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PRELIMINARY RESULTS OF THE
LOSS-OF-COOLANT HEAT TRANSFER STUDY
FOR N REACTOR

MAY 1971

PREPARED FOR
THE UNITED STATES ATOMIC ENERGY COMMISSION
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PRELIMINARY RESULTS OF THE LOSS-OF-COOLANT
HEAT TRANSFER STUDY FOR N REACTOR

by A. M. Sutey, D. E. Fitzsimmons, and R. E. Collingham

Driver fuel cladding, process tube and graphite temperatures were experimentally simulated with an electrically heated test assembly to establish the rate of radiation heat transfer from the fuel to the process tube following a loss-of-coolant incident in the N-Reactor. This information is necessary as supporting data and verification for the analytical description of such an incident.

The available results of the first three of a total of six experiments are presented herein. These results have been analyzed only in a preliminary fashion. Nevertheless, these results are suitable to allow DUN to evaluate, modify, and calibrate the MELT Code which is used to analytically describe the loss-of-coolant incident in N-Reactor. Complete results and details of this study will be presented in a program summary document which will be provided at a later time.

The test assembly used in this study consisted of a simulated outer surface of an N-Reactor fuel surrounded by an actual process tube, which was in turn surrounded by graphite. Each simulated fuel surface consists of Zircaloy which has been autoclaved by DUN personnel to adequately approximate the surface condition of N-Reactor fuels. A sketch of a typical test element is presented in Figure 1, which shows the locations of temperature monitors and voltage taps.

Considerable effort was made to ensure that the test assemblies used in this study simulated the surface characteristics of N-Reactor fuel. The low temperature emissivity of each simulated fuel piece was measured via a radiometer both before and after it had been subjected to the transient loss-of-coolant simulation. Also, the low temperature emissivity of several N-Reactor nonirradiated fuels were obtained with the radiometer. In this manner, a comparison of the emissivity of actual fuels and the simulations used in this study was made. Such a comparison will be most valuable in the application of the results of this study to N-Reactor fuels.

FIGURE 1. Sketch of Typical Test Element

In this study, temperatures of the simulated fuel cladding and process tube were set at 500 °F before the transient, whereas, graphite temperatures were set at 1000 °F. Superheated steam at 550-650 °F was allowed to flow at a low rate through the test assembly. At the start of the transients, a constant electrical power was supplied to the simulated fuel cladding for a period of at least three minutes or until fuel cladding temperatures exceeded 2000 °F. The magnitude of the power level supplied to the fuel cladding was estimated to provide temperature transients typical of actual N-Reactor fuels during a loss-of-coolant incident. Temperatures of the simulated fuel cladding and process tube generally increased to near 2000 °F and 1400 °F, respectively, whereas, graphite temperatures were maintained near 1000 °F. The resulting temperature transients were used to establish the transient radiation heat transfer rate or "emissivity" from the simulated fuel cladding to the process tube.

The run details for the experiments which have been analyzed thus far are presented in Table I.

Typical heat transfer results obtained for the simulated loss-of-coolant transients of this study are presented in Figures 2 through 8. Simulated fuel cladding and process tube temperatures, transient radiation factors and hydrogen evolution data are presented versus time in Figures 2-4, respectively, for experiment 347-01. Temperature and radiation factor results are presented at various axial and circumferential locations along the test assembly surface.

As shown in Figure 2, the temperature of the fuel cladding increased rapidly from 500 to 1700 °F, but leveled out in the range of 1800 - 1900 °F. The temperature of the process tube increased at a much slower rate and leveled out in the range of 1300 - 1400 °F. In the early stages of the transient, conduction and convection heat transfer mechanisms between the fuel cladding and process tube were unable to accommodate the energy input to the fuel cladding. Consequently, the fuel cladding experienced a rapid increase in temperature commensurate with the heat capacity of the simulated fuel cladding. However, as the temperature of the fuel cladding surface increased, the net radiation heat transfer from the fuel cladding to the process tube began to accommodate the energy input to the fuel. In the range of 1800 - 1900 °F the rate of energy radiated from the fuel to the process tube was nearly equal to the energy input to the fuel, and thus, the temperatures of the fuel cladding and process tube leveled out. Similar results are shown in Figures 5 and 7 for experiments 347-02, and Trial No. 2, respectively.

In Figure 3 transient radiation heat transfer factors are presented which correspond to the temperatures in Figure 2. Radiant heat transfer from the simulated fuel to the process tube can be described as

$$\phi_R = \sigma \bar{F}_{12} (T_{\text{Fuel}}^4 - T_{\text{Process Tube}}^4) \text{ where } \bar{F}_{12} \text{ is the overall radiation factor.}$$

The radiation factors in Figure 3 were calculated over various time increments during the transient via a heat balance on the fuel. The analysis included appropriate conduction, heat capacity, generation and radiation heat transfer

TABLE 1. Experimental Run Details

Test Assembly	Average Power Input			Steam Flow Rate Lb/Hr	Total Elapsed Time Sec	Final Temperature Conditions			Hydrogen Sample	Test Assembly Details			
						Simulated Driver Fuel Cladding °F	Process Tube °F	Graphite °F		Length In.	Clad- ding O.D. In.	Wall Thick- ness In.	Process Tube I.D. In.
Trial Tube No. 2	8.68	29,600	31,700	2	169	1940	1330	1010		18	2.406	.060	2.700
347-01	8.33	28,400	27,500	2	182	1875	1340	995		20	2.406	.060	2.700
347-02	8.33	28,400	27,500	2	180	1880	1310	1002		20	2.406	.060	2.700

Note: In all cases the initial driver cladding and process tube temperature was 500 °F whereas, that of the graphite was 1000 °F.

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FIGURE 2. Transient Temperatures - Experiment 347-01

FIGURE 3. Transient Radiation Factors - Experiment 347-01

FIGURE 4. Hydrogen Evolution - Experiment 347-01

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terms which will be described in the final report. The calculations were made assuming that heat transfer due to convection to the steam and heat evolved via chemical reaction were negligible. Results are not presented at times less than approximately 50 seconds. Because of the rapid temperature rise of the fuel cladding, response time of the surface thermocouples limited use of the calculated $\bar{F}_{12}$ values to times greater than one minute. The slightly higher $\bar{F}$ factors at early times in the transient are not considered to be real, but are the result of the aforementioned effects. At times greater than one minute into the transient, the heat transfer phenomena are radiation controlled and the calculated $\bar{F}$ factors are most accurate. Additional minor corrections will be applied to the radiation results; however, the results in their present form are satisfactory for preliminary use by DUN.

Results in Figure 3 and similar results in Figures 6 and 8 show that the overall radiation factor had a value near 0.7 for the duration of the experiments analyzed thus far. The radiation factor was not greatly dependent either on temperature in the range 1650 - 1950 °F, nor on elapsed time. Once fuel cladding temperatures leveled out near 1800 - 1900 °F, a very slight increase in $\bar{F}_{12}$ was noticed. This may be the result of a very small buildup of ZnO_2 caused by metal-water reactions; however, no significant changes in the radiation rate can be attributed to formation of oxide thickness.

In Figure 4, the volume of H_2 formed during the experiment is presented. Measurable quantities of H_2 began to appear near 100 seconds into the transient and increased to a maximum of approximately .32 liters at stp (.0143g-mole H_2) at the end of the transient. Consequently, the heat evolved due to chemical reaction was less than .3% of the electrical heat supplied to the simulated fuel and therefore, was neglected. No attempt was made to physically measure the thickness of the oxide which was formed.

Assuming that the simulated driver fuel cladding and the process tube are gray bodies having a view factor of 1.0, the experimental radiation factor (Gray Body Shape Factor) can be written

$$\bar{F}_{12} = \frac{1}{\frac{1}{\epsilon_1} + \frac{A_1}{A_2} (1/\epsilon_2 - 1)}$$

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FIGURE 5. Transient Temperatures - Experiment 347-02

FIGURE 6. Transient Radiation Factors - Experiment 347-02

FIGURE 7. Transient Temperatures - Experiment Trial No. 2

FIGURE 8. Transient Radiation Factors - Experiment Trial No. 2

If we also assume that the emissivities of the Zircaloy process tube and the Zircaloy simulated fuel cladding are equal, we have,

$$\epsilon = \frac{[1 + (d_1/d_2)]\bar{J}_{12}}{1 + (d_1/d_2)\bar{J}_{12}} = \frac{1.89 \bar{J}_{12}}{1 + .89 \bar{J}_{12}} \quad (1)$$

where ϵ is the emissivity. Calculated emissivity values using the experimental $\bar{J}_{12}$ values are presented in Table II and are compared with low temperature emissivities obtained with a radiometer. Low temperature emissivities were obtained both before and after each transient experiment.

As shown in Table I the experiment emissivities based on transient $\bar{J}_{12}$ values at times greater than one minute vary from approximately .79-.87 for the experiments analyzed thus far. These values compare reasonably well with the .74 low temperature emissivity values which were obtained with a radiometer after the experiments. It is recommended that the

TABLE II. Experimental Emissivities

Test Assembly	Results Obtained From Loss of Coolant Experiment		Low Temperature Measurements via Radiometer	
	$\bar{J}_{12}$	ϵ Equation 1	ϵ Before Experiment	ϵ After Experiment
Reference			.43	
Trial No. 2	.67-.78	.79-.87		
347-01	.67-.75	.79-.85	.61	.74
347-02	.66-.77	.79-.86	.56	.74
347-04			.57	.81
347-05			.46	.71-.85
347-06			.50	.82

NPR Fuel Samples

Sample No. 1

Nonirradiated, 12 in long, autoclaved inner shell of new fuel obtained from 333 Bldg. - DUN Fuels Fabrication

.40-.42

Sample No. 2

Nonirradiated 26 in. long outer shell of Mark IV fuel which was exposed to temperature and flow of N Hydraulics Loop (100-D) - Cleaned & decontaminated condition

.39

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experimental emissivities obtained during the loss-of-coolant experiment are used for transient high temperature calculations. Nevertheless, the low temperature emissivity numbers do provide considerable insight and comparison of radiation properties of both the simulated and actual fuel samples. As shown in Table II, the low temperature emissivities of the simulated fuel samples increased due to exposure to the loss of coolant transient. Before the experiment the simulated fuel samples had low temperature emissivities ranging from .4 to .6 and their surfaces were very black and shining. However, after being exposed to the very high temperature conditions during the loss-of-coolant experiments, the simulated fuel samples had low temperature emissivity values ranging from .71 to .85 and had dull black surfaces. Consequently, the results obtained thus far indicate that radiation heat transfer characteristics of the simulated fuel actually improved during loss-of-coolant experiment.

It should be noticed that new nonirradiated fuel has a low temperature emissivity of approximately .4. However, after fuel has been exposed to reactor conditions, it is possible that the emissivity of the fuel may increase. In fact, it is possible that the radiation characteristics of the fuel may be improved merely by exposure to high temperature and flow conditions typical of N-Reactor. It is recommended to obtain the low temperature emissivity of a nonirradiated fuel piece which has been operated in the N Hydraulics Loop at 100-D. Such a fuel piece should not be cleaned or decontaminated before low temperature emissivity measurements can be made. Such cleaning could destroy any dull surface characteristics which may be beneficial from a radiation heat transfer standpoint. This information will certainly be valuable to better establish in-reactor emissivities prior to a loss-of-coolant incident.

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