Modeling of Cladding and Fuel Motion
in a
Loss of Flow Situation
for
GCFR Safety Analysis
COO-2471-3

Technical Progress Report
(Annual)

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June 15, 1974 - March 15, 1975

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June 15, 1974 to March 15, 1975

Modeling of Cladding and Fuel Motion

in a Loss of Flow Situation for GCFR Safety Analysis

Contract No. AT(11-1)-2471

Summary: During the first nine months of the project (June 15, 1974 to March 15, 1975) methods and apparatus were developed to study the freezeout of molten cladding in a cooler blanket region. Three tests were run in which a mass of molten material from the core region of a GCFR flowed into a bundle of simulated blanket elements. In all cases plugging occurred in or before the first grid-spacer. Theories and preliminary models are in accord with these observations. These tests have been done with a 50/50-Pb/Sn alloy simulating the cladding and spacer grids and alumina simulating the fuel. Materials are being obtained for tests with stainless steel cladding and spacers.

Development is progressing well on an electrically heated fuel element which will be used to study the melting and motion of cladding in the core region for a loss of flow accident.

Preliminary models are being developed to calculate the motion and freeze-out of flowing cladding in the blanket region. The SAS-GAS and Argus codes (from Argonne) are being adapted for uses at Northwestern in conjunction with model development on the project.

A survey of fission gas effects in oxide during TOP cases was prepared and other codes (LIFE) were reviewed for possible value on the project. A set of reference physical parameters are being developed for the various materials used in the analysis and experiments.

The principal investigator (D. T. Eggen) devoted half time for three months during the summer of 1974 and at least one day (20% of full time) during the academic year to the project. Professors Lewis and Livengood devoted at least a half day (10% of full time) of each week during the academic year to the project.

Task 1: Techniques were developed to make simulated blanket bundles using cladding of Pb-Sn (50/50) alloy on aluminum oxide rods. The first process involved casting a cylindrical slug of alloy on a $\frac{1}{4}$ in. diam. steel rod and swaging it to a diameter of 0.312 in. The tube of alloy was then transferred to an alumina tube (1/16 ID, 1/4 OD). A draw rod (0.080 in. OD) was inserted with nuts (1/4 OD) on either end through the tubing hole. The cladding was drawn in two stages; first to an O.D. of 0.302 in. and then to 0.290 in. The cladding was "bonded" to the alumina tube to simulate a fuel element with a fuel diameter of 0.244 in. and clad O.D. of 0.238 in. (wall thickness of 0.020 in.). Later extruded tubing with an O.D. of 0.310 in. and an I.D. of 0.255 in. was obtained which eliminated the casting and swaging steps in fabrication.

A grid spacer structure was cast of the alloy. The average wall thickness in the spacer was 0.020 in., which is slightly thicker than the S.S. prototype (0.013 in.). The rises for centering the fuel elements, which were prototypical of an earlier GCFR design, intercept a larger fraction of free (coolant) space than current design. $\left[\frac{A_{cool}}{A_{cell}} \text{ (proto)} = 0.8274, \frac{A_{cool}}{A_{cell}} \text{ (test)} = 0.08004. \right]$ The significance of this difference has not been determined. The volume of the space was compensated for by reducing the length of the spacer from $\frac{3}{4}$ in. for the prototype to about $\frac{1}{2}$ in. for the test.

The test setup consisted of 24 in. alumina tubes clad over the lower 18 in. with the alloy tubing. Thirty-seven of these elements were bundled with two

spacer-grids located 10 in. apart. The upper grid was at seven in. from the top (bare end). The bundle was enclosed in a glass tube. The first experiment was enclosed in a round glass cylinder of 80 mm. I.D. Later experiments were enclosed in fabricated hexagonal tubes which fit the outer dimension of the grid spacer. These hexagon tubes were fabricated of plate (window) glass cemented at the edges with Sauereisen #1 cement, and taped with clear plastic to reduce hazards of shattering when the molten alloy hit the cold glass.

The tests were conducted with the "lower blanket region" at room temperature. Adiabatic calculations were made to determine the appropriate temperature for the molten pour. This was determined to be about 260 C (44 C superheat) based on the assumed temperatures of the stainless steel melt and blanket temperatures and the adiabatic melt fraction for the prototype. Approximately 3 kg of molten alloy were poured through a distribution cap into the blanket bundle. Movie (regular and high speed) pictures were taken to determine the flow rates and other phenomena.

In the first experiment (December 18, 1974), the molten material plugged up the center of the bundle at the grid spacer and the rest of the melt poured over the edges of the grid between the hex spacer and the round tube. Some melting of the upper cladding and grid occurred due presumably to the refreshed molten alloy which washed over it.

In the second experiment (January 17, 1975) the hex glass tube prevented the overflow. In this case the molten alloy stopped in the grid-spacer (very little ran through) and the top of the bundle filled with the molten material which solidified from the outside, inward and bottom, upward. Post test examination reveals that little if any melting of the grid spacer

or the cladding occurred, and very little of the alloy penetrated below the grid. [A few drips existed.]

A third test was run using the same bundle as for test 2. The upper 10 inches were cut off with a diamond saw. About one inch of the cladding was machined off the top and the grid spacer was located 12 inches below the top. Only 0.7 kg of molten alloy was poured and the alloy temperature was raised to 330 C (117 C superheat). The results were that a significant fraction of the molten alloy solidified in the tube section before the grid spacer and none penetrated the grid spacer. A small fraction of cladding melted near the upper end of the elements.

The conclusions are that the alloy starts to solidify (for the slow pour velocities) almost as soon as it enters the "cool" blanket region. It penetrates into the blanket region a depth probably determined by its velocity and superheat. The mechanism of solidification seems to be the steep temperature gradient that can be attained in the transient cooling state on the outer surface of the melt.

It might be noted that on an equivalent diameter basis the prototype grid spacer represents an equivalent diameter only 0.247 that of the open bundle. (For the test the ratio is 0.24.) Since the depth of penetration is proportional to the square of the equivalent diameter, this means that the grid is equivalent to about 16 cm of open bundle. A correlation developed at Argonne by Cheung⁽¹⁾ would indicate that for our test conditions (test 1 and 2) the molten material would penetrate about 14 cm. For the test 3 conditions the penetration would be about 18 cm. This is approximately the case.*

(1) F. B. Cheung, ANL Progress Report for March, 1975.

* Personal Communication with Robert Sevy, ANL, March 20, 1975.

Other tests were run on individual rods and phenomena. Molten alloy was poured down alloy troughs at different angles (to the vertical) - which simulated different flow velocities. A low angle (73° to vertical) test resulted in the front freezing after about 15 cm. for a pour of 0.5 kg 260 C. The tests at 55° and 45° to the vertical allowed the alloy to flow out the end of the 25 cm. long test section although some alloy solidified on the way down.

A test to determine the effects of flow through small holes was inconclusive. It was meant to test the possible effect of surface tension. It is now thought that the steep temperature gradient possible in the melt is probably responsible for the freeze off as the melt enters the grid spacer.

Through the kind cooperation of the General Atomics organization a set of six, 37-rod, stainless steel grid spacers has been obtained. Tubing is on order to fabricate 2 or 3 test assemblies using prototypical materials.

The stainless steel tests will be operated in an inert atmosphere (due to the high temperature). It is expected that the test will be run in the last month of this fiscal year or the first of the next. Assuming that all goes well this will complete task 1.

Task 2. Simulated Electrical Heated Fuel Elements. Analysis has been done which shows that appropriate rates of heating can be accomplished using electrically heated elements. The design of the elements consists of an alumina core on which is wound a nichrome heater. The coil is wound with a variable pitch to simulate a "chopped cosine" power function. The coil is fixed by Sauereisen #1 cement which also acts as a filler between the heater and outer alumina jacket. Alloy cladding will be drawn onto the ceramic element.

The overall length will be prototypic (1m-core) with a short upper and full lower blanket (total length 155 cm.).

A loop is being designed which will provide an inert (probably argon) atmosphere at ambient pressure. Provision will be made to heat and cool the circulating gas. Flows of 150 to 750 cm/sec will be possible. A glass section will allow observation and photography of the tests.

Preliminary experiments have been done with simple internally heated, clad elements. These indicate that as the alloy melts it sags beneath the "skin" of the cladding forming a bulbous drop. When the mass becomes heavy enough the skin fractures - locally - and the molten alloy runs out in a stream. The skin heals and the melting continues until the rupture repeats, unsw. It is postulated that the "skin" is an oxide film resulting on the surface of the melt in contact with air. Tests will be conducted with clean cladding and inert atmospheres.

Task 3. X-ray Techniques. No progress or planning has been done.

Task 4. Adaptation of Current Heat Transfer and Accident Codes for use in the Project.

The Argus transient heat transfer code for axially symmetric analysis has been adapted for use in the CDC 6400 Computer at Northwestern. The SAS-3A-GAS code will be used as the base line system. Calculational models developed on this project will be integrated into the system. The SAS-GAS routines for heat transfer reactivity feedback, fluid mechanics of the coolant, and others will be used to initialize our conditions and provide other service functions to follow the progress of accidents.

Task 5. Model for Melting, Motion, Freezeout and Channel Plugging of Cladding.

A preliminary model for motion, freezeout, and plugging of cladding in the blanket region has been developed. The model assumes that the molten metal is moving viscously under gravity. An initial velocity is assumed. Heat is

transferred from the molten flowing mass to the solid cladding on the blanket elements. Heat is transferred by conduction only in this model. Calculations using this code show a freezing out during transient. However, due to an anomaly the flow velocities calculated were too large and no freeze off occurred. Corrections are being made. A convection model to account for less heat transfer between the molten and solid materials will also be developed.

Task 6. Development of a Model for Fuel Melting and Motion with LOF Accident.

During the summer (1974) Mr. Wehner, a graduate student on the project, completed a literature survey and evaluation of the "Behavior of Fission Gas in Oxide Fuels in a Transient Over Power Accident". This report is available from the Center for Educational Affairs, Argonne National Laboratory. He also became familiar with the LIFE code which is expected to form a basis for development of a model for fuel melting and motion in a loss of flow accident sequence.

Task 7. No progress.