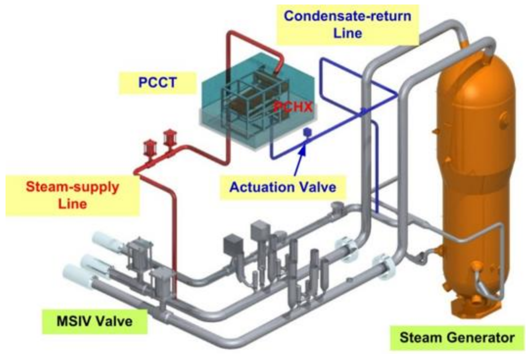

Fig.3. Passive secondary cooling by PAFS

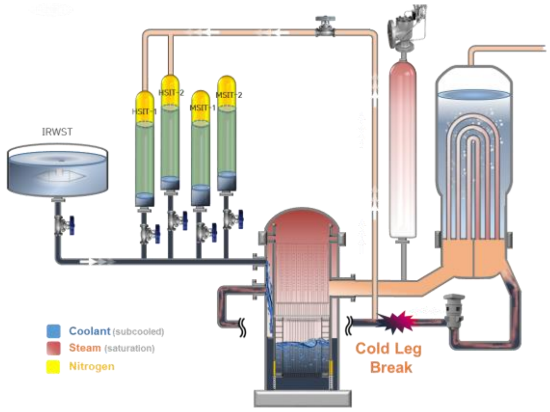

Fig.4. Passive core makeup by PAFS

Three tests will be performed on this topic by utilizing PECCS and PAFS. The target scenario for the C2.1 test is an SBLOCA occurred simultaneously at top and bottom nozzles (control rod nozzle and in-containment instrument nozzle) of reactor pressure vessel (RPV) with an operation of PECCS. The break size will be 2 inch-equivalent at the top and bottom of RPV, individually. In the PECCS concept, core makeup system comprises 2-train of high-pressure SIT (HPSIT), 2-train of SIT, low-pressure injection from an in-containment refueling water storage tank (IRWST), and a pipe connecting the cold leg and the HPSIT. Contrary to the previous test performed in the framework of the OECD/NEA ATLAS-2 project, the long-term cooling system of prototypic PECCS from an in-containment refueling water storage tank (IRWST) will be simulated in the C2.1 test.

In the C2.2 test, a 13 % cold leg break IBLOCA will be simulated with an operation of PECCS. This test can contribute not only to the expansion of the database for an IBLOCA with varying the break size and location but also to the validation of advanced passive safety system during an IBLOCA transient. The modality of PECCS operation will be the same as the C2.1 test.

The target scenario for the C2.3 test is an SLB at SG-1 with an operation of PAFS. A single train of PAFS will be utilized. The total failure of SIPs will be assumed in the present test. The relevant thermal-hydraulic phenomena anticipated in PAFS during an SLB transient will be highlighted.

2.3 Test C3 series

Natural circulation is a basic thermal-hydraulic phenomenon which affects the cooling of RCS during a high-pressure accident sequence such as a station blackout (SBO) and also a very low-pressure accident sequence such as a mid-loop operation condition. Due to its weak driving force compared to the forced circulation, precise evaluation on the natural circulation by utilizing system-scale safety analysis code is challenging. In particular, it is worth investigating the thermal-hydraulic characteristics anticipated in the natural circulation under asymmetric cooling condition as shown in Fig. 5. In case that secondary side of isolated SG is hotter than the primary side, a fast decrease of the primary system pressure may induce boiling at the outlet of isolated SG U-tube and natural circulation interruption (NCI). The NCI phenomenon may prevent the RCS to reach the entry conditions for operation of a residual heat removal system. In case of poor circulation in the loop, the boration could be problem during the cool-down. In case of loop flow stagnation, it may induce thermal shock in welds and cracks. Optimization of cool-down rate is important to prevent NCI during the natural circulation phase under asymmetric cooling condition. In order to investigate the natural circulation flow under an asymmetric cooling condition, the C3.1 test is composed of two test runs. In the Run 1, under constant pressure condition of RCS, SG-1 will be isolated. Accident management action of secondary system depressurization through an atmospheric steam dump valve of SG-2 will be imposed with specified cool down rate. In the Run 2, under steam release condition, SG-1 will be isolated. The steam will be released through a pilot operated safety and relief valve (POSRV) of pressurizer.

Natural circulation flow rate, fluid temperature distribution, boiling in hot U-tube, and flow stagnation in U-tube will be highlighted in the present test. It will provide a precise database for validation of the prediction capability against natural circulation under an asymmetric cooling condition. Also, an optimal cool-down rate to prevent loop flow stagnation can be quantitatively investigated.

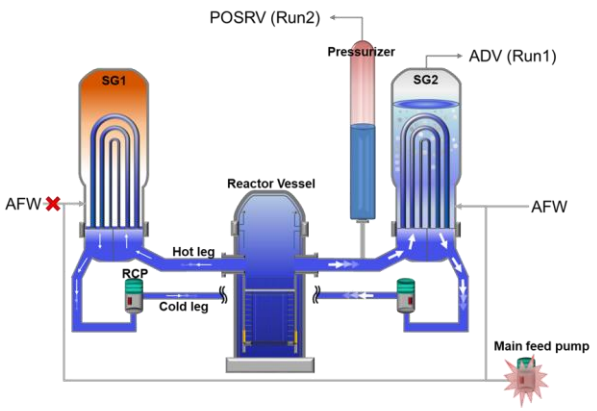

Fig.5. Natural circulation under an asymmetric cooling condition

2.4 Test C4 series

Design extension condition (DEC), including multiple failure accidents, attracts world-wide attention as a post-Fukushima action. Even though the exact definition of DEC varies depending on countries, its main background is to improve safety by enhancing the capability of NPPs to withstand conditions generated by accidents that are more severe than DBAs or that involves additional failures. Some DECs such as SBO and TLOFW were already taken into account in the previous OECD-ATLAS project. A multiple failure sequence was experimentally investigated in the OECD-ATLAS2 project.

Multiple failure accident is considered as high core damage frequency (CDF) in the not only deterministic safety analysis (DSA) but also probabilistic safety analysis (PSA) method. Regarding the multiple failure accident, the importance of the prevention and mitigation is magnified to prevent the accident progress to a severe accident situation. In principle, the fuel degradation should be prevented in any case for sustainable nuclear energy. Thus, continuous utilization of ATLAS is recommended for simulation of the various multiple failure accident and more severe DEC such as total loss of heat sink. An SBLOCA under an SBO condition was selected as one of the must-considered accidents in the view point of DEC from the safety analysis of APR1400 and OPR1000. In order to prevent the accident progress to a severe accident situation in case of an SBLOCA under an SBO condition, proper operation of accident management actions should be accompanied.

Total loss of heat sink due to a loss of power during a shutdown cooling is one of the multiple failure accidents. Risk of an accident during a shutdown cooling, when the decay heat is relatively high and the inventory of coolant is low, is relatively high due to the short response time with an unavailability of safety system. From a safety analysis code validation point of view, it is worth investigating an asymmetric natural circulation phenomenon through a PAFS operation with total loss of heat sink during a shutdown cooling operation.

The target scenario for the C4.1 test is an SBLOCA under an SBO condition. A 2-inch break on the hot leg SBLOCA will be simulated when the active core region is uncovered due to an SBO. Turbine-driven auxiliary feedwater will be supplied to both steam generators to remove the decay heat at specified time later after an initiation of SBLOCA as the first accident management action. The second accident management action is depressurization of the secondary system by steam dump to promote the primary system depressurization for the actuation of SIT. Initiation time of accident management actions can be a key parameter for system stabilization in the present test.

In the C4.2 test, a flexible scenario for a total loss of heat sink including a core heat-up sequence from low to high pressure will be investigated as shown in Fig. 6. The natural circulation on the primary loop and the passive secondary heat removal systems will be simulated for the validation of safety analysis code. Also, the effectiveness of PAFS on a total loss of the heat removal system during a shutdown cooling operation will be assessed.

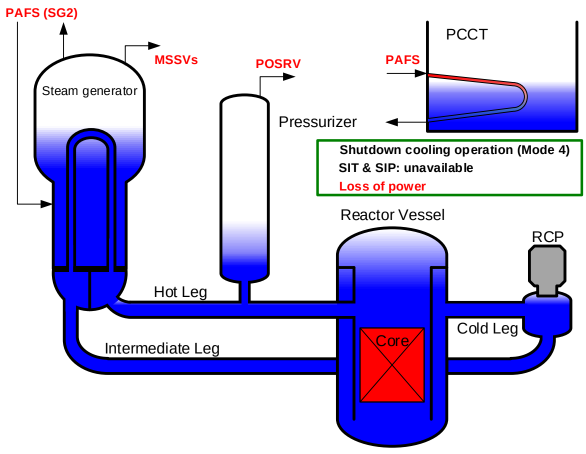

Fig.6. Simulation for total loss of heat sink accident

2.5 Test C5 series

A lot of IETs have been performed for the past decades by utilizing various large-scale facilities, but the scaling issues are still being debated and remain unresolved. To address the remaining scaling issues, a counterpart test to a large facility such as large scale test facility (LSTF) or primary coolant loop test facility (PKL) is essential and would be of interest to nuclear experts.

By comparing counterpart test data from different scale facilities, an extrapolation of the available IET database to a real plant scale will be exploited. The scaling inherent in a certain facility needs to be justified before its data is used for a safety analysis.

Uncertainties or discrepancies in computer code analysis can be reduced by addressing the scaling issues in a systematic manner. In particular, a comparison of scale parameters from different facilities for a selected key scenario is an essential step to identify the scaling discrepancies and to move to the plant applications. Such scaling issues and the scaling distortions embedded in the previous IET database can be highlighted by performing counterpart tests of ATLAS. Previous tests of LSTF and/or PKL performed at well-defined initial and boundary conditions can be good candidates for a counterpart test in ATLAS. One among the previous spectrum of SBLOCAs and IBLOCAs can be selected as a counterpart test. Loss of residual heat removal (RHR) during a mid-loop operation with openings is also being considered as one of the candidates for a counterpart test to the PKL-3 and -4 projects. Pre-test analyses will be performed to provide information necessary to define experimental conditions among the Project partners as well as the discussion on the alternative item.

3. Conclusions

The third phase of OECD/NEA joint project utilizing an integral effect test facility of ATLAS has been being operated from January 2021 to December 2024. A total of 10 integral effect tests in 5 different topics are to be performed in the framework of the OECD/NEA ATLAS-3 project. Utilizing the established IET database, simulation models and methods for complex phenomena of high safety relevance to thermal-hydraulic transients in DBA and BDBA will be validated. The present OECD/NEA ATLAS-3 project aims at the safety enhancement of operating NPPs by simulating the various accident transients in connection with the safety analysis technology. The thermal-hydraulic behaviors related to a RCS-containment integration, a passive core makeup, an IBLOCA, and a multiple failure accident such as an SLB combined with an SGTR, will be investigated in a systematic manner.

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