Test Plan for Aerosol Behavior in the SAPFIRE Facility

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Test Plan for Aerosol Behavior in the SAPFIRE Facility

Y. Himeno, S. Miyahara, and T. Kinoshita

Fast Reactor Safety Engineering Division
Oarai Engineering Center
Power Reactor and Nuclear Fuel Development Corporation
4002 Narita, Oarai-machi, Ibaraki 311-13, Japan

Abstract

Large scale sodium fire and aerosol behavior tests will start in April 1985 at the new facility, SAPFIRE. The main objectives of this program are to study the structural integrity of some of the plant safety systems and to study the aerosol behavior in the event of a sodium fire accident in an LMFBR. Test rigs for these studies are a 3m³ and an 80m³ closed vessels and a reactor secondary building simulating a concrete cell.

In regard to the test and the analysis of aerosol behavior, the following studies will be carried out in SAPFIRE Phase-1 during 1985 through 1987.

(1) To study the performance of components under decay heat removal operation and of post-accident monitors in the aerosol containing atmosphere.

(2) To study the aerosol leak and the plugging behavior through the narrow flow channels and small holes (channel model should be considered.)

(3) To improve and validate the ABC-INTG code.
Introduction

In recent years, an accurate evaluation of the response of the plant safety systems in aerosol bearing atmosphere in the event of a sodium fire accident in an LMFBR has become increasingly important. In the past decade, experimental studies have been carried out by many organizations, and these studies have contributed to the understanding of individual phenomena such as pool fire, spray fire, and aerosol behavior in a containment. The computer codes to analyze the above phenomena have also been developed. However, these early studies were insufficient to evaluate the response of the plant safety systems under aerosol conditions. In fact, the spray fire, pool fire, aerosol release, and aerosol transport will proceed almost simultaneously in the event of a real large sodium leak and fire accident. In addition, a large amount of sodium combustion heat and a large mass of sodium aerosols will be generated, if the accident occurs in a secondary building of the reactor. Such complex phenomena cannot be analyzed easily with the knowledge from the early studies alone. Hence, PNC is constructing a large scale sodium leak, fire, aerosol test facility, SAPFIRE, to conduct engineering scale tests.

The whole SAPFIRE program is divided into three phases, namely Phase-1 (from 1985 to 1987), Phase-2 (from 1988 to 1990), and Phase-3 (after 1991). In Phase-1, efforts will be directed to test and analyze the response of the Monju sodium fire and aerosol mitigation systems, particularly, those in the secondary building of the reactor. Phase-2 and Phase-3 are for the source term and the containment response R&D. In the present paper, the test plans for Phase-1 are explained.

1. General Features of Test Facility

Facility construction of SAPFIRE is under way at Oarai Engineering Center, PNC, to be completed at the end of March, 1985. Figure 1 shows the bird’s-eye view of the facility in which the following test rigs and utilities will be installed. Table 1 shows the main specifications of the test rigs.

Test Rigs

*SOLFA-1: Two-story high concrete cell.
*SOLFA-2: 80m³ steel vessel.
*FRAT-1: 3m³ steel vessel.

Utilities

*Aerosol Filtration System:
Two units. Each unit consists of HEPA filters and a water scrubber

*Sodium Supply System:
consists of a sodium heater, a 6m³ sodium recovery tank, and a 20m³ sodium storage tank equipped with a cold trap.
Sodium Cleaning and Solution Processing System

In regard to the test rigs listed above, SOLFA-1 is to demonstrate the integrity of the fire mitigation systems. SOLFA-2 is to obtain the test data to validate sodium fire and aerosol behavior codes and also to investigate the durability of components for decay heat removal operation in the aerosol containing atmosphere. Post-accident monitors are also tested in SOLFA-2. FRAT-1 is to make basic tests on sodium fires and aerosol behavior. The interaction between sodium and foreign materials will also be studied with FRAT-1.

2. Test Plan

The test matrix of SAPFIRE ranges from a sodium leak, sodium fire, and aerosol behavior to these interrelated phenomena as described. But, this paper emphasizes only those test items related to aerosol behavior. Table 2 shows the test items now being planned. The details of each item are as follows.

(1) Test of Reactor Components and Instruments under Sodium Aerosol Containing Atmosphere

In case of a large sodium leak accident in one of the secondary heat transport systems (SHTS) of the reactor, the operation is switched over to the decay heat removal mode. In this event, although each SHTS is physically separated from others by the concrete cells and the reactor building walls, sodium aerosols generated in an affected room may leak into neighboring rooms where other SHTS are operating for decay heat removal. This aerosol leak into the neighboring rooms results in the exposure of key components of SHTS to the aerosol containing atmosphere. Furthermore, in the affected room, electrical instruments of the post-accident monitors (PAMs) are also exposed to high temperature atmosphere containing high concentration aerosols.

Taking into account of the above operating conditions of the components and PAMs, the test of their reliabilities and integrities under the simulated accident conditions are essential. In Phase-1 of SAPFIRE, therefore, the tests are to be conducted by exposing the components and the instruments to sodium aerosols in SOLFA-2. The typical components and PAMs to be tested are a pony motor, an air-cooler for decay heat removal, a heat exchanger and a blower for the HVAC (heating, ventilation, and air conditioning) system, a sodium level meter, and a radiation counter. Among them, the tests for the air-cooler and the heat exchanger are most interesting. Early studies were concerned mainly with aerosol deposition under the conditions of natural convection. The deposition studies under forced convection have been very limited. Therefore, by making the tests on the heat exchanger, the deposition behavior under forced convective conditions will be studied in the presence of a very steep temperature gradient at the vicinity of the deposition wall.
(2) Test of Aerosol Leak through Narrow Path

For the realistic evaluation of the radiological consequences of an LMFBR, the modeling of aerosol leak through leak paths in the reactor containment is a key issue [1]. In addition, the environmental protection regulation in Japan is very strict. Therefore, the release of sodium aerosols into the environment should be evaluated accurately and should be limited to a very low level, even though the released aerosol from the secondary building are non-radioactive. But the state of the art is that the modeling is incomplete due to lack of test data.

In the tests, aerosol leaks through narrow gaps and channels will be studied by installing engineering models of a door, hatch or cable penetration in an aerosol duct that connects SOLFA-1 and SOLFA-2. The leak paths in this case are those that appear around the doors and the penetrations in the primary containment cells and the secondary building of the plant. Basic tests with simplified models of leak paths will also be made with FRAT-1.

(3) Aerosol Behavior Test

Following the development of the first versions of aerosol behavior code, ABC-1 and ABC-2 [2] in 1973, the code had been successively improved to ABC-3 [3] in 1974, ABC-3B [4] in 1979, and ABC-3C [5] in 1981. Later in 1983, the new version of the code, ABC-INTG [6], was developed. In the ABC-INTG code, the particle size distribution of the aerosol is discretized by the finite difference method, and the coagulation processes are calculated by using the sectional representation proposed by Gelbard et al [7]. This newly developed ABC-INTG joined the comparison study of aerosol behavior codes from 1982 through 1984, under the auspices of the Commission of European Community, together with the European codes (i.e., PARDISEK-IIIb, AEROSOLS-B1, AEROSOLS-A2, and AEROSIM). As reported elsewhere [8], the summary and the highlight of the comparison study regarding the ABC-INTG code is that the code predictions showed good agreement with those by the other codes which discretize the particle size distribution.

Despite the efforts, the codes so far developed and now widely used in many countries have their own limitations. One example is on the deposition rate calculation. As is well known, the deposition and the settling are the main sink terms for aerosols. Among them, the thermophoretic deposition is a major deposition process, if the temperature gradient at the vicinity of the wall is very large. However, the thermophoretic deposition rate cannot be accurately calculated by the code unless the temperature gradient data are available as input. This is due to the assumption in the codes that gas natural convection in a closed vessel and the resulting temperature gradient at the vicinity of the wall at different locations are all the same as those calculated from the conventional heat transfer correlation. This assumption makes the realistic evaluation all more difficult.
To improve the above limitation associated with thermophoretic
deposition rate calculation, aerosol behavior tests will be made by
using SOLFA-2. Thereafter, analyses will be made by combining ABC-INTG
with a gas natural convection code that calculates the temperature
distribution in the gas phase.

Reference

Containment Following HODA in LMFBF" (in Japanese), JAERI-memo
5251, April (1973).
Released in an LMFBF Hypothetical Accident (ABC-code)", JAERI-
mem 5481, August (1974).
Sodium Oxide, and Their Mixed Aerosols by Using ABC-3B", NUREG/CR-
1724, ORNL/NUREG/ TM-404, CSNI-45, April (1980).
[6] N. Mitsutsuka, Y. Himeno, S. Miyahara, M. Ito, and H. Obata,
"Aerosol Behavior Code, ABC-INTG - Features and Validation of the
sol Dynamics", Journal of Colloid and Interface Science, 78,
No.2, December (1980).
to the Sodium Oxide Aerosol Behavior in a Containment Building",
to be presented at the OECD/CSNI Specialists' Meeting on Nuclear
Aerosols in Reactor Safety, Karlsruhe, 4-6 September (1984).
Table 1 Main Specifications of the Test Rigs

<table>
<thead>
<tr>
<th>Test Rig</th>
<th>Geometry</th>
<th>Structural Materials</th>
<th>Volume</th>
<th>Maximum Over Pressure</th>
<th>Maximum Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLFA-1</td>
<td>Floor: 5m×5m</td>
<td>• Reinforced Concrete</td>
<td>175m³</td>
<td>+0.03bar</td>
<td>• Concrete=150°C</td>
</tr>
<tr>
<td></td>
<td>Height: 7m</td>
<td>• Steel</td>
<td></td>
<td></td>
<td>• Steel=650°C</td>
</tr>
<tr>
<td>SOLFA-2</td>
<td>Diameter: 3.6m</td>
<td>Stainless Steel</td>
<td>80m³</td>
<td>+2bar</td>
<td>450°C</td>
</tr>
<tr>
<td></td>
<td>Height: 9m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRAT-1</td>
<td>Diameter: 1.3m</td>
<td>Stainless Steel</td>
<td>3m³</td>
<td>+3bar</td>
<td>550°C</td>
</tr>
<tr>
<td></td>
<td>Height: 2.1m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(PSS-PSM-033)

Table 2 Test Items Related to Aerosol Behavior in SAPFIRE, Phase 1

<table>
<thead>
<tr>
<th>Item</th>
<th>Objective</th>
<th>Test Data To Be Obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component and Instrument Test</td>
<td>to verify reliabilities of DHR components and PAMs.**</td>
<td>• aerosol mass concentration&lt;br&gt;• aerosol particle size&lt;br&gt;• chemical composition of aerosol&lt;br&gt;• heat transfer coefficient of a heat exchanger&lt;br&gt;• electrical insulation of PAMs</td>
</tr>
<tr>
<td>Aerosol Leak and Plugging Test</td>
<td>to construct aerosol leak and plugging model</td>
<td>• aerosol mass concentration&lt;br&gt;• aerosol particle size&lt;br&gt;• chemical composition of aerosol&lt;br&gt;• pressure drop across a leak path&lt;br&gt;• leak path geometry</td>
</tr>
<tr>
<td>Aerosol Behavior Test</td>
<td>to improve aerosol behavior analysis and to validate the ABC-INTG code</td>
<td>• aerosol mass concentration&lt;br&gt;• aerosol particle size&lt;br&gt;• deposition and sedimentation rates&lt;br&gt;• temperature distribution&lt;br&gt;• heat transfer rates</td>
</tr>
</tbody>
</table>

(*) Decay Heat Removal. (***) Post Accident Monitoring.

(PSS-PSM-034)
Fig. 1 SAPFIRE Facility

大規模ナトリウム漏洩火災試験施設
サファイア施設

FSI施設

SOLFA (Sodium Leak, Fires, and Aerosols Test Rig)
FRAT (Fission Product and Radioactive Aerosol Release Test Rig)

(PSS-PSM-032)