UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

May 30, 2008

The Honorable Dale E. Klein
Chairman
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: PHEBUS FISSION PRODUCT (PHEBUS-FP) PROGRAM

Dear Chairman Klein:

During the 552nd meeting of the Advisory Committee on Reactor Safeguards, May 8-9, 2008, we reviewed the PHEBUS Fission Product (PHEBUS-FP) Program. During this review, we had the benefit of discussions with representatives of the NRC staff and the French Institut de Radioprotection et de Sûreté Nucléaire (IRSN). We also had the benefit of the documents referenced.

CONCLUSIONS AND RECOMMENDATIONS

- PHEBUS-FP is an example of a successful international cooperative research program. It is yielding data for validating and refining severe accident analysis computer codes and assessing the appropriateness of the accident source terms.

- The strategy for developing a mechanistic understanding of gaseous iodine behavior is appropriate and the planned work should be supported.

DISCUSSION

Characterization of the risks associated with nuclear power plants depends on an understanding of fission product release and transport during severe accidents. The PHEBUS-FP experiments simulate the major aspects of a severe accident, including degradation of irradiated fuel, release of fission products, transport of fission products through a simulated reactor coolant system, and release of the fission products into a simulated reactor containment. The data from these integral tests are valuable for validating and refining the models and computer codes used for reactor accident analysis, in particular the MELCOR code, and in assessing the appropriateness of accident source terms used in design basis dose assessment reviews. Overall, the current assessment of the results of the PHEBUS-FP tests supports many of the modeling assumptions in MELCOR and the basic premises used to develop the revised accident source terms referred to as the “NUREG-1465 source terms” or the “alternate source terms.” The tests, however, have yielded new insights and information.

For example, data obtained from the first two tests (FPT-0 and FPT-1) have been used to improve the modeling of fuel slumping in MELCOR. The tests also show that cesium (Cs) released from the overheated reactor fuel does not transport predominantly as cesium hydroxide (CsOH) as assumed currently in severe accident analyses. These analyses need to be modified to reflect this change in the dominant chemical form of cesium that transports through the reactor coolant system to the containment.

Another important finding was that silver vaporized from control rod alloys in tests FPT-0, -1, and -2 transported to the containment sumps, where it reacted with any dissolved iodine species to form insoluble AgI or $AgIO_3$. This limits the dissolved iodine concentration in the sump to low levels that are insufficient to support substantial partitioning of iodine from the sump into the containment atmosphere, regardless of the sump pH.

Even in test FPT-3, with B_4C control rods instead of Ag-In-Cd, a steady-state gaseous iodine concentration developed in the containment atmosphere and persisted for days (up to 96 hours). The steady-state concentration in the containment was independent of the containment sump pH in the range of pH=9 (basic) to pH=5 (acidic).

In an aqueous solution, iodine will partition into the atmosphere. This partitioning is affected by the total iodine concentration of the solution, the radiation dose rate to the solution, and the solution pH. This partitioning has been thought to be critical in determining the gaseous iodine concentration in the containment atmosphere. Thus, licensees that adopted the NUREG-1465 source terms were required to take measures to control the pH of the sump during an accident to ensure that the sump water would not become acidic and that gaseous iodine levels would be bounded by the assumption in NUREG-1465 that 5 percent of the iodine released into the containment is gaseous iodine. However, in the PHEBUS-FP tests, a steady-state concentration of gaseous iodine in the atmosphere was achieved independent of the sump pH. In addition, from prior work, it was expected that the rate of release of iodine from the sump to the containment atmosphere would increase as the temperature increased, and water evaporated from the sump would decrease as the temperature decreased, and vapor condensed in the sump. In the PHEBUS-FP tests, the observed behavior was opposite to this expectation.

PHEBUS is an integral test facility that is intended to be reasonably prototypical of a reactor situation. However, without a better mechanistic understanding of the observed phenomena, it is difficult to demonstrate that the results can be scaled to the reactor situation and that robust models can be developed to include in severe accident codes. The participants in the PHEBUS-FP program have developed a follow-on effort to try to develop the necessary mechanistic understanding.

It is currently hypothesized that observed behavior is due to interactions of the iodine with painted condensing surfaces above the sump. The follow-on programs [PHEBUS-ISTP (EPICUR) and CSNI BIP program] focus on tests that explore various aspects of the potential iodine interaction with painted surfaces and other surfaces within containment. In addition, they will examine the effects of prototypical sump debris, such as paint chips, fibrous insulation, and corrosion products on the partitioning of aqueous iodine into the atmosphere as gaseous iodine.

A better understanding of the iodine behavior observed in the PHEBUS-FP tests is clearly important for characterizing the radioactive source term during an accident. It may also have important implications for the resolution of the Generic Safety Issue-191, “Assessment of Debris Accumulation on Pressurized Water Reactor (PWR) Sump Performance.” Currently, a variety of chemicals are used to control the pH of the water in the sump during long-term cooling following a loss-of-coolant accident. Some of these chemicals, such as trisodium phosphate, are known to promote the formation of chemical precipitates that can exacerbate the problem of sump blockage on debris beds. If it can be demonstrated that the observed independence of the partitioning of iodine on sump pH in the PHEBUS-FP tests is more broadly applicable, then it may be beneficial in some cases to consider removal of these chemicals from containment sumps.

The PHEBUS-FP is an example of a successful international cooperative research program. It has yielded data for the validation and refinement of severe accident analysis computer codes and assessment of the appropriateness of the accident source terms. The follow-on programs also leverage international efforts and expertise to perform the tests necessary to develop and validate more mechanistic models that describe the behavior observed in PHEBUS-FP tests. These models will be incorporated into severe accident codes to provide a capability to predict the iodine behavior in PWR containments. Continuation of this work should be supported. We commend the staff for its active participation in this program to better understand the unexpected phenomena involving iodine partitioning observed in the PHEBUS-FP tests.

Sincerely,

/RA/

William J. Shack
Chairman

Dr. Dana Powers did not participate in the Committee’s deliberation regarding this matter.

References:

1. U.S. Nuclear Regulatory Commission, Memorandum dated December 19, 2007, from Farouk Eltawila, Director, Division of Systems Analysis, Office of Nuclear Regulatory Research, to Frank P. Gillespie, Executive Director, ACRS, Subject: Information for Briefing the ACRS on “Findings and Use of Results from Phebus-FP Tests to Validate the NRC’s MELCOR Severe Accident Code and Revised Accident Source Term (NUREG-1465),” (ML073520123).

2. Report dated May 8, 2002, from George E. Apostolakis, ACRS Chairman, to Richard A. Meserve, Chairman, U.S. Nuclear Regulatory Commission, Subject: PHEBUS-FP Program, (ML021430543).

3. U.S. Atomic Energy Commission, Technical Information Document (TID) 14844, "Calculation of Distance Factors for Power and Test Reactor Sites," 1962.

4. U.S. Nuclear Regulatory Commission, NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants," 1995.

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