THE GAS REACTOR IN-PILE SAFETY TEST PROJECT (GRIST-2)

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ABSTRACT

Although out-of-pile tests may be expected to confirm individual phenomena models in core disruptive accident analysis codes, only in-pile tests are capable of verifying the extremely complex integrated model effects within the appropriate time phase for these accidents. For this reason, the GRIST-2 project, the purpose of which is to design and construct an in-pile helium loop capable of transient safety testing in the TREAT facility in Idaho, forms a cornerstone of the U.S. GCFR safety program. The importance of the project, which was initiated under the Department of Energy [DOE (then ERDA)] support in 1976, may be seen in its multiorganizational makeup. The project currently employs over 15 engineers in design teams at Argonne National Laboratory (ANL), EG&G Idaho, and General Atomic (GA) with the overall project management and technical coordination having recently been vested in Helium Breeder Associates (HBA).

INTRODUCTION

The GRIST-2 objective is to provide an in-pile test loop in preparation for performing tests to verify analytical models and codes of gas-cooled fast breeder reactor (GCFR) fuels by experimental exploration of the consequences of loss of flow (LOF) and transient overpower (TOP) conditions with failure to scram. The project organization, experiment program, facility, helium system design, and schedule which have been selected to meet the objectives are described below.

PROJECT ORGANIZATION

To accomplish the project objective a multiorganizational project team has been developed with responsibilities for elements of the work breakdown structure, as shown in Figure 1. EG&G Idaho is responsible for the design and construction of the helium coolant system with related gas circulators, coolers, heater, in-pile tube, piping, controls, and safety systems. Argonne National Laboratory is responsible as the experimenter for supplying a test program plan, experiment requirements, and the test train assembly design. Argonne National Laboratory is also responsible as the facility integrator for ensuring the availability of the TREAT reactor, buildings, services, and systems and such modifications or new items as is necessary to support the GRIST-2 Project needs within the first phase of the Safety Research Experiment Facilities (SAREF). General Atomic has the role of developing and supplying GRIST-2 test fuel. The Department of Energy is responsible for establishing policy, overall program objectives, and funding and has recently assigned the project management and technical coordination responsibilities to HBA.

EXPERIMENT PROGRAM

In a fast reactor, the only means for termination of unprotected accidents is by removal of fuel. For rapid TOP events, the fuel heats up essentially adiabatically and starts melting within intact cladding. Analysis has predicted that for TOP events eventual fuel removal occurs as a result of cladding ruptures with resultant fuel ejection and sweepout into the coolant stream. For LOF events, clad melting and runout would precede fuel melting with fission-gas-driven dispersal, molten fuel slumping out of the core, and fuel-vapor-driven dispersal as the probable mechanisms for terminating the accident. Permanent removal of fuel from the core region into a coolable and subcritical geometry must be accomplished to prevent recriticality. With this in mind, the following important phenomena need investigation:

1. Transient Overpower Case

   a. Failure Threshold. Fuel pin failure mode and location is needed for TOP analysis. In-pile tests can generate information for failure location and cladding rip length while out-of-pile tests will provide supporting evidence for failure temperature and pressure relationship for roughened cladding.

   b. Fuel Motion and Gas Behavior. Information concerning the extent of fuel melting and motion (such as the potential for molten fuel draining inside a high-power pin) can be provided by in-pile tests. These tests will also show if any fuel vapor can be generated under TOP conditions.

   c. Fuel Fragmentation and Sweepout. In general, TOP accidents have been characterized as more benign events than LOFs. To support this argument, ultimate verification is expected to come from in-pile shaped transient integral tests which investigate fuel fragmentation size, sweepout, and the potential for plugging.

2. Loss of Flow Case

a. Transient Gas Release. Out-of-pile tests, mostly using short fuel specimens, can go a long way toward understanding transient gas release and potential swelling or frothing mechanisms. Declad fuel stability and fuel mechanical properties near failure can also be tested out-of-pile, but only integral in-pile tests can verify these mechanisms and their effects in a properly simulated time sequence and environment.

b. Cladding Relocation. Cladding relocation feedback can increase reactivity by several dollars. Reactivity effects can be reasonably predicted, while transient cladding refreezing in the lower axial blanket is much more difficult to analyze and can have a profound impact on the transient sequence. In-pile tests are needed to study the clad melting, relocation, and potential plugging effects in an integral LOF experiment since cladding behavior is expected to be coupled to fuel behavior during the transient.

c. Fuel Melting and Draining. The high GCFR coolant pressure requires high fuel enthalpies to cause fuel vaporization. If both fuel vaporization and fission gas dispersal mechanisms are ineffective, then it has been suggested that in the low-power regions, fuel melting and subsequent draining out of the core region may be the key shutdown mechanism for GCFR LOF accidents. In-pile tests should be conducted to quantify this potentially very significant mechanism which would be a major difference compared to LMFBR LOF accident behavior.

d. Fuel Vaporization and Plugging. The ultimate goal of these safety studies is to demonstrate that the release of radiological materials, particularly plutonium, to the offsite environment is within acceptable bounds. Fuel vaporization is the key mechanism that can generate radiological aerosol. Therefore, fuel vapor experiments are important not only to study its potential as a fuel dispersal mechanism but also to define initial conditions for plutonium aerosol analyses. Other important phenomena to be studied are the short-term (m-sec) behavior of molten fuel following a vapor-driven disruption. This is intended to assess (1) any potential for recriticality in fuel which might plug shortly into an axial blanket and build up behind such a plug and (2) the short-term heat losses and vapor condensation in partial or total penetration of axial blankets, particularly as this may influence the formation of fuel aerosols in the PCRV atmosphere. In-pile tests are needed to characterize this behavior adequately.

To study these phenomena, a preliminary GRIST-2 test plan of 18 separate tests has been developed which will cover a span of five years. Test phases I and II are for the fresh fuel behavior at the beginning of life (BOL) reactor state. Phase III is for the reactor state that contains irradiated fuel with a saturated content of helium and fission gas equivalent to that of significantly irradiated fuel. Phase IV is for larger bundle tests and scaling effects. Even though the plan is preliminary, it optimizes within a scheduling limitation of five years the important technical factors, namely type of accident (LOF, TOP), phenomenological uncertainties, type of fuel (UO_2, mixed oxide), reactor power region (high-power and low-power pins), fuel failure state, reactivity insertion rate, and preirradiation conditions.

FACILITY REQUIREMENTS

Existing test reactor facilities worldwide were screened as possible drivers for the GRIST-2 experiments described above. The driver requirements are severe in that

1. Relatively large numbers of fuel rods (up to 37) may be required in a given test.

2. Prototypic fuel and blanket lengths are required.

3. The required test fuel power and rate of change of power are very high.

4. Normal power/flow operation is desirable as initial conditions for the experiments of the candidate facilities.

The TREAT reactor at the ANL site at the Idaho National Engineering Laboratory (INEL) was found to be superior in every category of major importance to the GRIST-2 project.

The existing TREAT core (Figure 2) is comprised of a 19 x 19 square matrix of vertically-oriented fuel elements. The fuel is fully enriched uranium oxide dispersed in a graphite moderator with zircaloy-cladding in the fueled region. The reactor is basically uncooled; i.e., transient operation is essentially adiabatic. However, a means of drawing ambient air through the core is provided to hasten post-test cooldown of the core. A thick concrete biological shield encloses the reactor, and the facility is operated remotely from a control room located 0.8 km from the reactor building.

Prior to the initiation of GRIST-2 testing, an upgrade of the TREAT facility and driver capabilities will have been accomplished under the SAREF program. With this upgrade, TREAT should be capable of meeting an energy deposition requirement of 4000 joules/gram at the required power flatness to produce boiling of the GCFR fuel at rated pressure.

EXPERIMENT SYSTEMS

The GRIST-2 Experiment Systems consist of a helium supply system, a themal neutron filter a test train, and the necessary support equipment for assembly and disassembly operations. A calibration vehicle neutronically simulating the in-pile hardware is used for certain tests. A conceptual layout of the experiment systems is shown in Figure 3. A description of the equipment follows.

The GRIST-2 helium systems include a test loop, an in-pile tube (IPT), and auxiliary systems. The test loop will provide coolant for up to 37 fuel rods, 0.93 kg/s of helium at 10.0 MPa, and an inlet temperature of 588 K. Coolant flow rate will be controllable to simulate LOF accidents. The helium conditions are to be typical of those in the GCFR reactor. The IPT supports the experiment (test train) in the proper position in the TREAT Upgrade and contains the post-test experiment debris. Auxiliary systems include loop-charging, helium purification, and decontamination equipment. The system design will assure containment in the event the primary coolant flow is blocked during and after a test. Containment will be provided to control any fission product leakage within facility limits.

Helium flow (Figure 4) is provided by two circulators arranged in series. Flow discharging from the circulators provides primary flow to the test bundle. A local circulator bypass accommodates excess flow capability to optimize circulator performance. The primary flow passes through an electrical heater where it is heated to the desired test inlet temperature. The primary flow then passes through a flow control valve to the top of the reactor and to the IPT where it flows downward through the test bundle. The heated helium then flows upward through an annulus between the IPT and the test train. At the upper end of the in-pile assembly, it passes through a heat absorbing pebble bed, ensuring that the helium temperature exiting the IPT does not exceed 700 K. The return flow from the IPT passes through a particulate filter and then a cooler where its temperature is reduced prior to reentering the circulators. An additional line is provided to bypass a portion of the primary flow around the IPT. This feature permits the desired rapid flow changes through the IPT without grossly altering total flow or changing flow through the heater, cooler, and circulators.

The secondary helium system consists of secondary piping, circulators, cooler, filter, and the in-pile system. It is designed to operate at a reduced temperature but at a pressure above that of the primary coolant, furnishing helium cooling to the IPT primary and secondary pressure tubes, neutron filter, and melt cup during the test. This system will be designed for maximum reliability and simplicity.

The GRIST-2 helium system design provides the flexibility of performing transient depressurization tests at a future time. Tests requiring depressurization of the system would be accomplished by opening valves which direct flow to the low-pressure storage tank. The tank is sized so that when the loop system is fully depressurized, its pressure is approximately 200 kPa. The depressurization line would be equipped with a fixed orifice and plug valve so that the desired pressure decay rate could be achieved.

An annular thermal neutron filter (TNF), positioned between the primary and secondary containment vessels of the IPT, surrounds the cluster of test pins. The purpose of the TNF is to remove the bulk of the thermal neutrons impinging on the test pins, leaving principally the epithermal and fast components of the neutron flux.

The test train is situated in the center of the test reactor within the IPT and holds the actual test fuel bundle and associated test data instrumentation. In the test train, the test fuel assembly is made up of fuel elements that are reasonably prototypic of GCFR fuel and GCFR core design parameters.

The Support Systems includes facilities and equipment for the assembly, disassembly, storage, disposal and transfer of GRIST-2 experiment systems. The GRIST project is based upon the maximum possible utilization of existing TREAT, SLSF and HFEF facilities and equipment at the ANL-W site at INEL.

PROJECT SCHEDULE

Project requirements have been identified to date, and a detailed test plan is near completion. All major participants have begun work within the project (including SAREF project staff) with the appropriate responsibilities defined. The test loop conceptual design has been completed, and preliminary design efforts are underway. GRIST-2 facility completion and test loop operation is scheduled for 1985 followed by a five-year test program which will support the submittal of a final safety analysis report (FSAR) for the GCFR development plant in 1989.