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PROGRESS REPORT

SNAP AEROSPACE SAFETY PROGRAM

JANUARY-MARCH 1965

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AEC Research and Development Report

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SNAP AEROSPACE SAFETY PROGRAM
JANUARY-MARCH 1965
(Title Unclassified)

By

R. L. DETTERMAN

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I. PROGRAM SUMMARY

A. REENTRY AND ABORT STUDIES

1. Reactor Disintegration Projects

Analysis of the data obtained from the heat-lamp test of the coolant pipe of the RFD-1 flight-test model was completed. The value of the thermal conductance from the pipe wall to the thermocouple was found to be of the same order of magnitude as the conductance previously calculated by fitting the flight-test data with a postulated constant value of the heating ratio, F_q .

Ling-Temco-Vought (LTV) completed the wind tunnel test portion of the SNAP 10A-Agena aerostability experiments. Lockheed Missile and Space Company (LMSC) completed the aerostability study portion of this project. The results of the test and the associated study were being analyzed at the close of the reporting period.

The development plan for the Reactor Ablation-Disintegration Experiment (RADE) tests, which will be conducted at the NASA-Ames Research Center, was approved by the AEC. Fabrication of the test models to be used in the tests was nearing completion. A preliminary evaluation of the effects of NaK on the RADE wind tunnel facility was completed. The results of this study were being summarized.

A thermal analysis of the NaK pipes, pump, and the reactor was conducted to determine the effects of NaK on the SNAP 10A disintegration. Runs were made on an analog computer for the three cases of: (1) NaK flowing in the system, (2) NaK in the system but not flowing, and (3) no NaK in the system. Heating rates were used for two cases: (1) 30-degree angle of attack with one NaK downcomer pipe along the stagnation line, and (2) vehicle rolling with alternate heating of each NaK pipe. It was found that,

except for the filler pipes, none of the pipes would melt while NaK is flowing inside. When the flow stops, the pipe walls would heat rapidly and melt. There would be comparatively little difference between the cases of nonflowing NaK and no NaK in the system. The effect of the vehicle rolling would be to delay melting of the pipes at the sides of the reactor. The pipe across the top would, however, melt first in both reentry mode cases studied.

2. Fuel Reentry Burnup Projects

Trajectories were calculated for a SNAP 10A fuel rod and variously sized fragments of fuel released at a 400,000-ft altitude. The results will be used for evaluating possible consequences of high-altitude disassembly.

Maximum surface temperatures attained by a reentering SNAP 10A fuel rod were calculated as a function of release altitude. The three attitudes considered were cross-axial spinning, end-over-end tumbling, and random tumbling. The results indicate that fuel element burnup is enhanced for the tumbling rods as opposed to the spinning rods. The difference, however, is not substantial.

A first solution (neglecting heating effects due to surface oxidation) was obtained for an unclad SNAP 8 fuel rod released from an altitude of 250,000 ft. Aerodynamic heating was sufficient to completely ablate the rod within 75 sec after release (218,000 ft). Surface melting occurred at 62 sec after release.

3. Fuel Properties Project

The thermophysical properties of SNAP fuel were under investigation to provide information which is essential to the establishment of an accurate model for ablation during orbital reentry.

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During this quarter, a total of fifteen electrical resistivity tests and six thermal diffusivity measurements were made on SNAP fuel material. As a result, curves were established to represent these two properties as a function of temperature. Hydride compositions studied were $H/Zr_{eff} = 1.55$ and $H/Zr_{eff} = 1.90$.

Work on the kinetics of oxidation and dehydriding of the fuel involved the preparation of fuel samples for testing. Thirty pairs of hydrided (average $H/Zr_{eff} = 1.828$) and non-hydrided samples were prepared and preliminary experiments were performed.

Total normal emittance measurements of SNAP 10A core vessel material (321 stainless steel) were completed. Values were obtained to 2000°F on samples which were oxidized to simulate the orbital and RFD-1 reentry transients.

4. Abort and Post-Reentry Projects

The Series III, 100-ft drop tests of 7 test reactor vessels onto a reinforced concrete pad were completed. The results of the test series were analyzed and are summarized in Section V. The more severe fracture and disassembly of these test vessels, as compared to the Series II models (reported in the previous period), verified the improved impact disassembly characteristics obtained through both the internal and the external modifications. (These modifications are described in Section V.)

B. NUCLEAR STUDIES

1. Reactor Transient Projects

a. SNAPTRAN-1, -2

The coupled step transient tests were completed at the NRTS in Idaho. Data from all of

the tests were received at AI and were reduced and analyzed. The results of these analyses are summarized in Section VI. The temperature coefficients obtained lie in the range of -0.108 to -0.158 $1/^\circ F$.

The SNAPTRAN-1 impulse tests were begun at the IET in Idaho. In nine of the tests, which were performed by firing drum A, the reactor was at an initial power of less than 50 mw and the reactivity ranged between \$1.00 and \$2.42. In six additional single drum tests, the reactivity input was \$2.40 and the initial reactor power ranged between 1 and 40 w.

b. SNAPTRAN-3

Additional fuel sections recovered from the SNAPTRAN-3 experiment were examined to determine the hydrogen gradient and fission product density. Rupture areas in the cladding were also examined.

In the fuel material examined, although there was no noticeable radial hydrogen gradient, the longitudinal gradient ranged from $H/Zr_{eff} = 1.9$ to $H/Zr_{eff} = 1.4$. Autoradiographs were made of a cross section of the blistered fuel rod. The associated fission density was found to increase sharply in the region of the blistered area. Rupture areas of fuel element cladding were also examined and found to be typical of short-term burst tests.

c. Supporting Experiments

The coolant channel mockup for the water boiling study was assembled and the initial experiments were begun. The results of these experiments to date are summarized in Section VI.

2. Critical Configuration Projects

The generalized parameter study of the effectiveness of geometry changes, poison addition, and end reflectors in SNAP 10A cores to

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ensure subcriticality in water was continuing. Calculations of core diameter and core length changes as a function of radial reflector thickness for constant reactivity in the operational environment were completed.

The parameter study was extended to include the effect of 1.5-in. BeO end reflectors. Curves of the reactivity effect which would result from the various geometry changes studied thus far were being plotted.

The effect on the spectral temperature coefficient resulting from gadolinium poison on the SCA-4 fuel elements was calculated. For an optical thickness of 0.3 ($\Sigma_a t$ at 0.025 ev), the calculated coefficient is reduced from -0.03 to -0.004¢/°F in the beryllium-reflected SCA-4A and from -0.04 to -0.018¢/°F in the water-flooded SCA-4B. The measured prompt axial expansion coefficient is -0.04¢/°F. Thus, gadolinium poisoning to this level reduces the overall prompt temperature coefficient from -0.07 to -0.044¢/°F and from -0.08 to -0.058¢/°F in the SCA-4A and SCA-4B assemblies, respectively. Lower poison concentrations affect the coefficients less.

A two-dimensional DDK calculation for the SNAPTRAN-3, water-reflected model was

completed. The calculated excess reactivity of \$3.90 compares with the \$3.50 excess reactivity determined in the water-reflected SCA-4B experiments.

3. End-of-Life Shutdown Project

The development plan for the end-of-life natural shutdown studies was approved by the AEC. The initial experiments were begun.

C. DISPOSAL STUDIES

The initial investigation of the safety potential of basic disposal methods and of the significance of safety features which might be incorporated in core designs was completed. The disposal methods are orbit augmentation, controlled reentry, and in-orbit destruct. Core safety features include end-of-life shutdown, inherent subcriticality in water, design for early reentry disassembly, and design for intact reentry. It was concluded that: (1) inherent subcriticality in water and end-of-life shutdown are highly desirable and should be pursued vigorously, (2) design for early disassembly is preferable to intact reentry, (3) destruct devices should be developed, (4) ablation particle characteristics should be established, and (5) the practicality of boost and de-orbit devices should be investigated.

II. REACTOR DISINTEGRATION PROJECTS

A. EXPERIMENTS

1. SNAP 10A-Agena Aerostability Tests

Ling-Temco-Vought (LTV) completed the wind tunnel test. The results of the test were being analyzed. The final report was scheduled to be completed in the next reporting period.

Lockheed Missile and Space Company (LMSC) completed the aerostability study. The scope of this study included: (1) performing aerodynamic

consultation for the LTV wind tunnel test, (2) determining failure modes of SNAP 10A-Agena systems, (3) defining a range of initial conditions and determining the attitude history and the trajectories of reentering SNAP 10A-Agena configurations, and (4) providing aerodynamic characteristics of the SNAP 10A-Agena system through the complete angle-of-attack range including possible trim points. The analysis of data obtained from this study was in progress

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Figure 1. SNAP 8 RADE Destruct Model Components

and the final report was scheduled to be completed in the next reporting period.

2. Reactor Ablation-Disintegration Experiment (RADE)

Fabrication of the test models to be used in the RADE was nearing completion. The hardware consists of five models: (1) one calibration model with a SNAP 10A, a SNAP 8, and a hemispherical head, (2) two SNAP 8 destruct models, and (3) two SNAP 10A destruct models. The destruct models will consist of the appropriate vessel configuration and will simulate the SNAP 10A and SNAP 8 internal geometry, respectively. Figures 1 and 2 are photographs of the SNAP 8 destruct model shown disassembled and assembled, respectively. Essentially, the vessel dimensions are half-scale but the wall and upper grid plate thicknesses are full-scale. Zirconium-hydride rods will be used to simulate the fuel rods in both reactor models.

An analysis was in progress to determine the requirements for cooling the calorimeters (instruments) to be used on the calibration models. These calorimeters, which will be made of copper, will have the same external configurations as the reactor models, and they must be internally cooled to keep them from

melting while the local heat rates are being measured. It was found that design changes in the internal flow baffles are advisable to keep the calorimeters below their rated temperature of 400°F. These changes consist in making the baffle fit more closely to the inner surface of the top heads of the models, leaving approximately a 0.1-in. gap for water flow. If this is done, the calorimeters can be kept within the safe temperature limit with a reasonable flow of water.

3. NaK Effects on a Wind Tunnel Facility

A preliminary evaluation of the effects of NaK on the RADE wind tunnel facility was completed. The results of this study, which were being summarized, encompass such factors as energy release from burning NaK, the pressure generated by the NaK, the heat transfer, corrosion, handling, and cleaning of the facility.

B. ANALYSIS

1. Review of RFD-1 Flight-Test Data

The study of the effects of variations in the methods of treating thermal emissivity in the calculation of transient temperatures in the coolant pipe was completed. Thermal networks were devised with and without internal radiant

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energy reflection. The network with internal radiant energy reflection is complex and was positively checked out by comparing it with the simpler case of no reflection. Computations were performed with emissivities of 0.0, 0.3, and 1.0. The cases of 0.0 and 1.0 correspond exactly, with and without reflection, as would be expected. For the emissivity of 0.3, the calculated temperatures for typical conditions are nearly the same, with and without internal reflection of radiant energy. As a result of this effort, an equivalent thermal resistance between the thermocouple and the pipe may be determined and appropriate corrections made to the flight-test data.

The analysis of the data from the heatlamp test of the NaK pipe was completed. The value of the thermal conductance from the pipe wall to the thermocouple was found to be of the same order of magnitude as the conductance that was calculated last August by fitting the flight-test data with a postulated constant value of the heating ratio, F_q .

2. Effects of NaK on SNAP 10A Disintegration

A thermal analysis of the NaK pipes, pump, and the reactor was conducted using an analog computer. An analog model of the SNAP 10A NaK flow system was run successfully. Runs were made for cases of NaK flow as determined by heat flow in the pump thermoelectrics, NaK in the pipes but not flowing, and no NaK in the pipes. External heating rates were used for two cases: (1) 30-degree angle of attack with one NaK downcomer pipe along the stagnation line, and (2) vehicle rolling so that each NaK pipe is heated alternately in a cyclic manner. It was found that none of the pipes will melt while the NaK is still flowing, except for the filler pipes which do not have moving NaK inside them. When the flow stops, the pipe walls heat rapidly and melt. There is comparatively

little difference between the cases of nonflowing NaK and no NaK in the system. The effect of the vehicle rolling is to delay melting of the pipes at the sides of the reactor, but the pipe across the top melts first in both cases.

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Figure 2. SNAP 8 RADE Destruct Model
(Assembled)

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3. Wind Tunnel Data Analysis

The study to ascertain the correlations of heating rates at several locations on the SNAP 10A model at the several tunnel settings was completed. It was concluded that, except for some locations where shock waves and wakes impinged on the model, the use of the heating factor, F_q , invariant with tunnel setting, was justified.

The calculations of the tunnel flow conditions and corrected heating rates on the calibration spheres were completed. The results were being analyzed.

A study of the results of calculations of the flow in the tunnel during the wind tunnel test series was completed. It was found that the actual altitudes simulated in the tunnel were within 8,000 ft of those quoted previously.

4. Development of Basic Methods

The coding errors in the HYHEAT-2 code were corrected, and a sample run that was made for a two-dimensional flow problem appeared to be satisfactory.

The Cornell bow-shock code was revised to make it operable with the AI computing system.

Work on the TAP-3 code was resumed with the objective of getting the deck ready for file. A shortage of memory space with the code in its present form will require correction before the code can be converted to the new computing system expected to go into effect later this year.

The six-degree-of-freedom code was made operational. The program will continue to be improved as new computational methods are developed.

III. FUEL REENTRY BURNUP PROJECTS

A. EXPERIMENTS

The test plan for the forthcoming fuel arc-jet tests was approved. A tabulation of tasks required for the final development and preparation was being prepared. The use of ceramic end pieces on the cross-axial cylindrical specimens and the use of grooves to enhance ignition of the fuel were being studied.

The use of a laser shadowgraph to study the flow field about a fuel specimen in the arc-jet was being considered. Dr. Bomelburg of NAA-LAD was preparing the specifications for this equipment.

The fuel rod requirements for the Reactor Ablation-Disintegration Experiment (RADE) were determined. The material was requisitioned and appropriate planning, consistent with the schedule for the RADE, was made.

B. ANALYSIS

Trajectories were calculated for a SNAP 10A fuel rod released at an altitude of 400,000 ft and for variously sized fragments of fuel released from the same altitude. The results will be used to evaluate the possible consequences of disassembly at high altitudes.

Maximum attained surface temperatures for a reentering SNAP 10A fuel rod were calculated as functions of release altitude. Three attitudes were considered: (1) cross-axial spinning, (2) end-over-end tumbling, and (3) random tumbling. The results are shown in Figure 3. These results are pertinent for a fully catalytic fuel surface. Also, the assumption of instantaneous crack propagation through the fuel material (simultaneous cracking for all fuel increments) was made. The results indicate that fuel element burnup is enhanced for

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Figure 3. Maximum Surface Temperatures for Reentering SNAP 10A Fuel Elements

tumbling rods as opposed to rods spinning cross-axially. However, the difference is not substantial.

Reentry behavior calculations for a non-spinning SNAP 10A fuel rod with cross-axial heating indicate that melting of the fuel begins within 30 sec after release from 245,000 ft. The amount of aerodynamic heat transferred to the rod in this time, for this trajectory, is about 30% of the total heat transferred up to the point where the amount of heat loss by radiation equals the amount of heat available. The temperature distribution range around the circumference of the rod at the time of melting is about 1800°F. Attempts to estimate or bracket the time between initial fuel melting and complete ablation were being made.

Work was continuing on the SNAP 10A fuel element parametric study. To date, influence coefficients had been derived for the effect of emissivity, specific heat, initial temperature, initial hydrogen concentration, hydrogen diffusion coefficient, hydrogen heat of dissociation, heat of oxidation, fuel thermal conductivity, and q_{cyl} upon the heat necessary to cause initial melting of the fuel element. These

Figure 4. Unclad SNAP 8 Fuel Rod Reentry Behavior (release altitude = 250,000 ft; $W/C_{DA} = 9$)

influence coefficients were being incorporated into one general equation which will yield the heat necessary to ablate a SNAP 10A fuel element for any specified parametric and initial conditions. Further cases will be investigated to determine the influence of fuel element radius.

Cross influence between the various parameters investigated was also being studied. Test problems were being run to determine the accuracy of the parametric equation when various combinations of parameters are changed. A method for correlating the parameters, using dimensional analysis, was being studied.

A first solution was obtained for an unclad SNAP 8 fuel rod released from an altitude of 250,000 ft. The results are shown in Figure 4. All heating effects due to surface oxidation were neglected in this solution. Even so, the aerodynamic heating was sufficient to completely ablate the rod within 75 sec from release (218,000 ft). Surface melting occurred at 62 sec from release.

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TABLE 1
ELECTRICAL RESISTIVITY OF SNAP FUEL
(H/Zr = 1.90 eff)

Temperature (°C)	Resistivity, ρ (μ -ohm-cm)				Temperature (°C)	Resistivity, ρ (μ -ohm-cm)			
	247D-10B	247D-2A	247D-2B	247D-10A		247D-2	247D-5	248C-1B	248C-1A
18	37.42	NC*	NC	37.89	605	NC	107.68	108.11	107.86
135	48.96	NC	NC	49.25	699	NC	126.30	123.97	124.08
233	59.39	NC	NC	NC	603	NC	108.99	108.77	108.44
324	70.51	NC	NC	NC	501	NC	94.49	94.71	94.17
388	70.40	NC	NC	NC	389	NC	79.64	80.61	80.51
457	95.77	NC	NC	NC	595	NC	NC	105.81	105.97
536	93.73	92.42	NC	NC	546	97.20	NC	96.84	97.78
594	108.44	104.75	NC	NC	454	83.60	NC	83.11	87.13
592	107.72	104.14	NC	NC	330	NC	NC	68.57	NC
643	116.16	112.24	113.27	118.05	25	36.80	NC	36.50	NC
695	126.44	122.76	NC	128.20					
608	105.10	107.31	NC	NC					
531	97.41	94.18	NC	NC					
435	NC	81.54	NC	NC					
348	NC	71.53	NC	NC					
18	39.24	37.68	39.89	NC					

*NC = No Contact

TABLE 2
ELECTRICAL RESISTIVITY OF SNAP FUEL
(H/Zr = 1.55 eff)

Temperature (°C)	Resistivity, ρ (μ -ohm-cm)		Temperature (°C)	Resistivity, ρ (μ -ohm-cm)		Temperature (°C)	Resistivity, ρ (μ -ohm-cm)		
	247D-6	247D-1		246D-7A	246D-7B		248C-6	247D-6	247D-8
950	165.78	167.49	866	159.42	NC	908	169.14	165.51	166.30
805	154.98	151.59	735	141.07	144.00	774	152.47	149.40	149.89
722	145.70	144.04	586	125.73	127.87	639	135.73	133.72	132.93
652	138.02	136.24	454	110.35	106.02	517	122.36	124.11	119.54
557	129.58	126.48	326	96.75	97.48	346	99.83	100.72	101.58
461	119.71	115.32	22	65.80	66.50	146	80.55	80.06	80.74
337	104.21	101.43				24	67.47	66.00	67.00
245	93.56	91.57							
143	81.69	80.16							
16	64.45	65.96							

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IV. FUEL PROPERTIES PROJECT

A. THERMOPHYSICAL PROPERTIES

The thermophysical properties studied under this program are electrical resistivity, specific heat, thermal diffusivity, and emissivity. A brief summary of the efforts in obtaining these properties follows.

1. Electrical Resistivity

Electrical resistivity measurements were completed on Zr-10 w/o specimens hydrided to an H/Zr_{eff}^* atom ratio of 1.55 and 1.90.

The data are shown in Tables 1 and 2, and plotted in Figure 5. Results in Figure 5 are an average of eight samples for the $H/Zr = 1.90$ material and five samples for the $H/Zr = 1.55$ material. Electrical resistivity values for the delta-phase material ($H/Zr = 1.55$) vary from $65 \mu\text{-ohm-cm}$ at 25°C to $175 \mu\text{-ohm-cm}$ at 1000°C , while the resistivity of the epsilon phase ($H/Zr = 1.90$) material is $38 \mu\text{-ohm-cm}$ at 25°C and increases to $126 \mu\text{-ohm-cm}$ at 700°C .

2. Specific Heat

The specific heat of the SNAP fuel ($H/Zr = 1.90$ and 1.55) was being determined by means of the electrical pulse-heating technique. Samples used for electrical resistivity measurements are pulsed for specific heat determinations. Resistivity is used to determine the temperature of the sample at any finite time during the pulse. Pulse heating experiments are fast enough so that hydrogen losses from the sample are virtually eliminated over the temperature range of interest.

All the samples of $H/Zr = 1.90$ material had been pulsed; however, the data had not been reduced from the photographs of the oscilloscope

traces. This information will be put into a computer program developed this quarter for calculating the specific heat.

The delivery date for the drop calorimeter to be used for measurements in the beta-hydride region was rescheduled to the last of May. Plans were being made to have the facilities ready to hook up the instrument as soon as it is delivered.

3. Thermal Diffusivity

The thermal diffusivity of SNAP fuel is used to calculate the thermal conductivity by using the following equation:

$$k = \alpha C_p d,$$

where

k = thermal conductivity

α = thermal diffusivity

C_p = specific heat

d = density.

Figure 5. Electrical Resistivity of SNAP Fuel Alloy Hydride

* H/Zr_{eff} equals the atomic ratio of hydrogen to available zirconium atoms. In this report, H/Zr in all cases refers to H/Zr_{eff} .

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TABLE 3

THERMAL DIFFUSIVITY OF SNAP FUEL
(H/Zr = 1.90 eff)

Sample No. 246-D2		Sample No. 248-C3			
Temperature (°C)	α (cm ² /sec)	Temperature (°C)	α (cm ² /sec)	Temperature (°C)	α (cm ² /sec)
661	0.066	662	0.0675	21	0.145
661	0.064	662	0.0670	21	0.142
663	0.065	661	0.0670	202	0.104
683	0.061	660	0.0650	201	0.105
682	0.063	682	0.0662	195	0.107
670	0.065	682	0.0662	192	0.108
652	0.066	682	0.0668	292	0.091
652	0.066	682	0.0665	294	0.092
612	0.070	675	0.0662	295	0.092
605	0.070	675	0.0693	295	0.094
595	0.070	674	0.0662	387	0.082
589	0.070	674	0.0668	391	0.082
588	0.067	653	0.0697	394	0.082
525	0.074	654	0.0670	612	0.068
525	0.075	654	0.0668	620	0.068
525	0.070	612	0.0716	624	0.064
347	0.084	612	0.0670	514	0.077
349	0.082	601	0.0730	510	0.073
354	0.082	601	0.0693	92	0.136
198	0.103	601	0.0690	90	0.139
196	0.105	602	0.0700	87	0.132
194	0.111	558	0.0735	86	0.136
192	0.105	557	0.0735	44	0.143
21	0.140	553	0.0724	43	0.146
21	0.150	502	0.0777	41	0.153
21	0.150	503	0.0781	27	0.154
21	0.148	7	0.151	27	0.153
21	0.140	7	0.146		
96	0.123	7	0.145		
95	0.130	7	0.145		
93	0.128				
64	0.140				
63	0.139				
62	0.128				
44	0.143				
43	0.145				
43	0.145				
43	0.142				

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The thermal diffusivity measurements of H/Zr = 1.90 and 1.55 material were completed. These diffusivity measurements were made in the apparatus described in the previous quarterly progress report (NAA-SR-10797). Diffusivity results are shown in Tables 3 and 4, and plotted in Figure 6. Curves of diffusivity vs temperature for H/Zr = 1.90 decreases more rapidly than those for H/Zr = 1.55 material. The diffusivity of H/Zr = 1.90 is $0.149 \text{ cm}^2/\text{sec}$ at 25°C and falls to $0.065 \text{ cm}^2/\text{sec}$ at 700°C , while the H/Zr = 1.55 material decreases from $0.080 \text{ cm}^2/\text{sec}$ at 25°C to $0.041 \text{ cm}^2/\text{sec}$ at 1000°C .

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Figure 6. Thermal Diffusivity of SNAP Fuel Alloy Hydride

TABLE 4

THERMAL DIFFUSIVITY OF SNAP FUEL
(H/Zr = 1.55 eff)

246-D6		247-D1		246-D7	
Temperature (°C)	α (cm^2/sec)	Temperature (°C)	α (cm^2/sec)	Temperature (°C)	α (cm^2/sec)
26	0.0761	873	0.0471	929	0.0429
26	0.0761	878	0.0448	929	0.0444
26	0.0713	486	0.0494	930	0.0414
120	0.0646	495	0.0475	482	0.0466
220	0.0608	494	0.0498	499	0.0480
222	0.055	392	0.0538	385	0.0490
232	0.0559	393	0.0552	392	0.0476
302	0.0564	395	0.0547	398	0.0457
305	0.0544	292	0.0582	292	0.0547
404	0.0512	290	0.0569	290	0.0494
431	0.0539	243	0.0619	288	0.0571
498	0.0554	239	0.0622	287	0.0534
502	0.0512	235	0.0616	114	0.0662
505	0.0437	102	0.0704	112	0.0630
		100	0.0712	111	0.0594
		98	0.0736	62	0.0655
		58	0.0827	62	0.0734
		57	0.0787	47	0.0708
				47	0.0727
				36	0.0822
				26	0.0690
				26	0.0704

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4. Emittance Studies

Emittance studies on a SNAP 10A core vessel were completed. The objective of this work was to determine the emittance properties of the SNAP core vessel under reentry conditions. Initial studies, reported in the progress report for the previous quarter, were performed on samples machined from 316 stainless-steel bar stock. However, several problems evolved which caused the scope of the study to be changed. These problems were as follows:

1) For the original test procedure, emittance measurements were taken both prior to and after the simulated reentry oxidation. It was found that the oxide layer produced on these samples was nonadherent and could be removed by gentle rubbing. The oxidation of virgin 316 SS samples produced a tight, continuous layer. It was concluded that the early emittance test produced an oxide layer that was not representative of the reentry situation, and that the preoxidation emittance measurements must be deleted.

2) The type of finish as well as roughness of the sample surface affected the emittance as shown in Figure 7. The data show that a rougher surface does not necessarily have a higher emittance.

3) The purified (oxygen-free) argon atmosphere flowing around the sample in the emittance apparatus resulted in the gradual removal of the oxide film. This gave a decrease in emittance with respect to time during emittance measurements.

4) The mass of the 316 SS samples was too great to be heated rapidly enough for the RFD-1 reentry temperature transient, using the existing oxidizing equipment.

The program was altered in such a way that these problems were either eliminated or minimized. To obtain meaningful data as quickly as possible for the impending flight test (FS-4), a spare core vessel of the same material (321 SS) was polished and liquid honed to obtain a surface finish similar to FS-4. Samples, 1 in. in diameter, were then punched from the test vessel. This method of sample fabrication eliminated the need to determine the effect of surface finish on emittance since the finish was similar to FS-4. Also, because these samples were much thinner (0.032 in.), the existing equipment could be used to obtain the RFD-1 reentry temperature transients.

Emittance measurements were taken only after the oxidation was performed and, therefore, the emittance values were representative of actual conditions. The oxide-cleaning effect noticed during earlier emittance measurements was minimized by reaching the measuring temperature in as short a time as possible. The emittance vs time was recorded and the emittance change due to oxide removal was accounted for by extrapolating back to time zero.

Figure 7. Emittance vs Temperature-Effect of Surface Finish

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Figure 8. Schematic Diagram of Equipment Used to Measure Thermal Emittance

A schematic diagram of the emittance equipment is shown in Figure 8. The value measured was total normal emittance (ϵ). This quantity relates the amount of total thermal radiation emitted in a direction perpendicular to the sample surface to the amount of radiation that would be emitted from a black body (perfect emitter) at the same temperature. A radiometer was used to measure the amount of total thermal radiation of both the sample and the black body. The sample positions indicated in Figure 8 are for sample heating (position 2), black body measurements (position 3), and sample measurement (position 1). A sample of the radiometer output is illustrated in Figure 9. The radiation intensity of the black body (I_b) is measured with the sample in position 3, the sample is then quickly moved to position 1, and the radiation from the sample (I_s) is measured. The emittance is then obtained by taking the ratio, I_s/I_b .

Samples were oxidized according to orbital reentry-stagnation pressure, orbital reentry-wall pressure, and RFD-1 reentry-stagnation pressure transients. Emittance measurements were taken at the same temperatures as the oxidation transient end temperatures of 1200, 1500, 1800, and 2000°F. In this manner, emittance values taken at a specific temperature would be the result of the reentry oxide accumulated up to that temperature.

The emittance data pertaining to the actual core vessel obtained during this experiment are contained in Tables 5, 6, and 7. These data were plotted as a function of time and corrected for oxide removal by extrapolating back

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Figure 9. Sample of Radiometer Stripchart Data

TABLE 5
EMITTANCE VALUES FOR 321 SS CORE
VESSEL MATERIAL - ORBITAL
REENTRY WITH STAGNATION PRESSURE

Sample Number	Time to First Measurement (min)	Temperature (°F)	Time After First Measurement (min)	Emittance
7	13	2000	0	0.75
			3	0.725
			6	0.69
			9	0.64
20	15	2000	0	0.771
			3	0.740
			6	0.725
10	17	1800	0	0.66
			3	0.65
			6	0.633
9	18	1500	0	0.36
			3	0.374
			6	0.372
15	17	1200	0	0.320
			4	0.320
			8	0.320

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TABLE 6
EMITTANCE VALUES FOR 321 SS CORE
VESSEL MATERIAL - ORBITAL
REENTRY WITH WALL PRESSURE

Sample Number	Time to First Measurement (min)	Temperature (°F)	Time After First Measurement (min)	Emittance
16	15	2000	0	0.675
			2	0.625
			4	0.600
5	14	2000	0	0.75
			2	0.72
			4	0.70
8	12	1800	0	0.60
			2	0.59
			4	0.60
11	14	1500	0	0.390
			5	0.425
			6	0.435
30	16	1200	0	0.310
			4	0.322
			7	0.330

to the time at which the measuring temperature was reached. These corrected data are contained in Table 8 and are also plotted as a function of temperature in Figure 10. Also contained in Figure 10 are data for nonoxidized 321 and 316 stainless steel.

From this study, the following conclusions were reached:

1) Surface finish is very important in emittance measurements. The type as well as roughness of the finish must be considered.

2) While making emittance measurements at elevated temperatures, it was found that the oxide gradually disappeared from the test surface. The loss of oxide was attributed to decomposition in the oxygen-free argon used in the emittance equipment. A similar behavior should be expected in an ultra-high vacuum.

3) Heat treatment of type 316 SS at high temperatures (1800 to 2000°F), prior to oxidation, changes the character of the oxide film. Such films were nonadherent.

TABLE 7
EMITTANCE VALUES FOR 321 SS CORE
VESSEL MATERIAL - RFD-1 REENTRY
WITH STAGNATION PRESSURE

Sample Number	Time to First Measurement (min)	Temperature (°F)	Time After First Measurement (min)	Emittance
13	10	2000	0	0.55
			4	0.47
			6	0.45
			7	0.42
14	10	2000	0	0.60
			3	0.55
			4	0.53
			6.5	0.50
22	15	1800	0	0.53
			6	0.53
			10	0.54
			14	0.53
4	16	1500	0	0.49
			3	0.50
			7	0.50
3	18	1200	0	0.31
			3	0.31
			7	0.32
			15	0.32

TABLE 8
CORRECTED TOTAL NORMAL EMITTANCE
VALUES FOR 321 SS CORE
VESSEL MATERIAL

Orbital Reentry - Stagnation Pressure				
Temperature (°F)	1200	1500	1800	2000
Emittance	0.32	0.37	0.70	0.81
Orbital Reentry - Wall Pressure				
Temperature (°F)	1200	1500	1800	2000
Emittance	0.33	0.43	0.62	0.78
RFD-1 Reentry - Stagnation Pressure				
Temperature (°F)	1200	1500	1800	2000
Emittance	0.32	0.50	0.53	0.66

B. KINETIC STUDIES

Due to a manufacturing error, considerable difficulty was encountered in the calibration of the automatic pyrometer (Infrascope) mentioned in the report for the previous period (NAA-SR-10797). The calibration, which was completed, indicated that an accuracy of $\pm 10^\circ\text{C}$ may be expected.

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Figure 10. Emittance vs Temperature for Various Reentry Oxidation Transients and Nonoxidized Material

The necessary 30 pairs of fuel samples, both hydrided and nonhydrided, were prepared. The effective H/Zr of the hydrided fuel ranged from 1.818 to 1.833 with an average value of 1.828.

Preliminary experiments indicate that the maximum rate of temperature rise will be somewhat in excess of 3200°F/min using the 15-kw, 10-kc induction unit. This gradient should be sufficient to follow the prescribed transient curve shown in Figure 11.

Concurrent with the oxidation study, the determination of the normal emittance of the samples will be attempted. For this purpose, two automatic pyrometers will be used with one focused on the "black body" hole and with the other focused on the face of the cylindrical sample adjacent to the hole. Thus, the changes in emissivity can be determined as a function of oxidation over the prescribed temperature transients. The values obtained are expected to be more realistic than any heretofore published.

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Figure 11. Sample Temperature vs Time of 5/8-in.- Diameter by 5/8-in.-Long Kinetic Study Fuel Samples

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V. ABORT AND POST-REENTRY PROJECTS

The Series III, 100-ft drop tests of 7 test reactor vessels onto a reinforced concrete pad were completed. The primary objective of this series of tests was to study the validity of two different methods of inducing vessel disassembly.

The first of these methods consisted of adding a small circumferential ring at the top and

bottom of the external vessel wall (see Figure 12). One test vessel without grooves and three with grooves were dropped.

The second of these methods consisted of using the same grooved-type vessels used in previous tests but with 1/8-in. steps machined in six of the outer peripheral dummy elements and in the six dummy internal reflectors (see Figures 13 and 14). Three vessels of this design, each of which had different groove depths, were dropped. The groove radius of 0.002 in. was the same for all the test vessels that incorporated grooves.

The results of the test series were analyzed and are summarized in Table 9. The more severe fracture and disassembly of these test vessels as compared to the Series II models verified the improved impact disassembly characteristics obtained through both the internal and the external modifications.

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Figure 12. Components of Externally Modified Series III Drop Test Vessel

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Figure 13. Modified Dummy Fuel Elements and Internal Reflectors Used in Series III Drop Tests

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Figure 14. Partial Loading of Internally Modified Series III Drop Test Vessel (Showing positioning of dummy elements and reflectors)

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In order to determine the relative fracture behavior of some 400-series steels and high-strength steels such as A-286, as compared to 316 stainless, true stress-true strain curves

were being prepared for these materials from data in the literature. The unit energy for fracture will be calculated using these curves.

TABLE 9
RESULTS OF SERIES III DROP TESTS

Vessel Number	Type Modification	Wall Thickness (in.)	Groove Depth (in.)	Results
31	Internal	0.032	0.015	Longitudinal and circumferential fracture
32	Internal	0.032	0.010	Longitudinal and circumferential fracture; 15 elements displaced from core (see Figure 15)
33	Internal	0.032	0.005	No fracture
34	External	0.032	0.015	Complete disassembly of vessel and core (see Figure 16)
35	External	0.032	0.010	Longitudinal and circumferential fracture
36	External	0.032	0.005	Longitudinal and circumferential fracture; 12 elements displaced from core (see Figure 17)
37	External	0.032	None	Partial circumferential tearing

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Figure 16. Test Vessel No. 34
After 100-ft Drop

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Figure 15. Test Vessel No. 32
After 100-ft Drop

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Figure 17. Test Vessel No. 36
After 100-ft Drop

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VI. REACTOR TRANSIENT PROJECTS

A. SNAPTRAN-1, -2

1. Experiment

The coupled step transient tests which were begun during the previous reporting period were completed. The test data are summarized in Table 10 and supersede those data presented in the report for the previous quarter.

Nine SNAPTRAN-1 impulse tests were performed at the IET in Idaho by firing drum A. The reactor was at an initial power of less than 50 mw. The test numbers and respective reactivity insertions were as follows:

<u>Test No.</u>	<u>Reactivity (\$)</u>
163	1.00
164	1.50
165	2.00
166	2.20
167	2.20
168	2.20
169	2.20
170	2.42
171	2.42

Six single drum impulse tests were run at a reactivity input of \$2.40. The reactor initial power was varied for these runs. The preliminary data were as follows:

<u>Test No.</u>	<u>Initial Reactor Power (w)</u>
173	1
174	7
175	12
176	17
177	30
178	40

Fabrication of all of the energy probes, except one, for the SNAPTRAN-2 destructive test was completed. Additional materials were re-

quired to finish fabrication of the one remaining probe. Completed were four single zirconium-hydride probes, four single 10 w/o uranium-zirconium-hydride probes, six multiple 2.5 w/o uranium-zirconium-hydride probes, two multiple 5 w/o uranium-zirconium-hydride probes, and one multiple zirconium-hydride probe.

The following hardware for the SNAPTRAN-2 destructive test was shipped to the NRTS:

- 1) "A" Drum Shaft Assembly
- 2) "D" Drum Shaft Assembly
- 3) "D" Impulse Drive Assembly
- 4) "A" Impulse Drive Assembly.

The drum shaft holding fixtures and other miscellaneous hardware, including the blast shields used in the checkout of SNAPTRAN-1, were also shipped.

Phillips Petroleum Co. planned to begin assembly of the SNAPTRAN-2 machine in the next reporting period and to perform a mechanical checkout of the drum drive as soon thereafter as possible.

2. Analysis

A review and check of the SNAPTRAN-1 step series test results were made. The data summarized in Table 10 supersede the data presented in the report for the previous quarter. The results from individual transients (peak power, energy at peak power, temperature increase at peak power, temperature coefficient, reciprocal period, and energy coefficient) were being combined into summary plots. A least-squares fitting procedure was being used to determine the best values for the prompt fuel temperature coefficient and the prompt energy coefficient.

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TABLE 10
SUMMARY OF STEP TRANSIENT TESTS

Test Number	Reactivity Insertion (\$)	Peak Power (Mw)	Period (msec)	Energy Release To Peak Power (Mw-sec)	Approximate Total Energy Release (Mw-sec)	Temperature Increase To Peak Power (°F)	Temperature Coefficient (¢/°F)
111	0.485	0.124	6670	2.17	4.8	201	-0.136
112	0.66	0.35	2410	2.48	8.0	217	-0.142
113	0.80	0.76	1020	2.8	3.5	235	-0.119
115	0.91	1.18	340	1.7	4.4	165	-0.137
116	0.96	1.87	152	1.43	3.9	135	-0.118
119	0.99	2.92	50.6	0.61	1.7	63	-0.117
121	1.03	9.2	22.0	0.42	1.2	52	-0.107
124	1.02	8.1	22.0	0.38	1.5	41	-0.111
126	1.06	28.8	12.0	0.68	2.5	70	-0.108
128	1.09	44.0	8.20	0.75	1.8	151	-0.130
131	1.15	126	5.25	1.29	3.0	129	-0.126
133	1.25	301	3.30	1.95	4.5	179	-0.140
136	1.34	495	2.42	2.40	5.9	235	-0.155
138	1.36	650	2.35	3.02	7.0	265	-0.140
140	1.41	770	1.96	3.1	7.0	283	-0.144
142	1.48	1000	1.67	3.7	7.7	316	-0.142
144	1.48	948	1.74	3.43	7.6	294	-0.158
147	1.00	6.0	26.3	0.375	1.2	37	-0.126
149	1.00	5.17	31.4	0.38	0.98	39	-0.117
151	1.03	13.4	17.2	0.47	1.2	51	-0.113
155*	0.29	-	21750	-	-	-	-
157	0.72	0.573	1490	2.91	4.35	262	-0.118
159	1.34	502	2.54	2.44	5.3	222	-0.139

*Corrected power normalization not yet completed

Techniques for treating the digitized data from those energy probes and power channels that are not used in the routine analysis of the experiments were being worked out and will be incorporated into a separate computer program. These data will be used to calculate energy and reactor period as a check on the routine analysis.

It was verified that the electronic noise filter which was used in digitizing the drum position

data on impulse transients 166 through 178 introduced a constant time shift into the data. To verify this, transients 166 and 178 were digitized again without the filter. The drum reactivity calculated from the unfiltered data was then compared with results determined by shifting the original filtered data by 1 msec. The resulting drum reactivity traces agree throughout the transient within a few cents.

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2X
A

2X
B

2X
C

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Figure 18. Cladding Failure Areas (SNAPTRAN-3)

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The agreement between this corrected drum reactivity and the six-group reactivity determined from the power is much better than that obtained using the previously filtered drum data. Although agreement is excellent at peak reactivity on transient 166, the calculated reactivity is about 15¢ below the drum reactivity at the time of peak power.

In order to explain this discrepancy, the following steps were taken: First, the data from transient 164 were requested. This was a \$1.50 impulse test. A well established kinetics model and prompt neutron lifetime is available for this size reactivity insertion. Any disagreement between the six-group reactivity and drum reactivity should then be due to errors in the drum reactivity. Second, an error analysis will be undertaken to estimate the uncertainty in the drum reactivity calibration curves being used.

A computer program was outlined and was being written for use in additional analysis of temperature data from the SNAPTRAN-1 step series. Radial and axial plots of the experimental energy generation will be compared to the theoretical fission density distribution at different times during the transient. The analysis will be used with the data from the super-prompt critical step transients in the time region where heat loss from the energy probes can be neglected. Data from 5 and 10 wt % U energy probes (hydrided and not hydrided) will be correlated. In the previous analysis of the step tests, only data from the 10 wt % U-ZrH_x energy probes were used.

Sample impulse transients to be used as guides for the forthcoming test series were calculated using the SNAPKIN code. The results indicate that the maximum safe reactivity insertion lies between \$3.50 and \$3.80. The

results also indicate that the energy release, and hence the fuel temperature, is strongly dependent on the initial power level. As the limiting reactivity input is approached, it will become necessary to accurately control the initial power level.

Calculations were made to predict the energy release from the SNAPTRAN-2 destructive test. The critical parameters affecting the transient were chosen with suitable associated uncertainty limits to yield a maximum, a minimum, and an expected energy release. The predicted energy releases (sensible heat) are 72, 32, and 46 Mw-sec, respectively.

A reactor transfer function for high-frequency excitations, based on the two-node reactor kinetics equations, was calculated. Two characteristic frequencies are predicted by the model. The predicted frequencies will be compared with the results of the noise analysis experiments as a check on the values of the kinetics parameters.

B. SNAPTRAN-3

During this reporting period, experimental studies were terminated on the evaluation of the SNAPTRAN-3 fuel debris. These data were being analyzed and assembled into a topical report.

Several rupture areas of SNAPTRAN-3 fuel element cladding were examined. The cladding material is chromized Hastelloy-N, 0.015 in. thick. Ruptured areas are shown in Figure 18. Metallographic examination of the failed cladding indicated extensive deformation and transgranular failure. This type of failure is typical of short-term burst tests. The rupture shown in Figure 18c is a tear along the weld seam.

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Figure 19.
Microcracked Region of
Fuel in
Element No. E-26

250X

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Figure 20.
Fuel From Element No. E-26
Showing Large Cracks and
Associated Regions of Low
Hydrogen Composition

250X

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Fuel samples were investigated to determine hydrogen gradients and fission product density. A longitudinal section of the blind end of element No. E-26 was examined for hydrogen content. While it was found that the radial hydrogen gradient was not appreciable, the longitudinal gradient ranged from $H/Zr_{eff} = 1.9$ at the cold end to about $H/Zr_{eff} = 1.4$ at the hot end of the sample. The material in this gradient was heavily microcracked as shown in Figure 19. In addition, there were several macrocracks which had surrounding edges of dehydrated material (see Figure 20). It appears that the overall hydrogen gradient is a function of the temperature profile, with more hydrogen being expelled in the hotter regions. The dissociated hydrogen collected at small defects, causing microcracking as local pressures exceeded the strength of the material. The hydrogen escaped from the rod through these microcracks and subsequent macrocracks.

Autoradiographs were taken on several pieces of fuel. Of particular interest was a transverse section of the blistered fuel rod (E-25). This rod was located in the outer ring of elements and calculations indicated that the fission density in the outer edge of this rod was considerably higher than in the rest of the core. The autoradiographs were made by placing the fuel section directly on X-ray film. Radiation from the decay of fission products in the fuel exposed the film and, upon development, the film showed an optical density gradient proportional to the fission density in the fuel. An optical densitometer was used to "read" the film in arbitrary density units. Both diametrical and circumferential density profiles (see Figure 21 and 22) were measured. These figures indicate that the fission density was considerably higher in the blistered region, and substantiates the theory that the blisters were caused by a localized

high-temperature, high-flux region. Blisters were subsequently formed as the dissociated hydrogen pressure deformed the ductile dehydrated surface layer.

Figure 21. Diametrical Density Profile of Blistered Rod E-25

Figure 22. Circumferential Density Profile of Blistered Rod E-25

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C. SUPPORTING EXPERIMENTS

1. Coolant Channel Mockup Water Boiling Study

a. Experiments

The coolant channel mockup was assembled and the first two experiments were conducted. In the first experiment, the entire coolant channel was immersed in water and the power to the heaters was increased by increments. When the power to the heaters reached 3.5 kw, violent boiling and chugging was noted. At a power of 5.1 kw, the surface temperature within the channel started increasing. This required a power reduction to prevent possible damage to the test apparatus. The experimental results are summarized in Table 11.

In the second experiment, the power to the heaters was 3.1 kw. In this experiment, intermittent chugging and steady boiling was noted. Using the movable thermocouple, an axial temperature distribution was found. This temperature distribution is plotted in Figure 23.

Two additional experiments were run. The frequency of chugging and axial temperature distributions was measured as a function of

4-14-65

7611-0781

Figure 23. Coolant Channel Mockup Axial Temperature Distribution

TABLE 11

TEMPERATURE AND POWER FOR AN IMMERSED COOLANT CHANNEL

Power (kw)	Water Inlet Temperature (°F)	Maximum Surface Temperature (°F)	Remarks
0.70	72	195	
1.02	72	212	
1.30	72	220	
1.86	72	228	
2.61	72	238	
3.48	77	250	Chugging, boiling
3.96	80	258	Chugging, boiling
4.46	82	268	Chugging, boiling
5.12	83	390*	Chugging, boiling

*Maximum temperature recorded before power was reduced.

channel power. In one, the top end of the channel was 5 in. below the water surface. In the other, the water level was 3/4 in. below the top end of the channel. In the first case, steam was expelled from the channel into a water environment. Part of the steam condensed into the water and the rest rose to the water surface. In the case of the partially filled channel, hot water and steam were expelled into an air environment. In both cases, the expulsion took place in spurts.

Following a modification to provide for piping of the distilled water directly to the storage drums, additional experiments were run. In these experiments, the power level was held

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constant and the water height and inlet temperature were varied. Because the water came out of the channel in a spray, it was impossible to determine a chugging frequency by direct counting of water spurts. Instead, the frequency of the oscillations of the outlet thermocouple readings was recorded. It was found that this frequency was the same as the chugging frequency. The frequency was measured for several water levels. The chugging effect was noted at water levels that were below the midpoint of the channel, which is the area of peak heating.

At the close of this reporting period, an experiment was performed to determine the maximum possible heat input to a partially filled channel. The heaters were turned up to their rated power (6.05 kw) and the water level was incrementally reduced. Steady boiling was noted as long as there was more than 4 in. of water in the channel. Below this level, the temperatures in the upper part of the channel increased rapidly.

During the course of this experiment, one of the three heating elements failed. The heating elements were removed and new elements were being installed. Once the new elements are installed, additional experiments will be performed. In these experiments, the channel will be completely immersed in water. Measurements will be made of the heat required to produce incipient boiling as a function of overall water height and as a function of the angle of the channel from the vertical.

b. Analysis

A study was made of the correlation between the surface temperature of the coolant channel mockup and the center temperature of the fuel in a SNAP reactor. The temperature drop from the center of the fuel to its surface is 145°F/kw of channel power. At 3.1-kw channel power,

steady boiling was noted with a maximum surface temperature of 260°F. If a SNAP reactor had been at these conditions, the center fuel would have been about

$$T = 260^{\circ}\text{F} + (145^{\circ}\text{F/kw})(3.1 \text{ kw}) = 710^{\circ}\text{F}.$$

A model was developed that will give the temperature rise of water flowing through the coolant channel mockup. So far, this model is applicable only to a nonboiling case. When compared with experiments, the model may be able to give the threshold power for initiation of boiling as a function of inlet temperature.

An analytical model of the coolant channel mockup was hypothesized for predicting the chugging frequency when the channel is partially filled with water. In this model, boiling is assumed to take place one-third of the distance from the bottom of the channel to the top of the water column. This factor of one-third was determined by analysis of experimental measurements.

Using this analytical model for chugging, two additional analytical models were hypothesized. The first of these gives the amount of water within the channel as a function of time during the chugging cycle. This amount is a function of the inlet temperature, water level, and average reactor power. The second analytical model gives the location of the water within the channel during the chugging cycle. The location of the water is a function of inlet temperature, water level, and average reactor power.

2. Transient Nuclear Test (TNT) Experiment

Some of the AI capsules that were exposed to the TNT destructive experiment were recovered and shipped to the AI hot cell facility at Santa Susana. In this shipment, there were 15 capsules which were largely intact and undamaged.

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None of the 15 were located at the closest-in position to the reactor. Three had been located in the second position, 5 in the third position, and 7 in the farthest-out position. In addition to the 15, several other capsules that were partially damaged were included in the shipment. Some of these may give useful data.

The disassembly of the capsules and the inspection of fuel and of the measuring devices were begun.

VII. CRITICAL CONFIGURATION PROJECTS

A. EXPERIMENTS

MYLAR tape coated with two different concentrations of gadolinium oxide for experiments on intrinsic subcriticality were obtained. Up to three concentrations may be tested on the fuel element cladding; more than this number of concentrations may be tested on the core vessel. The accuracy and uniformity of the coating is expected to allow excellent reproducibility in the water (SCA-4B) and operational (SCA-4C) experiments.

An experimental program was specified to confirm the results of analytical studies of increased gadolinium poison effectiveness in a water environment as compared to an operational environment. The experimental program will require measuring the reactivity effect in the SCA-4A and SCA-4B assemblies of various concentrations of poison on the fuel elements and around the core vessel. Concentrations from 0.0 to $0.3 \Sigma_a t$ (at 0.025 ev) on the fuel elements and 0.0 to $10 \Sigma_a t$ (at 0.025 ev) on the core vessel will be studied. The SCA-4B assembly will be reactivated for these tests.

D. TREAT EXPERIMENTS

Five capsules were shipped to the TREAT (Transient Reactor Test) reactor in Idaho. They were irradiated and were scheduled to be returned to the AI Santa Susana facility for analysis.

B. ANALYSIS

The generalized parameter study of design changes to ensure subcriticality in water was continuing. Calculations of core diameter and core length changes as a function of radial reflector thickness for constant reactivity in the operational environment were completed. BeO end reflectors were not included. The range of parameters studied up to this point is as follows:

- 1) core diameters: 6 to 8.05 in.
- 2) core lengths (no end reflectors): 12 to 18 in.
- 3) negative reactivity in water: 0 to \$12
- 4) radial reflectors: 2 to 3.5 in.

In this study, the effects of poison addition, geometry changes, and end reflectors were calculated individually as a function of system (reactor and shadow shield) weight. To obtain a negative reactivity effect of \$10.0 in a water-flooded-and-reflected SNAP 10A core, the minimum weight penalty would be about 31 lb

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(by geometry changes only). By combining some of the design methods considered (for example, \$2.0 worth of BeO end reflectors replacing fuel, \$5.5 worth of geometry changes, L/D increase, and \$2.5 worth of Gd poison in the core vessel), a weight penalty (reactor and shadow shield) of about 28 lb results. The core design is perturbed by: (1) increasing the fuel length by 1.98 in., (2) adding 0.91 in. of BeO on each end of the fuel, (3) decreasing the diameter of "homogenized" fuel in the core by 1.25 in., (4) poisoning the core vessel with Σ at ≈ 0.06 of Gd, and (5) compensating for negative reactivity effects in the operational reactor by adding 0.77 in. of Be to the radial reflector.

The generalized parameter study of the effectiveness of geometry changes in the SNAP 10A reactor to ensure subcriticality in water was extended to include the effect of 1.5-in. BeO end reflectors. At the close of the reporting period, curves of reactivity effect in water and radial reflector thickness, as a function of core length and diameter, were being prepared for each of several BeO end-reflector thicknesses. Also, curves showing the reactivity effect in water and core-diameter changes, as a function of radial reflector thickness and BeO end-reflector thickness, were being plotted for several core lengths.

The effect on the spectral temperature coefficient resulting from gadolinium poison on the SCA-4 fuel elements was calculated with DTF-II cell calculations and temperature-dependent H and Zr cross sections. The effect is dependent upon gadolinium concentration. For an optical thickness of 0.3 ($\Sigma_a t$ at 0.025 ev), the calculated spectral temperature coefficient is reduced from -0.03 to -0.004 ϵ /°F in the beryllium-reflected assembly (SCA-4A) and from -0.04 to -0.018 ϵ /°F in the water-flooded assembly (SCA-4B). The measured prompt axial expansion coefficient is -0.04 ϵ /°F. Thus, gadolinium poisoning to this level reduces the overall prompt

temperature coefficient from -0.07 to -0.044 ϵ /°F and from -0.08 to -0.058 ϵ /°F in the SCA-4A and SCA-4B assemblies, respectively. Lower poison concentrations affect the coefficients less. These calculations were conducted to support hazards analysis for intrinsic subcriticality experiments. The concentration is the highest to be tested on the fuel elements in this series of tests.

Information was being assembled to evaluate the nuclear hazards of gadolinium-poisoned MYLAR tape on the SCA-4A fuel elements. Ramps of 8 ϵ /sec and a temperature coefficient of -0.05 ϵ /°F were used. The effects of steps in reactivity (that might occur from flaking of the MYLAR tape at 800°F) will be studied. Experiments show that the tape flakes and falls from the cladding at $\sim 800^\circ\text{F}$. Spectrum effects of gadolinium poison reduces the prompt temperature coefficient approximately 50% in the most heavily poisoned condition. The effects of all of these perturbations is not expected to increase the nuclear hazards significantly.

A two-dimensional DDK calculation for the SNAPTRAN-3, water-reflected model was completed. The calculated excess reactivity was \$3.90. This compares with the \$3.50 excess reactivity determined in the SCA-4B experiments for a water-reflected reactor. A convergence criteria of 0.001 was used in the DDK calculation. The reactivity was still decreasing as the convergence criteria were met. It is expected that the reactivity would be somewhat less if a stricter convergence criteria were used.

Several 16-group, DTF and AIM-6 calculations of the SNAPTRAN-3 prompt neutron lifetime were performed by means of the 1/v poison addition method. All of the calculations, ranging from 1/v to 1000/v, indicated a prompt neutron lifetime of about 16 μsec .

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VIII. END-OF-LIFE SHUTDOWN PROJECT

Volume calibration of the isotherm apparatus and preliminary zirconium dissociation pressure measurements were completed. Room temperature volume determinations of the system manifold were made to an accuracy of $\pm 1\%$. The pressure-measuring portion of the system varies with respect to the height of mercury in the manometer and can be accounted for by knowing the internal dimensions of the manometer tubing. The "effective" volume of the retort portion of the system was determined as a function of temperature to $\pm 1.5\%$.

Zirconium-hydride dissociation pressure measurements were made to determine the reproducibility of the equipment and methods. The dissociation pressures of a zirconium-deuteride specimen were also determined and compared with zirconium-hydride pressures to provide a means for determining to what extent isotopic additions affect zirconium-hydride dis-

sociation pressures. Table 12 and Figure 24 present a tabulation and plot of these results (reported in the order in which they were obtained).

Zirconium-hydride specimens were analyzed for possible gaseous contaminants, oxygen and nitrogen, after typical runs. Of the three samples analyzed, no greater than 65 ppm O_2 was found, including the samples taken from the surface. The nitrogen content did not increase over that in the starting material. This indicates that samples prepared in this apparatus are relatively free of gaseous impurities.

TABLE 12

COMPARISON OF DISSOCIATION PRESSURES FOR ZIRCONIUM HYDRIDE AND DEUTERIDE

Pressure (mm)	H/Zr	Pressure (mm)	D/Zr
164	1.696	189	1.695
349	1.748	131	1.668
494	1.771	100	1.647
563	1.780	357	1.742
572	1.782	522	1.768
289	1.740	600	1.77
248	1.724	298	1.733
159	1.696		
114	1.673		
256	1.730

Figure 24. Isotherm Plot of Zirconium Hydride and Deuteride Dissociation Pressures