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Modeling of Cladding and Fuel Motion
in a
Loss of Flow Situation
for
GCFR Safety Analysis
COO-2471-2

Progress Report 2

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October 1, 1974 - December 31, 1974

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Prepared for the U.S. Atomic Energy Commission

Reactor Safety Research Division

under Contract No. AT(11-1) - 2471

February 15, 1975

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Progress Report

October 1 through December 31, 1974

Modeling of Cladding and Fuel Motion in a Loss of Flow Situation for GCFR Safety Analysis

Contract No. AT(11-1)-2471

Summary: Work continued on Tasks 1, 2, 4, and 5. The most significant results were on Task 1 where a model two-foot long 37-element fuel assembly was fabricated. A test was made to study the effects of falling molten metal into a simulated blanket region. The liquid was initially entrained in the upper grid spacer and some melt through was experienced. However most of the molten metal (50 Pb/50 Sn) bypassed the cluster and was lost from the test. Redesigning of the assembly enclosure will alleviate this problem. A new assembly has been fabricated and will be tested in the near future. Alloy tubing was obtained from National Lead Company which will speedup the fabrication process and hopefully more tests will be run soon. Materials are on hand for the fabrication of shaped electrical heaters for Task 2 and test units are being made. The SAS-3A-GAS program is being adapted to the CDC computer and useful parts will be used on the facility at Northwestern.

Task 1. Pouring Experiments (Weber and Eggen) The objective of this first pouring experiment was to gain a feel for the mechanisms by which molten cladding, descending from the core region, interacts with the cladding and grid spacers of the blanket region in a loss of flow accident. Of specific interest was the question of whether the molten cladding would pass through the blanket region or whether it would freeze in this region, blocking the coolant channels.

To model the actual stainless steel cladding and spacers, an alloy of 50/50 Pb-Sn was selected because of its low melting temperature, its workability and its wide phase transition temperature range similar to that of stainless steel. A "fuel" material of aluminum oxide (Al_2O_3) was selected because of its availability and its similitude to ceramic, uranium-oxide fuel. Though there are significant differences between the thermal properties of Al_2O_3 and UO_2 , the time scale over which this experiment takes place is short enough that thermal interactions between the fuel and cladding were considered insignificant compared to the interactions between the molten and solid cladding.

To construct the clad fuel elements, lead-tin tubes were cast, swaged, and drawn through a die onto a 0.250 inch aluminum oxide rod. The final outside diameter of the clad fuel rod was 0.290 in. The clad section of the rod was 18 inches long with 6 inches of unclad ceramic at the top to represent the bottom of the core from which the cladding had melted. Thus the overall length of the assembly was 24 inches (Fig. 1).

To simulate the grid spacers, lead-tin alloy was cast in an aluminum mold to produce a hexagonal spacer with 37 rod positions at a pitch of 0.386 inches (Fig. 2). To facilitate reliable pouring, the spacer walls were made thicker than those of the real GCFR, tapering from 0.020 inches at the top to approximately 0.027 inches at the bottom. To maintain the same volume of metal as in the CCFR, the spacers were made shorter; nominally 0.5 inches rather than 0.75 inches.

The 37 rod bundle was assembled with one spacer positioned 1 inch below the top of the cladding and the other 10 inches below the upper grid of the assembly (Fig. 1).

To allow for the even distribution of molten cladding to be poured down the fuel rods, a diffuser plate was constructed. Thirty-seven holes were drilled in the top of a 3 inch diameter solid aluminum cylinder in the proper hexagonal pattern, with larger corresponding holes drilled in the bottom. Each of the 37 ceramic rods would fit loosely into a hole in the bottom of the aluminum, so the molten cladding, when poured onto the top of the cylinder, would be distributed evenly into the 37 holes and down the corresponding fuel rods. (Figure 3 shows the experimental set up.)

To model the GCFR accident situation as closely as possible it was desirable to operate the experiment at temperatures which would preserve the same final liquid to solid cladding ratio as in the GCFR. The cladding from the core region of the GCFR, comprising 65% of the total cladding volume was assumed to be at an average temperature of 3000°F ; and the blanket cladding, comprising 35% of the total was assumed to be at 1070°F . Assuming an adiabatic mixing of these two components, a final composition of approximately 60% liquid and 40% solid at 2498°F was calculated. In order to preserve these fractions in the experimental situation it was determined that the blanket fuel rods could be started at 68°F and the molten cladding (a total of 7.3 pounds) could be poured at approximately 480°F . To ensure that this molten temperature was maintained while the lead-tin passed through the diffuser, the aluminum cylinder and surrounding cup were wound with a nichrome heater to maintain a temperature of 480°F , as indicated by a thermocouple imbedded in the aluminum cylinder (Fig. 3).

The various components of the experimental assembly were positioned with clamps, and an 80 mm pyrex tube was placed around the fuel bundle. When the diffuser and the molten lead-tin, heated in a stainless steel beaker, reached 480°F, and the pyrex tube was preheated with a torch to prevent cracking, the apparatus was ready for the pouring.

The molten alloy was poured rapidly into the diffuser cup and quickly ran down into the fuel assembly. Much of the molten material (about 60%) flowed out the bottom of the pyrex tube to solidify in the catcher pan, while the remainder solidified in various locations within the pyrex shield. This pouring procedure was filmed with a slow motion camera for later study (Fig. 4a and 5a,b,c).

After the assembly was allowed to cool down, the pyrex tube was broken away and the rod bundle was cut in half lengthwise with a band saw. Not until this point was it readily obvious what had actually taken place (Fig. 6).

Observations: The descending molten cladding had stripped away most of the blanket cladding above the top grid spacer, but the cladding below this top spacer appeared totally undamaged (Figs. 4 and 6). Close inspection of the top spacer, in cross section, indicated that the flowing cladding had clogged the spacer in most areas after melting through some or all of its thickness near the periphery of the bundle (Fig. 6). It appeared that the remainder of the molten cladding spread outward at the top spacer and flowed down the inside of the glass tube in six streams corresponding to the six sides of the assembly, where there was the greatest space between the hexagonal bundle and the cylindrical glass tube (Fig. 5).

In the GCFR the particular molten cladding motion observed here could not occur due to the close fitting hexagonal shroud which surrounds each assembly. It is, therefore, not known exactly what the behavior of the cladding would be if prevented from flowing down the outside of the assembly. It may, for example, melt the top spacer away completely and flow through, or it may solidify within the assembly.

In short, this initial experiment was inconclusive in testing the question at hand. It did, however, prove the feasibility of the manufacturing and experimental techniques used, and indicate the types of changes that must be employed in the next experiment in order to obtain more conclusive results, which includes preventing the overflow at the grid spacers.

Physical Properties

Certain physical properties are of interest in the modeling of cladding motion and fuel motion. Many of these have been programmed into simple functions to be used in numerical models. The codes may call up functions which will then calculate the parameter for the condition of "current" temperature, pressure, or other variables.

In the experimental modeling, lead-tin (50/50) alloy is used to model stainless steel and Al_2O_3 is used to simulate UO_2 rods. The following parameters are used in simulating conditions for the test

	Stainless Steel	Pb/Sn*
heat capacity, C_p (cal/g-C)	0.12 (0-100C) ¹	0.051 (16-183C) 0.046 (liq 216-300C)
latent heat of fusion, λ (cal/gm)	76.7 ²	12.8 (183-216)
thermal conductivity, k (cal/cm-sec-C)	0.0372 (100C) ¹ 0.0500 (500C) ¹	0.111 (54C)
density, ρ (gm/cm ³)	8.0 ¹	8.89 (20C)
viscosity, μ (poise)	0.062 ⁵	0.0127 (350C)
liquidus temperature T_l (C)	1397 ¹	216
solidus temperature T_s (C)	1371	183
$\alpha = k/c_p$ (calc) (cm ² /sec)	0.040 (93C) ³ 0.0516 (727C) ³	0.250
c/λ (calc) (C)	1.56×10^{-3}	3.91×10^{-3}

(1) Metals Handbook, 8th Ed., Vol. 1
p. 423

(2) from Bob Bergeron's Report

(3) LMFBR Handbook, p. 316SS-14

(4) calculated from data given

(5) from Dave Weber at ANL

* All data on 50/50 Pb-Sn solder
from: Metals Handbook, 8th
Edition, Vol. 1, p. 1064.

As can be seen the α for Pb/Sn is five to six times that for stainless steel which means the heat is transmitted faster - reaches equilibrium fast. The c/λ ratio shows Pb/Sn over twice that of stainless steel. The effect is to require a larger fraction of the heat available in the molten material to bring the solid material to the incipient molten condition. That coupled with the higher α which involves how much of the solid material takes part in the partition of heat explains to some extent the larger amount of freezing experience in the test that was calculated.

Other simulant materials will be investigated to improve the experimental modeling. Numerical modeling will attempt to improve our understanding of the important parameters.

Task 2: Molten Clad Motion Simulation in an Electrically Heated Array of Elements.

(Schmid and Weber). Materials were received for the shaped power heater elements. These included aluminum tubes ($\frac{1}{16}$ in. ID, $\frac{1}{8}$ in. OD for the heater core and $\frac{3}{16}$ in. ID, $\frac{1}{4}$ in. OD for the insulating sheath); Nichrome wire and ribbon; and Pb/Sn alloy tubing - 6 ft. long, 0.255 in. ID and 0.305 in. OD. The current design uses 0.028 in. Nichrome wire wound with a variable pitch on the core. The wire is held in place and insulated with Saureissen cement-No.1. The cement also provides a bond with the outer insulating sheath. The Pb/Sn "cladding" is drawn onto this heater unit in the manner developed for Task 1. No units have been completed.

Task 4: Incorporation of Routines and Data for Numerical Modeling. (Wehner and

Chang). The functions and data used in SAS and LIFE have been programmed onto our computer. Values for parameters used in our numerical modeling can be obtained as a function of temperature, pressure, etc. as required by the modeling codes.

One of the students is working with the ANL staff to incorporate the SAS-3A-GAS program on the Berkeley CDC 7800 machine. Parts of the code will be put on the NU-CDC 6400.

Task 5: Calculational Model for Cladding Motion (Chu). The model for melting

and freezing of a molten mass of metal falling through a coolant channel is being refined. Simple experiments are planned using single rods to check the model.

Task 6: Calculational model for Fuel Failure and Motion (Wehner).

No progress. Work devoted to Task 4.

Fig. 1 The assembly process for the blanket bundle. Grids are located seven (7) inches and 17 inches from the top of the elements. The upper six (6) inches of the 0.25-in. Al_2O_3 "elements" are bare, the lower 18 inches are clad with Pb/Sn (50/50) alloy 0.020-in. thick.

Fig. 2 The grids are cast of Pb/Sn alloy. On the left is an as cast part, the center is the partially assembled mold, and a finished grid-spacer is on the right.

Fig. 3 The experimental setup prior to the run. The upper insulated cup distributed the molten alloy over the element bundle contained in a round glass tube.

Fig. 4 Assembly after the run.

Fig. 5 Three views around the assembly showing that the main flow was around the bundle.

Fig. 6 Longitudinal section through the bundle. Some melt through occurred at the outer edges of the upper grid and the cladding was stripped above the grid.

Milestone ChartProgress on Tasks

- Task 1 Pouring Experiments (proposal Task 11,12)
- Task 2 Electrically Heated "Fuel Element" Cladding Motion Experiments (proposal Task 13,14)
- Task 3 X-ray monitored Cladding Motion Experiments (proposal task 15)
- Task 4 Adaption of Current Codes and Data for (proposal tasks 1,2,3)
- Task 5 Calculational Model of Cladding Motion (proposal tasks 4,5)
- Task 6 Calculational Model for Fuel Failure Mode and Location (proposal tasks 6,7,8)
- Task 7 Combined Model with Reactivity Feedback Effects (proposal tasks 9,10)