1.6 OVERVIEW OF SEVERE ACCIDENT RESEARCH AT JAERI

SUGIMOTO, Jun

Severe Accident Research Laboratory
Department of Reactor Safety Research
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken, Japan 319-1195
Phone: +81-29-282-5995, Fax: +81-29-282-5570
E-mail: sugimoto@sarl.tokai.jaeri.go.jp

ABSTRACT

Severe accident research at JAERI aims at the confirmation of the safety margin, the quantification of the associated risk, and the evaluation of the effectiveness of the accident management measures of the nuclear power reactors, in accordance with the governmental five-year nuclear safety research program. JAERI has been conducting a wide range of severe accident research activities both in experiment and analysis, such as melt coolant interactions, fission product behaviors in coolant system, containment integrity and assessment of accident management measures.

Molten core/coolant interaction and in-vessel molten core coolabiliy have been investigated in ALPHA Program. MUSE experiments in ALPHA Program has been conducted for the precise energy measurement due to steam explosion in melt jet and stratified geometries. In VEGA Program, which aims at FP release from irradiated fuels at high temperature and high pressure under various atmospheric conditions, the facility construction is almost completed. In WIND Program the revaporization of aerosols due to decay heating and also the integrity of the piping from this heat source are being investigated.

Code development activities are in progress for an integrated source term analysis with THALES, fission product behaviors with ART, steam explosion with JASMINE, and in-vessel debris behaviors with CAMP. The experimental analyses and reactor application have made progress by participating international standard problem and code comparison exercises, along with the use of introduced codes, such as SCDAP/RELAP5 and MELCOR.

The outcome of the severe accident research will be utilized for the evaluation of more reliable severe accident scenarios, detailed implementation of the accident management measures, and also for the future reactor development, basically through the sophisticated use of verified analytical tools.

Keywords: Severe Accident, Accident Management, Melt Coolant Interactions, Fission Product, Containment Integrity, ALPHA, WIND, VEGA

1 INTRODUCTION

During a light water reactor(LWR) severe accident various phenomena that threaten the integrity of the pressure vessel and the containment vessel could occur. The occurrence of a severe accident is extremely unlikely since LWRs are designed based on the defense-in-depth concept. However, in order to quantify the safety margin and potential risks of LWRs, severe accident research is of importance. Studies are also required for the evaluation of accident management measures to prevent and mitigate the severe accident.

In accordance with five-year nuclear safety research program authorized by Nuclear Safety Commission(NSC), where severe accident research has been selected as one of important research issues, Japan Atomic Energy Research Institute(JAERI) has been conducting a wide range of severe accident research both in experiments and analyses. [1]-[2] In the present paper, recent severe accident research and some related activities at JAERI are described.

2 CURRENT RESEARCH STATUS

2.1 Integrity of Reactor Pressure Vessel and Containment Vessel

To clarify phenomena affecting containment integrity during a severe accident, ALPHA (Assessment of Loads and Performance of containment in Hypothetical Accident) program has been performed. The program has facilities to investigate (a) melt-coolant interactions[3], (b) molten core-concrete interactions, (c) FP aerosol behavior,[4] and (d) leak behavior of containment penetrations.[5] Currently in melt-coolant interactions, steam explosion and molten core coolability have been extensively studied.

The MUSE (MUlti-configuration in Steam Explosions) experiment has been conducted to study the energetics of steam explosions in terms of various contact modes between the melt and coolant, i.e., melt pouring, stratified and melt/coolant injection.[6] The conceptual diagram of the experiments is illustrated in Fig.1. Effects of melt masses, water subcooling, jet shapes, jet velocities, and system constraints on the mechanical energy have been identified. The results suggest that the penetration and dispersion phenomena of a water jet inside the melt play important roles in determining energetics of steam explosions.

The JASMINE (JAERI simulator for Multiphase Interaction and Explosion) code has been developed to model the whole process of steam explosions and to assess the pressure loads on surrounding structures.[7] JASMINE has two modules, one to model the relatively slow premixing process and the other to model the rapid propagation process.[8]

In-vessel debris coolability experiments were conducted in order to study the coolability of a molten core within RPV lower plenum. Experiments have been performed with aluminum oxide (Al2O3) up to 50 kg as a debris simulant produced by thermite reaction.[9] Ultrasonic measurement showed that there were 1 to 2 mm gaps elsewhere between solidified debris and lower head surface. It is suggested that these gaps have contributed to a good cooling of a lower head. The development of CAMP code is in progress for the analysis of in-vessel debris coolability behaviors.

2.2 Source Term Evaluation

VEGA (Verification Experiments of FP Gas/Aerosol release) program, as shown in Fig. 2, on FP release from irradiated fuels has been initiated. The characteristics of the FP release, such as non-volatile FP species, will be examined under high temperature (3273 K) and high pressure (1MPa) conditions.[10] Re-irradiation of fuel specimen with NSRR reactor at JAERI will be made to produce short life FPs such as I-131.

Small-scale basic experiments have been performed with the WAVE (Wide range Aerosol model Verification) facility to investigate aerosol behaviors within a piping. Also efforts have been made for the development and validation of analytical models on aerosol behaviors based on the experimental results.[11]

The analysis of the integrity of a steam generator U-tube during secondary system depressurization was performed with SCDAP/RELAP and the JAERI developed FP analysis code, ART. The analysis showed that the potential for steam generator tube rupture after core heat up due to FP deposition cannot be ignored during secondary system depressurization.

2.3 Integrity of Piping of Reactor Cooling System

The WIND (Wide range piping INtegrity Demonstration) project has been conducted to evaluate the integrity and safety margin of reactor piping under severe accident conditions. The WIND project consists of tests and analyses related to aerosol behaviors and piping structural integrity.[12]

Aerosol deposition and revaporization tests are being performed in WIND project. A cesium iodide aerosol was introduced into test sections as shown Fig. 3. The test results show that the formation of a natural convective secondary flow of gases resulted in the deposition of cesium iodide onto the ceiling and side wall areas of the test sections and that the dominant deposition mechanisms were the condensation of the vapor and the thermophoresis of aerosol of cesium iodide. The results obtained from the aerosol deposition and revaporization tests have been applied for the validation of ART code.[13]

Piping integrity tests are in progress. Stainless and carbon steel test pipes are pressurized with nitrogen and heated up to approximately 15 MPa and more than 1273K, respectively. It was found from post-test photographs that the pipe failures resulted from crack propagation initiated at the outer surface and progressing to the inner surface of the pipes. The test pipes deformed and failed due to high-temperature creep, which has been analyzed with ABAQUS code. Creep equations based on the measurements are applied in the creep analyses.[14]-[15]

2.4 Collaboration with Universities

In universities wide variety of basic research activities have been conducted, such as experiments and code developments on fuel-coolant interactions, in-vessel melt behaviors, and fission product behaviors, mostly in the joint work between universities and JAERI.

For example, visualization study on hot particle-water interaction during premixing of steam explosion has been performed by using neutron radiography (NRG) method by Mishima et al.[16]

Numerical analysis of premixing of steam explosion has been conducted using MPS method, one of direct simulation techniques by Koshizuka et al.[17] The calculated results were in reasonable agreement with experiments.

Experiment has been conducted for the estimation of chemical forms and vapor pressure of fission products under high temperature conditions using Knudsen cell by Yamawaki et al.[18]

Creep damage analysis of piping has been conducted by using an isotropic damage rule of the Kachanov-Rabotonov type as a creep constitutive equation based on measured properties by Miyazaki et al.

3 RELATED ACTIVITIES

NSC has been reviewing the regulatory safety examination guides, such as siting criteria and source terms for the revision based on the state-of-the art knowledge on severe accident research. Also in November 1995 NSC issued the statement on the accident management that the accident management strategies proposed by utilities are generally reasonable, the implementation of the accident management including operational procedures is to be determined and that further research activities are necessary. Industries are completing the detailed implementation of the accident management measures. Also industries are establishing a self-regulatory document for the containment design of the future reactors.

JAERI has been participating in most of international collaboration and agreement, such as CSARP by USNRC, ACE/MACE by EPRI, PPHEBUS-FP by IPSN and EC, and RASPLAV by OECD.

Since the severe accident research conducted so far has provided many valuable information on phenomenology and contributed to the implementation of accident management strategies, the closure of severe accident issues has been widely discussed. Figure 4 shows such an example of the closure of severe accident issues and its application to future reactor design in Japan. After TMI accident, severe accident research was initiated and was accelerated after Chernobyl accident as in most nuclear countries. The outcome of severe accident research will be effectively utilized for the revision of regulatory guides, such as siting and source term, for detailed implementation of accident management measures, and also for the industry's self-regulatory document for containment design. If this will be successfully achieved, it will be one major element of closure of severe accident issues. However there still remain some unresolved phenomena, such as in-vessel coolability, ex-vessel steam explosion, and some FP behaviors. Research on these unresolved issues will be continued partly to be reflected for the closure of severe accident issues and partly for the application to future reactor development.

4 SUMMARY

Extensive research activities on severe accident are being conducted at JAERI. The research results will be utilized for the revision of safety examination guides and detailed implementation of the accident management measures.

It is noted that the international collaboration in severe accident research is of great importance. In this context JAERI with NUPEC have been holding Workshop on Severe Accident Research in Japan(SARJ) since 1990 for the effective information exchange.

Although a new governmental five-year nuclear safety research plan is under discussion, the severe accident research will probably approach to the closure, along with research results from the world, in next century by contributing to the enhancement of the nuclear safety.

REFERENCES

[1] Sugimoto, J., Proc. Int. Seminar Heat and Mass Transfer in Severe Accidents, Cesme, Turkey(1995).
[2] Sugimoto, J.(Ed.), Proc. SARJ-97, Yokohama, JAERI-Conf 98-009(1998).
[3] Yamano, N., et al., Nuclear Engineering and Design, vol.155, Nos.1-2, pp. 369-389, (1995).
[4] Kudo, T. et al., Proc. 3rd Int. Conf. Cont. Design & Operation, Toronto, Canada (1994).
[5] Yamano, N. et al., Nucl. Eng. Design, vol. 145, No. 3, pp.365-374 (1993).
[6] Park, H.S. et al., Proc. 11th International Heat Transfer Conference, Kyungju (1998).
[7] Moriyama, K. et al., Proc. ICONE-4, New Orleans, USA (1996).
[8] Yang, Y. et al., Proc. ICONE-7, Tokyo, Japan (1998).
[9] Maruyama, Y. et al., To be published in Nucl. Eng. Design (1998).
[10] Hidaka, A. et al., Proc. SARJ-98, Tokyo, JAERI-Conf(1998).(to be published)
[11] Hidaka, A., et al., Nucl. Sci. Technol. Vol.32, No.10, pp.1047-1053 (1995).
[12] Hashimoto, K., et al., Proc. ICONE-3, Kyoto, Japan (1995).
[13] Hidaka, A. et al., Proc. NURETH-8, Vol. 2, 595-604, Kyoto, Japan (1997).
[14] Maeda, A. et al., Proc. ICONE-5, Nice, France (1997).
[15] Harada, G., et al., 1998 ASME/JSME Joint Pressure Vessel and Piping Conf., U.S.A. (1998) .
[16] Mishima, K., et al., Proc. SARJ-98, Tokyo, JAERI-Conf(1998).(to be published)
[17] Koshizuka, H., et al., Proc. OECD Mtg. FCI, Tokai, Japan, JAERI-Conf97-011(1998).
[18] Yamawaki, M., et al., JAERI-Tech 98-003(1998)(in Japanese).

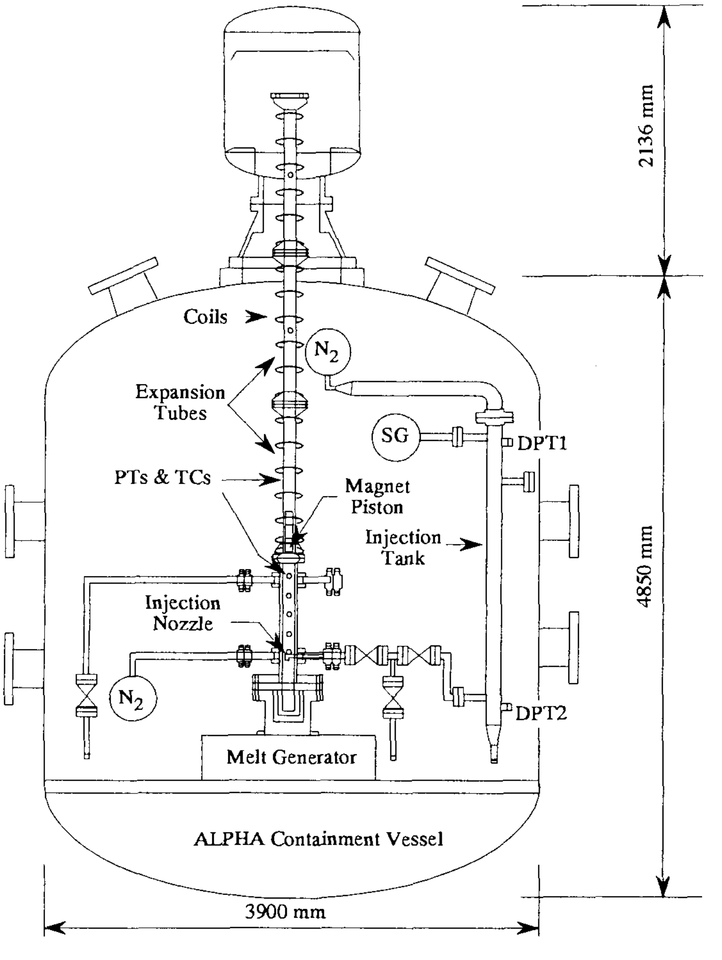

Fig.1 In-Vessel debris coolability experiments in ALPHA

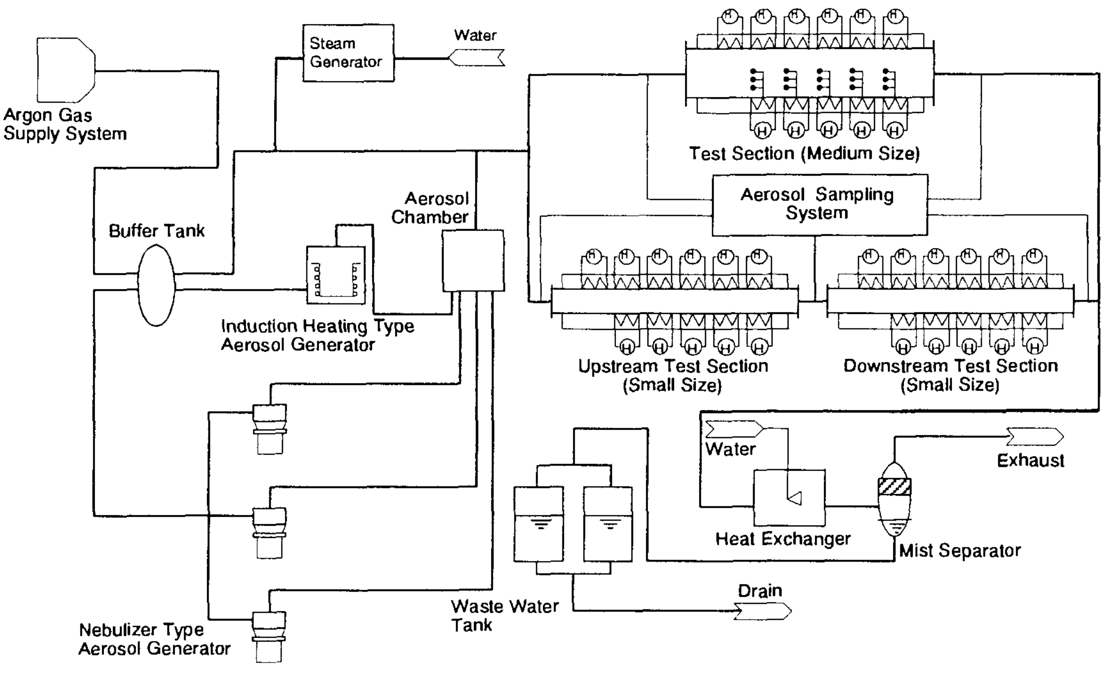

Fig.2 Aerosol behavior test facility in WIND

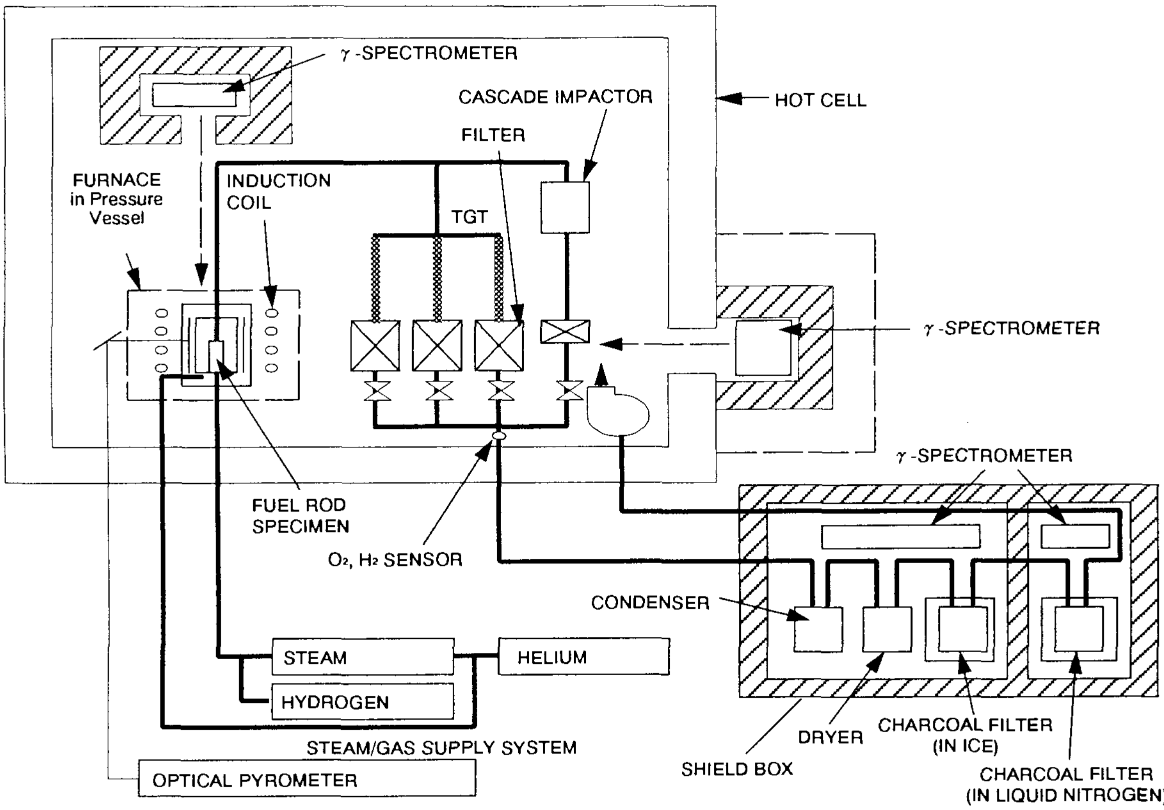

Fig.3 Conceptual diagram of VEGA test facility

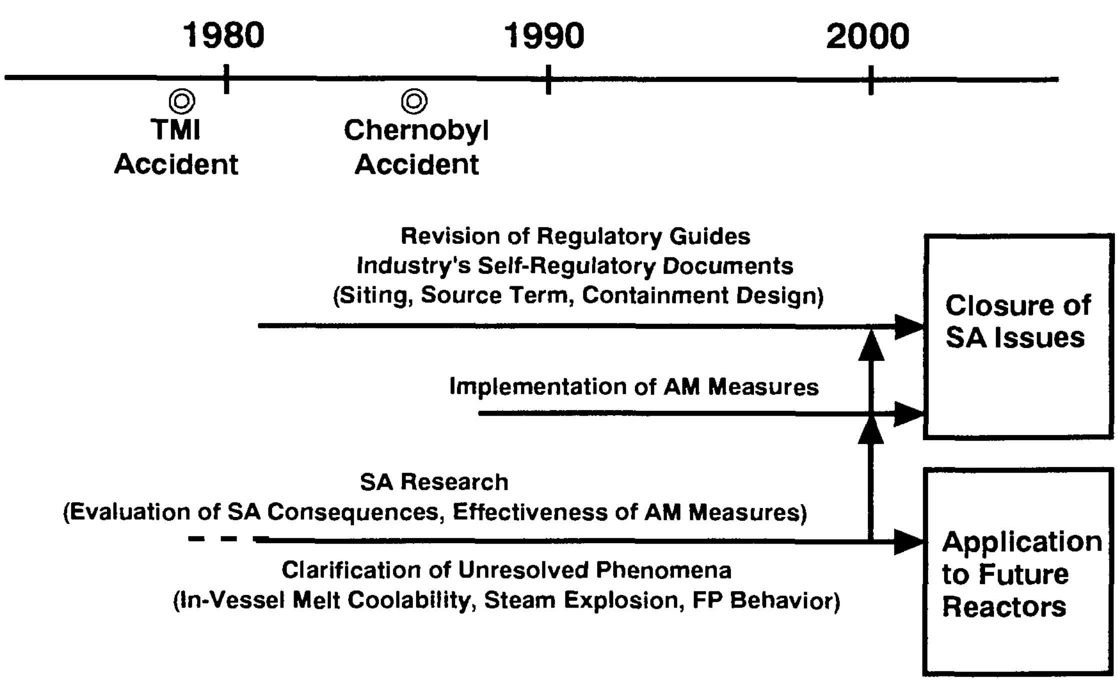

Fig.4 Closure of severe accident issues and its application to future reactors