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Review of SFR In-Vessel HCDA Source Terms

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1. Introduction

An effort has been made in this study to search for and review the literatures on the studies of the phenomena related to the release of radionuclides and aerosols to the reactor containment of the sodium fast reactor (SFR) plants (i.e., in-vessel source term. Review work is focused on the experimental programs to investigate the phenomena related to determining the source terms, with a brief review on supporting analytical models and computer programs.

As a result of the severe accidents experienced at TMI and Chernobyl, much work has been done on the energetic CDA bubble source term (also called 'primary' or 'instantaneous' source term) defined as the amount of radioactive material released from the reactor vessel to the containment due to the rapid expansion of fuel or sodium leading to a failure of the vessel head[1,2,3]. In this study, the research programs conducted to investigate the CDA (core disruptive accident) bubble behavior in the sodium pool for determining 'primary' or 'instantaneous' source term are introduced. The research programs to investigate the release and transport of fission products(FPs) and aerosols in the reactor containment (i.e., in-containment source term) are not described in this study.

2. CDA Source Term Programs

An energetic CDA involves rapid hydrodynamic core disassembly with two-phase fuel expanding into the void space and a bubble of vaporized fuel and fission products formed in the sodium pool. If fuel-coolant interaction (FCI) occurs, a sodium vapor bubble will expand into the sodium pool, carrying fuel particles from FCI and fission products of various chemical and physical forms. Since the particle sizes of fuel condensation aerosol (<0.1 μm) and those of particles from FCI fragmentation(>10 μm) are quite different , aerosol process may be significantly different in the two cases[1,3]

The behavior of the fuel vapor bubble in the sodium pool was of the main interest in the KfK-FAUST experiments [4,5]and ORNL-FAST program[7]. Meanwhile, a sodium vapor bubble was the main concern in the EXCOBULLE/CARAVELLE program[6] in France and a code development program in Japan[8].

2.1 KfK-FAUST Program

FAUST is an experimental KfK program to give contributions to the assessment of the instantaneous source term, especially on particle transport and retention in gas bubbles from the core to the cover gas after a high pressure discharge. In the first phase (FAUST-1A/1B), experiments were performed with rupture disks and discharge pressures up to 4 MPa of gas-particle mixtures (iron or nickel powder) into a water pool at two geometries. In the second phase (FAUST-2A/2B), the water pool was replaced by a 500 ^oC sodium pool, into which more realistic material (UO_2 powder) was discharged. It was observed in the underwater tests (FAUST-1A/1B) that [4]

- Rapid bubble oscillation and strong entrainment in the beginning phase cause inertial impaction and wash-out of the discharged particles.
- With the exception of extremely low discharge pressure, airborne particles have never been detected in the cover gas, which implied that the retention factors are greater than 10^4.

In the FAUST-2A tests, the amounts of simulation material carried along with the sodium into external traps were very small (RF $>10^3$) with the exception of elementary iodine(RF=8). Iodine was released in gaseous form and chemical reaction was the only retention mechanism. Amounts of SrO and NaI released were very close to the detection limit, which is near RF=10^5.

The test results of the FAUST-2B are qualitatively in same line with those of the FAUST-2A. The retention factors were between 10^4 and 10^6 for the particulate materials (NaI, CsI, SrO) . The RF for iodine increased proportional to the amount of sodium in the pool [4,5].

2.2 CEA-EXCOBULE/CARAVELLE Programs

These underwater experiments have been performed representing SuperPhenix reactor, for which the design of the primary containment was first based on the adiabatic expansion of a bubble resulting from a fuel vaporization or FCI [6].

The EXCOBULE experiments were performed in CEA/Grenoble to investigate the heat transfer between a bubble and the surrounding medium. This was achieved by studying the expansion and collapse of hot water sources contained in glass balls inside a cold water pool.

The CARAVELLE program was performed in CEA/Cadarache to investigate the aerosol transfer and leakage through openings in the roof in a more representative facility simulating (1/17 scale) the reactor vessel of the SuperPhenix . The test results from EXCOBULE and CARAVALLE were used to verify the IRIS code, which was subsequently used for reactor calculations [6].

2.3 ORNL-FAST (Fuel Aerosol Simulation Test)

Underwater tests had been conducted first to understand the trend of CDA bubble behavior and then, more realistic under-sodium tests were performed at ORNL. Bubbles were produced by realistic material (UO_2 pellets) with realistic energy rates (higher than 350J/g, temperature above 5,000K) to simulate aerosols produced following CDA). Fission product behavior was not studied, however. The quantity of aerosol released from the sodium pool was found to be a small fraction of the aerosol yield. The depth at which the aerosol was generated was found to be the most critical parameters affecting release. Three factors affecting small release were identified to be [7],

-bubble size was less than or equal to the pool level, so aerosol in the pulsating bubble remained submerged in the pool,

-bubble lifetimes were shorter than characteristic buoyant rise times,

-hydrodynamic theory predicts that pulsating bubbles are propelled away from a free surface.

2.4 JAEA's CDA Bubble Study

An effort was made in Japan to understand a basic nature of the transport phenomena of fuel particles in CDA. A simple test was performed using the argon bubble in water, to investigate the changes in shape and velocity of the bubbles rising in a pool. Spherical cap-shaped bubbles were observed and their motion was analyzed.

As for the analytical effort, the FTAC code was developed to estimate the transport of the relatively large (> 10 μm) fuel particles resulting from FCI [8].

3. Conclusion

There are not much source term studies made so far for the metallic fueled core of the SFR. More in-depth review on the source terms of the oxide fueled core of the SFR is the first step to be made to identify the phenomena and issues to investigate further for determining the source terms out of the SFR core loaded with the metallic fuels. It will be valuable, in the mean time, to review the applicability to the SFR of the results of the regulatory as well as research programs for determining the LWR source terms.

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