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Invited Article

RESEARCH EFFORTS FOR THE RESOLUTION OF HYDROGEN RISK

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ABSTRACT

During the past 10 years, the Korea Atomic Energy Research Institute (KAERI) has performed a study to control hydrogen gas in the containment of the nuclear power plants. Before the Fukushima accident, analytical activities for gas distribution analysis in experiments and plants were primarily conducted using a multidimensional code: the GASFLOW. After the Fukushima accident, the COM3D code, which can simulate a multidimensional hydrogen explosion, was introduced in 2013 to complete the multidimensional hydrogen analysis system. The code validation efforts of the multidimensional codes of the GASFLOW and the COM3D have continued to increase confidence in the use of codes using several international experimental data. The OpenFOAM has been preliminarily evaluated for APR1400 containment, based on experience from coded validation and the analysis of hydrogen distribution and explosion using the multidimensional codes, the GASFLOW and the COM3D. Hydrogen safety in nuclear power has become a much more important issue after the Fukushima event in which hydrogen explosions occurred. The KAERI is preparing a large-scale test that can be used to validate the performance of domestic passive autocatalytic recombiners (PARs) and can provide data for the validation of the severe accident code being developed in Korea.

1. Introduction

After the Three Mile Island Reactor 2 (TMI-2) accident (near Middletown, PA, USA) in 1979, a substantial amount of research has been performed to control hydrogen gas in the containment. In European countries, an important research result to control hydrogen gas is the implementation of passive autocatalytic recombiners for pressurized water reactors (PWRs) with a large dry containment. However, the boiling water reactor (BWR), which has a relatively very small containment volume in comparison to a PWR was adapted as an inert concept to control hydrogen gas by injecting nitrogen gas into a small containment. This concept to control hydrogen gas in a BWR was an action item after the TMI-2

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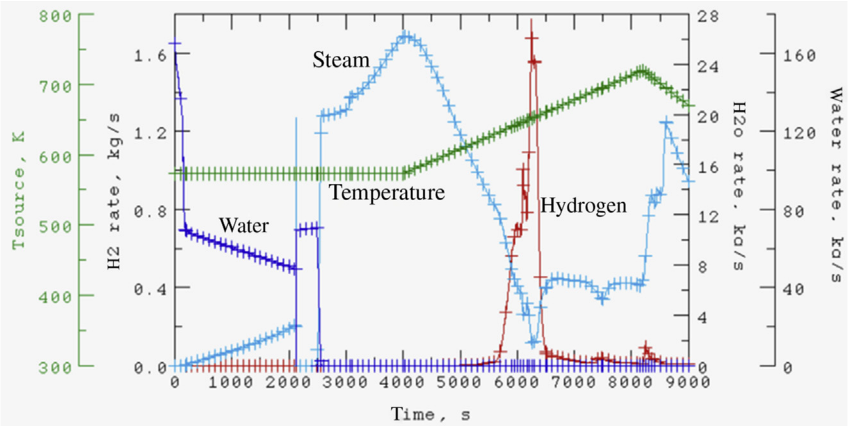

Fig. 1 – Hydrogen and steam source in loss of coolant accident.

accident [1]. However, hydrogen explosions unfortunately occurred in the reactor building of the BWRs of the Fukushima plants [2]. This explosion caused the large release of the fission product into the environment.

After the large explosions in the Fukushima accident, a precise prediction of gas distribution under various containment thermal hydraulic conditions has become an important issue. The explosion behavior can be estimated from precise hydrogen distribution in the containment. However, it is not easy to precisely predict the hydrogen distribution in a containment where many structures and components exist. In addition, hydrogen experts are interested in hydrogen explosion behavior based on the hydrogen distribution because the reactor building was destroyed by hydrogen explosions in the Fukushima plants.

Two international activities commenced after the Fukushima accident. The Organization for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA) Hydrogen Mitigation Experiments for Reactor Safety (HYMERS) project [3] was launched to precisely predict gas distribution in the containment. The main objective of this project is to enhance the reliability of advanced computational analysis devoted to containment thermal hydraulics. It is necessary to continue the validation of models of the code to improve confidence in the plant analysis results and the predictive ability of the models of the code; to have experiments with a well-instrumented spatial and temporal grid in line with modeling issues and with real control of the boundary conditions; to reach a significant level of accuracy on the gas mixture composition during the mixing process because the consequences of a combustion [e.g., 11–13 volume percent (vol%) of hydrogen in air] can be totally different; and to cover the broad spectrum of phenomena during a severe accident in a light water reactor (LWR) such as geometric effects and the effects of safety systems.

Another international activity to remove the hydrogen threat is the performance test of PARs, which can simulate an accident without electricity under severe accidents conditions, thus, the OECD/NEA Thermal-hydraulic, Hydrogen, Aerosol and Iodine (THAI) Project was performed [4]. The frame of the first phase of the OECD–THAI project was aimed at providing nonexistent or inaccessible experimental data for the validation of developed analysis methods and codes to predict hydrogen distribution, combustion behavior, and PAR behavior under representative reactor conditions. Significant progress has been achieved by demonstrating the transferability of helium to hydrogen distribution behavior and by providing comprehensive data for the validation of computational fluid dynamics (CFD) and lumped parameter simulation codes. With regard to code validation, phenomena such as the formation and dissolution of the stratification of different gases remain partly open. In spite of significant improvements in available computer codes, deficiencies still exist in modeling certain phenomena. Uncertainties continue to appear in the modeling of deflagrations and the modeling of the performance of PAR under special conditions such as an under spray or low oxygen supply. The general performance of the PAR is satisfactory, but some adverse effects occur with iodine present in the gases. An effort to validate the performance of PARs has continued. The original objectives of the OECD-THAI2 [5], which was a follow-up project to the OECD-THAI1, will address open questions concerning the behavior of: (1) graphite dust transport in a generic high-temperature gas-cooled reactor (HTGR) geometry; (2) release of gaseous iodine from a flashing jet and iodine deposition on aerosol particles; and (3) hydrogen combustion during spray operation and PAR operation under the condition of extremely low oxygen content. However, after the Fukushima accident, the test cases have been changed toward PAR performance tests with spray operation.

2. Outstanding issues

The integral analysis codes, the so-called lumped codes such as the Modular Accident Analysis Program (MAAP) [6] and the Methods for Estimation of Leakages and Consequences of Releases (MELCOR) [7], were primarily used in the past and are now the main tools used to evaluate hydrogen safety in nuclear plants. These lumped codes are capable of easily analyzing an accident sequence for a long time with regard to the computational calculation time. The