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PROGRESS REPORT
SNAP AEROSPACE NUCLEAR SAFETY PROGRAM
OCTOBER-DECEMBER 1965
(Title Unclassified)

AEC Research and Development Report

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SNAP AEROSPACE NUCLEAR SAFETY PROGRAM
OCTOBER-DECEMBER 1965
(Title Unclassified)

By

R. L. DETTERMAN

Project Manager

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I. PROGRAM SUMMARY

A. REENTRY AND ABORT STUDIES

1. Reactor Disintegration Projects

The Reactor Ablation-Disintegration Experiment (RADE) radiant heat tests conducted at the AI Santa Susana facility were completed. In the heat flux calibration runs, data were recorded at several body locations at a lamp input power of 12 kw and at some selected body locations at a lower level of radiant heat flux. The data indicate a change in heat flux with time, with a leveling off after about 4 to 5 min.

Following completion of the calibration runs, 15 selected model thermocouples were connected for the acceptance test runs. These runs were conducted at two levels of radiant heat flux at a vacuum of about 10^{-3} torr to provide a qualification check of the NASA-Ames integrated data acquisition system and to confirm the analytical description of the test models.

The test plan for the RADE wind tunnel tests to be conducted at NASA-Ames was completed and testing was scheduled to begin in the next reporting period. All components for the gold-plated, copper calorimeter model were complete except for some of the internal thermocouple wiring. A stress analysis of the model support structure was completed in which the minimum factor of safety was calculated to be 3.83 for failure and 1.92 for yield.

The first two 10,000-hr, self-weld tests were successfully completed in which uncoated 316 stainless steel and beryllium were held under contact pressures of 100 psi at 1000°F in a 10^{-8} - to 10^{-9} -torr vacuum. Microscopic examination, verified by weight gain measurements, showed that considerable transfer (estimated at approximately 30% of the apparent contact area) of beryllium to stainless steel occurred.

Two additional 10,000-hr, self-weld tests of colloidal graphite-coated 316 stainless steel and beryllium were also completed. The materials were tested under the same conditions as the first two tests, except that one system lost vacuum during one of these tests. No metal transfer from beryllium to stainless-steel surfaces was observed by means of microscopic examination as was the case for the uncoated specimens. A chemical and metallographic analysis was in progress.

As a beginning of the fuel element separation study, a TAP-3 thermal model of one end of a fuel element (including the pin, cap, and some fuel) and the portion of the grid plate associated with one fuel element was analyzed. Results indicated that if the grid plate and the ends of fuel elements are in good thermal contact, the grid plate in the vicinity of the fuel element pin will heat up more slowly, since the fuel element acts as a heat sink.

Several TAP-3 runs were made for analysis of a reentering reactor core bundle and additional runs were in progress. Some conclusions that can be noted to date are as follows:

1) End-on heating causes faster heating and melting of the grid plates than side-on heating.

2) Heating of the grid plate occurs more quickly when the grid plate is not in good thermal contact with the ends of the fuel elements.

3) When the grid plate is separated from the fuel, the plate heats more quickly (and hence melts first) at points corresponding to the outer edge of the elements behind it. (This does not occur when the grid plate is in good contact with the fuel.)

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2. Fuel Reentry Burnup Projects

Checkout test runs on zirconium hydride material were completed in preparation for the fuel arc-jet tests. Throughout the first of these runs, the specimen was stationary. In the four subsequent runs, the specimens were rotated at approximately 120 rpm. The alumina tubing protecting the tungsten rod holder withstood the arc-jet environment and was therefore used in the actual fuel tests.

The first phase of the fuel arc-jet test series was completed. One-half of the Configuration-III and all of the Configuration-IV fuel specimens were run. Five runs utilizing the Configuration-II specimens were also made. Due to minor problems, however, the laser-schlieren system was not used when planned. Also, during all but one of these runs, the internally mounted thermocouple of each specimen failed to function because of an open junction at the coupling of the lead wire to the sheathing.

The remaining phase of the tests will include the laser-schlieren system. The specimen configurations to be tested include the remaining Configuration-III and Configurations-V and -VI. It was also anticipated that the remaining Configuration-II specimen from the first test series will also be run with this final group of tests after it has undergone minor repairs. A detailed analysis of the test runs will be conducted at the completion of the final test series.

Probabilities of initial fuel ablation at various release altitudes were calculated for SNAP 10A fuel elements tumbling at random or spinning cross-axially. These calculations are based on the latest set of reference parameters. The resulting probability values are tabulated in Section III and supersede previously reported values^{(1)*} which were based on earlier parameter data.

*Superscripts refer to the References listed at the end of this report.

The analytical TAP-3 model was used to calculate the thermochemical behavior of SNAP 8-type fuel elements during atmospheric reentry. Results of these calculations for an element tumbling at random and one spinning cross-axially are plotted in Section III. Also, the conditions at the time of initial ablation are tabulated.

3. Fuel Ablation and Particle Formation Projects

The particle experiment test plan, summarizing the analytical studies which utilize the Particle Ablation Model (PAM), was completed. From these studies, it appears that the fraction of the particle that is ablated due to vaporization is a function of altitude (air density), initial velocity, and heating mechanisms. The initial size of the particle has little effect on the fraction of the particle that is ablated. This conclusion, however, applies only over the limited size-range studied (250- to 3400-micron diameter). Particle sizes smaller than 250 microns had not yet been studied as extensively as larger sized particles and, consequently, no conclusion had been reached for these smaller particle sizes.

The analysis of the ablation of SNAP fuel particles during reentry was continuing. In the parameter survey of the properties and mechanisms affecting ablation, the following six parameters had been studied: (1) oxide vaporization, (2) emissivity, (3) oxidation characteristics, (4) aerodynamic heating, (5) specific heat of the particle, and (6) density of the particle. The effect of these parameters on the final particle sizes is tabulated in Section IV.

The fission product inventory was determined for reentry occurring at 10, 50, 100, and 2000 yr after reactor shutdown. These studies show that the primary sources of radioactivity in these cases are Sr^{90} and Cs^{137} for the first three cases and

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Cs¹³⁵ and Zr⁹³ for the 2000-yr case. A tabulation of the most active fission products in SNAP fuel 1 yr and 50 yr, respectively, after shutdown was prepared.

4. Fuel Properties Project

Major experimental effort on the thermo-physical property studies was concerned with thermal diffusivity measurements of 1.81 and 0.50 H/Zr fuel materials and the pulse-heating of 1.81 H/Zr samples. In addition, the data generated under the data comparison program at Atomics International and at Battelle Memorial Institute were exchanged between the two organizations. A meeting was held at BMI by members from both groups, to discuss these data.

Preliminary thermal conductivity measurements of the unhydrided fuel samples made at BMI, using their longitudinal heat flow apparatus, indicated that the sample undergoes anomalous structural changes during the measurements, resulting in inhomogeneity of the sample. Further work at AI involving the radial heat flow thermal conductivity apparatus was therefore suspended.

Experimental work on the oxidation kinetics of solid SNAP fuel was completed. Rates of oxidation and hydrogen loss were established for hydrided fuel as a function of the reentry thermal transient. Initial data are presented but further data reduction is necessary to establish accurate rate constants. Oxidation rates on the unhydrided fuel alloy were obtained using a greater airflow than on the previously reported data. It was concluded that the greater airflow around the samples did not appreciably alter the oxidation behavior of the alloy. Effort was being concentrated on the construction of test apparatus to study the oxidation behavior of the molten fuel alloy.

5. Reactor Disposal Projects

A test plan was prepared designed to determine the residual particle size resulting from destruction of SNAP fuel rods by detonation of an explosive charge. The test objectives would be: (1) to verify the feasibility of fuel element rupture and subsequent dispersal by explosive destruct, (2) to determine fuel residue particle size as a function of explosive charge size, and (3) to optimize the explosive charge location for destruction of a fuel element bundle.

An analysis of wind measurements was made as part of the atmospheric fallout studies. This analysis confirmed that wind gusts (the difference between peak and lull speeds) are directly proportional to the value of the average wind.

A draft of a report on the radiological aspects of reentry burnup was completed.⁽²⁾ Surface air concentrations from a megacurie release as submicron particles in the mesosphere were calculated. The highest concentrations result from a lower polar stratosphere release and high concentrations persist for the longest time interval for a mesospheric release.

B. NUCLEAR STUDIES

1. Reactor Transient Projects

a. SNAPTRAN-1

The remainder of the data from the SNAP-TRAN-1 test series was received and the initial data reductions and analysis were essentially completed. These final transients were coupled drum step tests, of which several were initiated at elevated temperatures. A summary of the initial analysis of these transients is tabulated in Section VII.

Several improvements and refinements were made to the data analysis portion of the COMPOST computer program. These include an improved

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straight-line fit to the plot of compensated reactivity ($\Delta\rho$) vs average core temperature change (ΔT). This gives a more accurate average temperature coefficient. A new analysis of several prompt critical transients from the initial step test series was performed. The changes in temperature coefficients brought about by this new analysis is summarized in Section VII-B.

An extensive investigation of energy probe behavior and calibration was begun to investigate the possible causes of the variations in temperature coefficients in the different series of tests. A post-test metallurgical examination of the energy probes used in the test series was also undertaken.

The analysis of the control drum interaction experiments was completed. A difference of about 3% was found in the worth of inserting two opposite drums vs two adjacent drums. The errors observed in the analysis were expected to lead to errors considerably smaller than 3% in the actual experiments; thus, they are expected to be of no consequence.

b. SNAPTRAN-2

Several series of tests were conducted at the IET facility of the NRTS in preparation for the SNAPTRAN-2 destruct test.* These included scram tests, shake tests, control drum synchronization tests, and system noise tests. Transient testing was also initiated at the IET. The results of this testing are summarized in Section VII. Non-nuclear, dry-run tests were also conducted to evaluate, among other things, the countdown procedures.

Data from the SNAPTRAN-2 transient testing were received and the initial analysis was essentially completed.

Several SNAPKIN-VI transients were calculated to determine if the impulse drums should be shimmed during the destruct test. A partially shimmed configuration was decided upon. Preliminary calculations were completed to evaluate the new configuration and indicated that all the reactivity (\$4.90) can be inserted before any significant temperature rise has occurred. The calculations were based on starting powers of both 0.1 and 1.0 mw. It also appears that this reactivity insertion can be accomplished if the impulse drums are as much as 1 msec out of synchronization.

2. Critical Configuration Projects

DTF-II calculations of the reactivity worth of the water reflector in the SCA-4B water immersion experiments were performed. The differences between the 37-rod assembly and the 31-rod, 6-lucite-rod assembly were found to be quite small.

Modifications in core geometries to achieve intrinsic subcriticality in cores of the general type as SNAP 8 were being studied. Variations of core diameters from 7.75 to 10.0 in. were studied; core lengths necessary to provide excess reactivity during operation were yet to be determined.

Critical core lengths, as a function of radii, were calculated for the core geometry study experiments. The purpose of this analytical study is to provide a general outline for the experimental program using the SCA-5 fuel in an infinite water environment. The incremental reactivity worth of water height on the SCA-5 fuel assembly was estimated to establish proper test procedures.

The loading of 9 in. of SCA-5 fuel pellets into the fuel tubes for the SCA-4B critical assembly was completed and loading approach to critical was initiated.

*The actual destruct test was conducted during the preparation of this report on January 11, 1966. Details on the results of this test will be included in the progress report for the next reporting period.

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3. End-of-Life Shutdown Project

Experiments were being conducted to measure the effect of tritium additions on the dissociation pressure of SNAP fuel. The extent to which ${}^3_2\text{He}$, formed by tritium decay, will cause swelling of SNAP fuel was also under investigation. These tests represent a portion of the work to determine the feasibility of using the

decay mechanism as a reactor shutdown device.

A comparison of the dissociation pressures of $\text{ZrH}_{1.66-1.80}$ and $\text{ZrH}_{1.57-1.71}\text{T}_{0.09}$ was made. In addition, sufficient ZrH_x and ZrT_y dissociation pressure vs temperature data were made to establish H/Zr and T/Zr = 1.70 isochore curves over a narrow range of temperatures and pressures.

A series of sixteen SNAP fuel-swelling samples with ${}^3_2\text{He}$ concentrations of 1.5 to 3.5×10^{19} atoms/cc were annealed at 1500°F . These tests indicated, from pre- and post-annealing density measurements, that ${}^3_2\text{He}$ at 1500°F and at concentrations as high as 3.5×10^{19} atoms/cc will contribute little to gas-induced fuel swelling.

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Figure 1. Reactor Ablation-Disintegration Experiment (RADE) Radiant Heat Test

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II. REACTOR DISINTEGRATION PROJECTS

A. EXPERIMENTS

1. Reactor Ablation-Disintegration Experiment (RADE)

a. Radiant Heat Test (AI-Santa Susana)

The RADE-B model radiant heat flux calibration runs were completed. A photograph of the partial test setup is shown in Figure 1. Data were recorded at several body locations at a lamp input power of 12 kw and at some selected body locations at a lower level of radiant heat flux. The data indicate a change in heat flux with time, with a leveling off after about 4 to 5 min. The sensors required repair at the splice between the stainless-steel and flexible teflon leads, because the epoxy melted and shorted the copper lead wires. Also, nickel wires at the vessel feedthrough tubes were changed to copper to maintain continuity from the sensor to the recorder.

Following completion of the RADE-B model radiant heat flux calibration runs, 15 selected model thermocouples were attached to the chromel/alumel plug-adaptor assembly to route the instrumentation from the vacuum chamber to the recorder for the acceptance test runs. These test runs were conducted to provide a qualification check of the integrated data acquisition system and to confirm the analytical description of the test models. Thermocouple and calorimeter data were recorded on the NASA-Ames data acquisition equipment at two levels of radiant heat flux at a vacuum of about 10^{-3} torr. The recorded data were being processed for comparison with the results from the analytical model. The model was then removed from the vacuum vessel and the hardware was shipped to the thermocouple shop.

The thermocouple and heat sensor data recorded on magnetic tape during the RADE-B model radiant heat test were transcribed on graph paper (mv vs time) for analysis.

b. Wind Tunnel Test (NASA-Ames)

The gold-coated calorimeters were cemented into all the gold-plated, copper calorimeter model components. Figure 2 shows the vessel and the three interchangeable heads which constitute the RADE calibration model. The finished components were sent to the thermocouple shop for internal wiring, which was about 70% complete. Following assembly, the water coolant loops will be pressure tested for leaks and flow tested to verify that the predicted flow rates are obtained.

Seven asymptotic calorimeters were cemented into the vessel with an epoxy. Two tests were made to check out the epoxy prior to its use. The tests were made with a dummy calorimeter installed in a copper plate with the epoxy. After curing at 200°F for 3 hr, a helium pressure test at 150 psi showed no leakage. A second test was made with an internal water pressure of 100 psi. An acetylene torch was used to bring the plate temperature to an indicated 482°F. No leakage occurred during this test.

Certification of the PVC tubing for protection against breakdown voltages of 37,500 volts was begun. This tubing will be used at NASA-Ames to electrically float the instrumentation.

The NaK fill tubes on the copper calorimeter model were analytically examined to ascertain the possibility of excess temperature during the Ames test. The transient analysis indicates that these parts reach a maximum temperature of ~1400°F for a 10-min run, which is within the allowable temperature limit and beyond the range of expected test time.

A stress analysis of the RADE model support structure was completed. The minimum factor of safety was calculated to be 3.83 for failure and 1.92 for yield. Because of the supersonic flutter problem, however, representatives

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Figure 2. Reactor Ablation - Disintegration Experiment (RADE) Calibration Model Components

from NAA-LAD recommended increasing the stiffness of the support structure in all directions. Necessary design parameters were acquired from NAA-LAD and incorporated into the redesign.

The model support system, diffuser section, and instrumentation feedthrough plate assembly were being assembled. A model setup in the shop will be made to check the assembly and operation of the component parts prior to shipment to Ames.

2. Self-Welding Tests

The first two 10,000-hr, self-weld tests were successfully completed. These tests combined uncoated 316 stainless steel with beryllium

at 1000°F. The materials were held under contact pressures of 100 psi in a system maintained in the 10^{-8} -to 10^{-9} -torr vacuum range. Adhesion between materials separated hot were less than for materials separated cold. The adhesion measurement for the test specimens separated at 1000°F was 8 oz.; but for the specimens separated at room temperature, the adhesion was 25 oz. Microscopic examination, verified by weight gain measurements, showed that considerable transfer of beryllium to stainless steel occurred. This transfer was estimated at approximately 30% of the apparent contact area.

Two additional 10,000-hr, self-weld tests of colloidal graphite-coated 316 stainless steel

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and beryllium were also completed. The materials were held at 1000°F under contact pressures of 100 psi. No adhesion forces were detectable upon reverse loading to separate the metals. Adhesion forces cannot be measured below 0.1 lb. One of the test systems was held in the 10^{-8} -to 10^{-9} -torr vacuum range during the test period, but the other system lost vacuum during the test. This resulted in probable partial oxidation of the coating and metals. No metal transfer from beryllium to 316-stainless-steel surfaces was observed by means of microscopic examination as reported for the foregoing uncoated specimens. Coating coverage was estimated to be better than 90%, which was sufficient to prevent microscopically observed material transfer. The coatings, observed from the test in which a vacuum had been successfully maintained, were flaky and generally continuous on the beryllium surface, but were more granular in appearance on the 316-stainless-steel surface. The colloidal graphite appeared to be loosely adherent on both surfaces. A detailed chemical and metallographic analysis was in progress.

B. ANALYSIS

1. RADE Analytical Model Development

The Thermal Analyzer Program (TAP) analog of the completed RADE-B experimental model was checked out. This TAP model consists of the complete NaK inlet pipe and a 180-degree portion of the top head, upper grid plate, and reactor core. It incorporates conduction and radiant heat transfer between all members of the reactor model. The model allows heat to be introduced as input to all portions of the external surface of the RADE-B model. This will enable the effect of the NaK inlet pipe shadow in the radiant heat tests or of various angles of inclination in the NASA-Ames wind tunnel tests to be included in the analytical

description of the RADE-B experimental model. The initial checkout calculation was made using a uniform heat input of $144 \text{ Btu/ft}^2\text{-sec}$ over the entire external surface of the reactor model for a period of 5 sec. This heat input was chosen so that the model would reach elevated temperatures in a short period of time. Although this heat rate is not actual RADE test conditions, some qualitative results were obtained from the initial calculations. When the top of the NaK inlet pipe reaches melting temperature, portions of the top head are in the 900 to 1500°F range; the upper grid plate is ~90°F; the vessel wall is ~1800°F; internal reflectors are ~85°F; and the rods are ~80°F. The initial temperature of the model was assumed to be 80°F.

Using the calibration results of the initial RADE-B radiant heat tests, geometric heating factors were calculated for various portions of the experimental model. These factors and the varying heat output of the quartz lamps were incorporated into the analytical model.

The TAP-3 analog of the RADE-A model core was completed and checked out. The network for the top head and grid plate was being completed. The radiation view factors between various portions of the top head and the upper grid plate were calculated. Calculations were then made for the configuration (A·F) factors for the radiation paths between the top head and the upper grid plate. The conduction resistances within the top head and upper grid plate were being calculated.

2. Fuel Element Separation Study

A TAP-3 thermal model of one end of a fuel element, including the pin, cap, and some fuel, was analyzed. Also, the portion of the grid plate associated with one fuel element was included. The heat input was applied to the upper surface of the grid plate at $Q = 1.0 \text{ Btu/in.}^2\text{-sec}$.

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Results indicated that if the grid plate and the ends of fuel elements are in good thermal contact, the grid plate in the vicinity of the fuel element pin may heat up much more slowly, since the fuel element acts as a heat sink. As a result, the grid plate may melt in a pattern corresponding to the outer radii of fuel elements such that a little piece of grid plate may stay with each fuel element.

Several TAP-3 runs were made for analysis of the reentering reactor core bundle. Additional runs were in progress. Some expected conclusions that were confirmed are: (1) end-on heating causes faster heating and melting of the grid plates than side-on heating; (2) heating of the grid plate occurs more quickly when the grid plate is not in good thermal contact with the ends of the fuel elements; and (3) when the grid plate is separated from the fuel, the plate heats more quickly (and hence melts first) at points corresponding to the outer edge of the elements behind it. This does not occur when the grid plate is in good contact with the fuel.

Although this study represents only a beginning of the analysis of fuel separation and the analytical model is rather crude, the following interesting preliminary observations were made: (1) For the case where the grid plate is separated from the fuel by a gap, the melting temperature of the plate is reached at the outer edge in about 18 sec after release, or approximately 245,000 ft; the last fuel element is separated at 36 sec, or approximately 240,000 ft. (2) For the case where the grid plate is in good thermal contact with the fuel elements, these events take place at 75 sec and approximately 223,000 ft and 100 sec and 212,000 ft, respectively. The release altitude for both cases was 250,000 ft; no adjustments were made for

the changing geometry, and the heat of fusion was not incorporated.

Preliminary temperature profiles for the grid plate of the separated reactor core bundle were determined for a release altitude of 250,000 ft and various modes of reentry. Again, it is apparent that if the grid plates are not in contact with the ends of the fuel elements (except at the pins), then grid plate burnup on reentry will be greatly enhanced. As the reactor core bundle is reentering, the outer edges of the grid plates melt first, so that (in the model being considered) the outer ring of fuel elements (and Be reflectors) are the first to separate from the core. Once the fuel elements start to separate, the $W/C_D A$ of the remaining bundle decreases while the total heating increases.

3. Development of Basic Methods

A study was being made of thermodynamic conditions and velocity gradients in the gas aft of the shockwave at the front of a blunt body in hypersonic flow. Both equilibrium and nonequilibrium gas chemistry were being considered. This study will lead to the development of better methods for correlating data and predicting heating on blunt-nosed reentry bodies.

A correlation of stagnation-point heating rate data in the low Reynolds number regime is shown in Figure 3. This correlation is based on use of the Reynolds number aft of the shock wave, Re_2 , multiplied by the dimensionless velocity gradient at the stagnation point, $(R_N/V_2)(dU_e/ds)$, or by its equivalent, $\sqrt{(2-\epsilon)/\epsilon}$. Epsilon, ϵ , is the density ratio across the shock wave, ρ_1/ρ_2 . This figure shows how the 1952 data of Drake and Backer, when so corrected, agree with the data from more recent experiments.

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Figure 3. Correlation of Stagnation - Point Heating
Rate Data in Low Reynolds Number Regime

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III. FUEL REENTRY BURNUP PROJECTS

A. FUEL ARC-JET EXPERIMENT

An initial checkout test run on zirconium hydride material was completed at the beginning of this reporting period. The specimen was stationary throughout the run. The test run lasted for approximately 4 min at condition C($H_s = 7200$ Btu/lb, $P_T = 0.073$ atm). The alumina tube protecting the tungsten rod holder withstood the heat of the jet during the entire run.

Data taken from the initial checkout run consisted of pyrometer (surface temperature) readings, laser-schlieren photography, and motion picture coverage. The results of the laser-schlieren photography were not of the quality and quantity required. The laser did not have the required power repeatability on consecutive shots. The output faded with each succeeding shot and did not repeat at one pulse per second as required by the specifications. The laser was subsequently modified to meet its specification. A rotating mirror and associated circuitry were installed to replace the fluid prism for Q-switching. The laser head was then returned to the NAA-LAD facility.

Four subsequent checkout test runs on zirconium hydride were also completed. The samples were rotated at approximately 120 rpm. The alumina tubing withstood the jet stream environment and was therefore used in the actual fuel tests.

The first phase of the fuel arc-jet test series was completed. One-half of the Configuration-III and all of the Configuration-IV fuel specimens had been run. The Configuration-III specimens have diameters equivalent to SNAP 10A and SNAP 8 fuel elements. The Configuration-IV specimens had the same diameter as the SNAP 10A elements and had grooves around their circumference for one-half their length.

Figure 4 shows Configuration III-A-2 specimens assembled with alumina insulation tubes. Photographs of all the other specimen configurations were included in the progress report for the previous period. Figure 5 shows a Configuration III-A-2 specimen installed on rotator and lowered to test position in the tunnel. The particle catcher is also shown in the test position. Configuration III-A-2 and Configuration III-B-1 test specimens are shown after the Series No. 3 runs in Figures 6 and 7, respectively. The particle catchers used for several of these runs are shown in Figure 8.

Figure 4. Fuel Arc-Jet Test Configuration III-A-2 Assembled With Alumina Insulation Tube

Testing of Configuration-II fuel specimens was also completed. Due to a minor problem with the laser head, the laser-schlieren system was not used. A total of five runs were made, and during all but one, the internally mounted thermocouple failed to function. This was

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Figure 5. Fuel Arc - Jet Test Configuration III-A-2 on Rotator and Lowered to Test Position

caused by an open junction at the coupling of the lead wire to the sheathing. This was detected on one of the samples prior to insertion into the tunnel. It is anticipated that a repair can be made and the final (sixth) Configuration-II specimen can be run with the final group of tests.

A general review was conducted of all the film data (24 ft/sec and 400 ft/sec) of the completed fuel arc-jet test runs. The film is of good quality, and a detailed analysis of the test runs will be conducted at the completion of the test series.

The remaining phase of the tests will include the laser-schlieren system. The configurations to be tested with this system are the remaining Configuration-III, Configuration-V (same as II,

but without a thermocouple), and Configuration-VI. The Configuration-VI specimens have the same diameter as SNAP 8 elements and are 3 in. in length. They will be tested with their principal axis parallel to the jet stream. The latter two configurations will also be used for laser particle photography.

B. ANALYSIS

Probabilities of initial fuel ablation at various release altitudes were calculated for SNAP 10A fuel elements tumbling at random or spinning cross-axially. These calculations are based on the latest set of reference parameters. The resulting probabilities are summarized in Table 1. These probability values supersede previously reported values which were based

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Figure 6. Series No. 3 Test Specimens After Runs - Configuration III-A-2

Figure 7. Series No. 3 Test Specimens After Runs - Configuration III-B-1

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Figure 8. Particle Catchers After Series No. 3 Test Runs

TABLE 1
PROBABILITIES OF INITIAL ABLATION OF A
REENTERING SNAP 10A FUEL ELEMENT

Release Altitude (ft)	Probability of Initial Ablation, Random Tumbling	Probability of Initial Ablation, Cross-Axial Spinning
400,000	0.99977	0.9956
350,000	0.99997	0.9988
300,000	0.999992	0.99955
275,000	0.99994	0.9995
250,000	0.978	0.8698
239,500	0.78*	0.50*
229,000	0.50*	0.18*
225,000	0.35	0.105
200,000	0.0053	0.0006

*Interpolated values

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TABLE 2
DRAG COEFFICIENTS AND BALLISTIC COEFFICIENTS
FOR A SNAP 8 FUEL ELEMENT

	Cross-Axial Orientation			Random Tumbling	
	C_D	A_P (ft ²)	$W/C_D A_P$ (lb/ft ²)	$C_D A_P$ (ft ²)	$W/C_D A_P$ (lb/ft ²)
Free-molecule flow (above 320,000 ft)	2.85	0.0667	4.79	0.06173	8.07
Transition regime (from 320,000 to 240,000 ft)	$C_D = 1.55 + 1.3$ $\exp -\frac{1}{3.5} \frac{\rho_\infty}{\rho_s \lambda_s}$	0.0667	variable	$C_D = 0.06173 + (0.0511)$ $\exp -\frac{1}{3.5} \frac{\rho_\infty}{\rho_s \lambda_s}$	variable
Continuum flow (below 240,000 ft)	1.55	0.0667	8.81	0.11283	14.74

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Figure 9. Q_{AVAIL} and Q_{REQ} vs Release Altitude for a SNAP 8 Fuel Element Tumbling at Random

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Figure 10. Q_{AVAIL} and Q_{REQ} vs Release Altitude for a SNAP 8 Fuel Element Spinning Cross-Axially

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on earlier parameter data.⁽¹⁾ The values shown reflect the confidence limit given to the analytical model solution and include the most recent physical property data available. In addition to firmly establishing the relative significance of the heating parameter influence coefficients, these probability analyses quantitatively determine the relationship of probability of fuel rod melting and the accuracy of specific parameters within the model. Thus, it is possible to determine the increase in probability of initial ablation of a SNAP 10A fuel element if the accuracy of any of the parameters is increased by a known amount.

A study on the reentry behavior of SNAP 8-type reactor fuel elements was begun. A reference trajectory was selected for a SNAP 8 reactor system vehicle. This reference trajectory was calculated using the RESTORE digital code for a decaying polar orbit with an end-on vehicle orientation and a step ballistic coefficient ($W/C_D A$) value of 77 lb/ft^2 (free-molecular flow) and 153 lb/ft^2 (continuum flow). Drag coefficients and ballistic coefficients were determined for random-tumbling and cross-axial-spinning flight orientations. The values are summarized for the different flow regimes in Table 2. The equations, upon which these calculations are based, were derived in previous (SNAP 10A) studies.

The analytical TAP-3 model was used to calculate the thermochemical behavior of SNAP 8-type fuel elements during atmospheric reentry. Results of calculations appropriate for a random-tumbling element and for release altitudes between 200 and 300 kilofeet are shown

in Figure 9. In this figure, Q_{REQ} (the integrated cold-wall aerodynamic heat rate, integrated between the times of release and melting) and Q_{AVAIL} (the total, integrated, cold-wall aerodynamic heating available in the trajectory) are plotted, both as functions of release altitude. From the figure, it is evident that melting of the fuel is predicted for all release altitudes above 200 kilofeet. At 240 kilofeet, the available heating is about twice that required to initiate fuel ablation and, at still higher release altitudes, Q_{AVAIL} becomes nearly triple the heat required to initiate ablation.

The conditions at the time of initial ablation are shown in Table 3 for a random-tumbling SNAP 8-type fuel element. Compared to previously calculated results for a SNAP 10A fuel element, these SNAP 8 fuel element burnup altitudes and velocities are substantially higher.

The corresponding results for a cross-axial-spinning element are shown in Figure 10 and in Table 4. In the figure, Q_{REQ} and Q_{AVAIL} are plotted as a function of release altitude. From the figure, it is evident that melting of the fuel is predicted for all release altitudes above 210 kilofeet. Values of Q_{REQ} are relatively constant, except at higher release altitudes. At about a 250-kilofeet release altitude, the available heating is about twice that required to initiate fuel ablation.

The conditions at the time of initial ablation are shown in Table 4 for a cross-axial-spinning SNAP 8 fuel element. These conditions are of interest in the fuel particle disintegration and dispersal studies.

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TABLE 3
CONDITIONS AT THE TIME OF INITIAL ABLATION FOR A SNAP 8
FUEL ELEMENT TUMBLING AT RANDOM

Release Altitude (kilofeet)	Time After Release (sec)	Altitude (kilofeet)	Velocity (ft/sec)	Flight Angle (degrees of arc)
300	189	266	23,695	-1.11
275	77	259	23,618	-0.94
260	56	246	23,008	-1.05
241	41	226	21,638	-1.42
220	33	203	18,832	-2.01
210	33	192	16,874	-2.49
200	37	176	13,150	-3.60

TABLE 4
CONDITIONS AT THE TIME OF INITIAL ABLATION FOR A SNAP 8
FUEL ELEMENT SPINNING CROSS-AXIALLY

Release Altitude (kilofeet)	Time After Release (sec)	Altitude (kilofeet)	Velocity (ft/sec)	Flight Angle (degrees of arc)
300	178	260	22,390	-1.53
275	68	260	22,835	-1.04
260	47	248	22,269	-1.09
241	34	229	20,723	-1.43
220	31	205	16,835	-2.22
210	33	192	13,958	-3.00

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IV. FUEL ABLATION AND PARTICLE FORMATION PROJECTS

A. EXPERIMENTS

The particle experiment test plan was prepared. It summarizes the analytical studies made using the Particle Ablation Model (PAM). From these studies, it appears that the fraction of the particle that is ablated due to vaporization is a function of altitude (air density), initial velocity, and heating mechanisms. The initial size of the particle has little effect on the fraction of the particle that is ablated. It should be noted, however, that this applies only over the limited size-range studied (250- to 3400-micron initial diameter). Particle sizes substantially smaller than 250 microns had not yet been studied as extensively as had the foregoing and, consequently, no conclusion had been reached for these smaller particle sizes.

The suspension of particles in a tube for which dimensions are large with respect to the particle size was investigated. It was calculated that flow perturbations and turbulence could adversely affect particle stability. Two other techniques being investigated were:

- (1) particle suspension in a porous cup and
- (2) particle suspension in a tube for which dimensions are of the order of magnitude of the particle size.

The objectives of the analytical experimental programs were reviewed by Dr. Bomelburg at NAA-LAD. Several methods of gathering particle temperature and size data were considered in some detail. Dr. Bomelburg will specifically investigate densitometer and radiometric techniques of measuring particle temperature and Kerr cell and laser techniques of measuring particle size.

B. ANALYSIS

Preliminary observations of particle collector operation and movies of SNAP fuel arc-jet tests indicate that rod ablation results initially

in particles varying from large molten globules and flakes of surface oxide in the millimeter-size range down to small particles in the micron-size range.

Several improvements in the Particle Ablation Model (PAM) were checked out. These improvements include new aerodynamic heating relationships, radiation heat-loss relationships, and mechanisms for oxidation. Further improvements were being made to increase the versatility of the code. The new improvements are related to the method of data input, data checking, and output. These changes were necessary for the future development of the model, which will include the fractional removal of fission products and the ability to use the model for studying the reentry behavior of particles other than SNAP fuel material.

The analysis of the ablation of SNAP fuel particles during reentry was proceeding in the following areas:

1. Parameter Survey

Using the current PAM, a parameter survey of the properties and mechanisms affecting ablation was being made. Six parameters had been studied to date. These are: (1) oxide vaporization, (2) emissivity, (3) oxidation characteristics, (4) aerodynamic heating, (5) specific heat of the particle, and (6) density of the particle. Table 5 shows the final sizes for the standard cases and the final sizes from each parameter study.

In the standard cases, the particles are oxidized by a free-molecule mechanism, have an emissivity of 1.0, and the oxide is considered to follow the relationship of Hock, Nakata, and Johnson.⁽³⁾ In studying the effect of these parameters, the following changes were made: For the vaporization study, the oxide was assumed to follow the relationship of Nakata,

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TABLE 5
EFFECT OF VARIOUS PARAMETERS ON FINAL PARTICLE SIZE

Release Altitude (ft)	Initial Radius (microns)	Final Radius (microns)							
		Standard	Vaporization	Emissivity	Oxidation	Aerodynamic Heat = 0	C _p = 0.09	C _p = 0.05	Density = 450
170,000	500	241	358	201	391	286	240	242	241
177,000	630	349	495	300	515	441	348	350	349
189,000	688	425	566	377	575*	601	423	426	425
203,000	900	625*	793*	568*	778*	877*	624*	627*	626*
215,000	1195	940*	1146*	880*	1080*	1193*	939*	941*	944*
228,000	1660	1429*	1647*	1380*	1553*	1660*	1429*	1430*	1444*

*Size at 20 sec after release

McKesson, and Pollock.⁽⁴⁾ This latter relationship yields lower values of vapor pressure. In the emissivity study, the emissivity was changed to 0.8. In the oxidation study, the oxidation rate was assumed to be one-half of the free-molecule rate.

In the standard cases, the particles experience free-molecule aerodynamic heating and have a specific heat of 0.07 Btu/lb-°F and a density of 375 lb/ft³. In studying the effect of these parameters, the following changes were made: For the aerodynamic heating study, the heating from this source was made equal to zero. In the specific heat study, specific heats of 0.09 and 0.05 Btu/lb-°F were used. In the density study, the density was changed to 450 lb/ft³. In the future, a study will be made wherein the density will be lowered to 300 lb/ft³.

Using a more advanced version of PAM, a study was made of the effect of metal vaporization on final particle size. This more advanced version of PAM includes the vaporization of the unoxidized metal whenever all of the oxide has been vaporized.

2. Analysis of Experiments

The Particle Ablation Experiment Model (PAEM) was applied to an experiment performed

and reported by Nelson.⁽⁵⁾ Nelson observed that a 165-micron-diameter particle exploded 165 msec after ignition. This experiment was analyzed with PAEM, using two oxidation mechanisms: free-molecule oxidation and one-half of free-molecule oxidation. Using the first oxidation mechanism, the particle was completely vaporized in 5.5 msec. With the second mechanism, complete vaporization occurred in 12.9 msec. The experiment, however, was performed at high pressure (625 torr) and the free-molecule oxidation mechanism is only applicable at low pressures (such as in particle reentry). Calculations have shown that the oxidation rate is diffusion-limited under these experimental conditions.

Modifications were made to PAEM to describe the oxygen mass flux and the convective cooling for these laboratory experiments. A checkout of the results obtained with this modification were being made.

A modification to PAEM, that considers a variable particle velocity, was being checked out. This version of PAEM will yield information on the location of the particle as a function of time, and it will be used in the particle experiment design analysis.

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3. Flow Regimes

A study of the flow regimes that a particle experiences was being made. The flow regime can be classified according to the Knudsen number (a ratio of the mean free path of gas molecules to the radius of the particle). For the particle sizes and altitudes of interest, the particles are in free-molecule ($Kn \gg 1.0$) through transition ($0.01 < Kn < 1.0$) flow.

An improved aerodynamic heating relationship was checked out and found to be operating correctly. This relationship provides the Stanton number as a function of the Knudsen number. Previously, free-molecule heating had been used at all times.

4. Fission Product Release

The fission product inventory was determined for reentry occurring at 10, 50, 100, 200, and 2000 yr after reactor shutdown. These studies show that the primary sources of reactivity in these cases are Sr^{90} and Cs^{137} for the first three cases and Cs^{135} and Zr^{93} for the 2000-yr case. Both strontium and cesium have vapor pressures greater than zirconium; therefore, they may vaporize before the zirconium. Thus, the particle will be less radioactive when it reaches the lower atmosphere.

A model was formulated that will give a simple description of the volatilization of the

radioactive fission products from reentering SNAP fuel particles. The data necessary for this model were being obtained.

Vapor pressure equations for 12 fission product elements were derived from tabulated data by means of the least-squares method. These equations are required in PAM for extrapolation to elevated temperatures.

A tabulation of the most active fission products in SNAP fuel 1 yr after shutdown and 50 yr after shutdown was prepared. This information was obtained from the output of the FISDK (FISsion product DECAY) code and is tabulated in Tables 6 and 7.

A fission product vaporization subroutine was prepared for PAM. This subroutine will calculate the decrease in the inventory of 20 fission products by two mechanisms. The first mechanism is removal due to zirconium oxide vaporization. It is assumed that fission products are trapped in the zirconium oxide as it is formed and are removed as the oxide vaporizes. The second mechanism is the fractional vaporization of these isotopes once the zirconium oxide layer has been removed from the particle.

This preliminary study has shown that most of the fission products can be removed once the oxide coating on the particle is removed (unless their vaporization is diffusion limited).

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TABLE 6
IMPORTANT ISOTOPES ONE YEAR AFTER SHUTDOWN

Rank	Isotope	Concentration (atoms/cc)	$\frac{\text{Mev}}{\text{sec-cc}}$	Percent of Total	Half-Life
Beta Activity					
1	Pr ¹⁴⁴	0.325×10^{16}	0.229×10^8	35.6	200 day
2	Y ⁹¹	0.360×10^{15}	0.116×10^8	18.0	58 day
3	Sr ⁹⁰	0.195×10^{17}	0.932×10^7	14.6	28 yr
4	Cs ¹³⁷	0.208×10^{17}	0.792×10^7	12.3	30 yr
5	Zr ⁹⁵	0.391×10^{15}	0.544×10^7	8.4	65 day
6	Sr ⁸⁹	0.286×10^{15}	0.490×10^7	7.6	50 day
7	Kr ⁸⁵	0.930×10^{15}	0.128×10^7	2.0	10.6 yr
8	Ru ¹⁰⁶	0.483×10^{15}	0.413×10^6	0.6	1.01 yr
9	Pr ¹⁴¹	0.302×10^{14}	0.181×10^6	0.3	33 day
10	Sb ¹²⁵	0.439×10^{14}	0.149×10^6	0.2	2 yr
			0.644×10^8	99.6	
Gamma Activity					
1	Pr ¹⁴⁴	0.325×10^{16}	0.180×10^8	46.1	200 day
2	Zr ⁹⁵	0.391×10^{15}	0.104×10^8	26.6	65 day
3	Cs ¹³⁷	0.208×10^{17}	0.101×10^8	25.7	30 yr
4	Ru ¹⁰³	0.130×10^{15}	0.283×10^6	0.7	39.7 day
5	Sb ¹²⁵	0.439×10^{14}	0.222×10^6	0.6	2 yr
6	Eu ¹⁵⁵	0.892×10^{14}	0.672×10^5	0.2	4 yr
			0.392×10^8	99.9	

TABLE 7
IMPORTANT ISOTOPES 50 YEARS AFTER SHUTDOWN

Rank	Isotope	Concentration (atoms/cc)	$\frac{\text{Mev}}{\text{sec-cc}}$	Percent of Total	Half-Life (yr)
Beta Activity					
1	Sr ⁹⁰	0.579×10^{16}	0.277×10^7	51.332	28
2	Cs ¹³⁷	0.670×10^{16}	0.255×10^7	47.315	30
3	Kr ⁸⁵	0.377×10^{14}	0.521×10^5	0.966	10.6
4	Sm ¹⁵¹	0.994×10^{15}	0.208×10^5	0.385	80
5	Cs ¹³⁵	0.219×10^{17}	0.390×10^2	0.0007	3×10^6
6	Zr ⁹³	0.227×10^{17}	0.286×10^2	0.0005	9.5×10^5
7	Eu ¹⁵⁵	0.183×10^{11}	0.241×10^2	0.0004	4.0
8	Nd ¹⁴⁴	0.204×10^{17}	0.177×10^2	0.0003	5×10^{15}
			0.539×10^7	99.9999	
Gamma Activity					
1	Cs ¹³⁷	0.670×10^{16}	0.325×10^7	99.836	30
2	Sm ¹⁵¹	0.994×10^{15}	0.519×10^4	0.159	80
3	Eu ¹⁵⁵	0.183×10^{11}	0.137×10^2	0.004	4
			0.326×10^7	99.999	

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V. FUEL PROPERTIES PROJECTS

A. THERMOPHYSICAL PROPERTIES

1. Thermal Diffusivity

The thermal diffusivity of 1.81 H/Zr fuel material was measured in the range of 25 to 685°C. The data obtained are given in Table 8 and shown in Figure 11. There appears to be a slight inflection in the curve at about 580°C, which is believed to correspond to the ϵ - δ phase transition.

A 0.50 H/Zr sample was also measured in the range of 15°C to about 950°C. The data were being reduced and analyzed, but the information obtained thus far indicate that:

- 1) The room temperature value is about $0.059 \text{ cm}^2/\text{sec}$.
- 2) The temperature coefficient is slightly negative and nearly constant between room

temperature and about 400°C, the diffusivity being approximately $0.050 \text{ cm}^2/\text{sec}$ at the latter temperature.

3) The behavior above 400°C is quite anomalous; i. e., there are breaks in the curve at temperatures of about 400, 475, and 515°C.

The reduction of additional data that had been obtained was expected to narrow the uncertainty limits of these breaks in the curve.

2. Specific Heat

Three 1.81 H/Zr samples were pulse-heated to just above the apparent phase transformation temperature (about 580°C). Results of the computer analyses of the runs indicate that the specific heat values of the three samples agree within 3% in the range of 200 to 600°C, as shown in Figure 12.

TABLE 8
THERMAL DIFFUSIVITY OF 1.81 H/Zr SNAP FUEL

Temperature (°C)	Diffusivity (cm^2/sec)	Temperature (°C)	Diffusivity (cm^2/sec)	Temperature (°C)	Diffusivity (cm^2/sec)	Temperature (°C)	Diffusivity (cm^2/sec)
25	0.112	99	0.0979	672	0.0555	418	0.0645
25	0.112	98	0.0929	658	0.0528	498	0.0641
163	0.0883	96	0.0945	653	0.0592	501	0.0649
125	0.0962	88	0.0979	650	0.0531	505	0.0626
155	0.0945	87	0.0929	648	0.0528	507	0.0599
213	0.0862	58	0.101	648	0.0582	417	0.0641
233	0.0775	58	0.101	647	0.0555	510	0.0665
270	0.0723	58	0.105	648	0.0539	535	0.0626
275	0.0792	52	0.101	631	0.0558	540	0.0650
286	0.0822	52	0.104	622	0.0547	543	0.0609
306	0.0770	52	0.101	618	0.0576	548	0.0623
332	0.0759	335	0.0718	612	0.0576	552	0.0576
336	0.0743	323	0.0718	608	0.0573	555	0.0612
345	0.0748	325	0.0723	604	0.0570	560	0.060
345	0.0682	361	0.0649	601	0.0585	562	0.0579
685	0.0539	368	0.0682	601	0.0589	562	0.0612
684	0.0539	371	0.0718	16	0.106	565	0.0595
682	0.0550	369	0.0691	17	0.115	567	0.0634
682	0.0520	418	0.0619	17	0.106		
682	0.0513	418	0.0673	100	0.0921		

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Figure 11. Thermal Diffusivity of 1.81 H/Zr Fuel Sample

Figure 12. Specific Heat of Hydrided H/Zr = 1.81 (eff) Fuel Samples

Figure 13. Specific Heat of Unhydried Specimen

TABLE 9
OXIDATION AND DEHYDRIDING OF FUEL
(~ 300 cfh)

Sample No.	Run Duration (sec)	Maximum Temperature (°F)	Temperature at End of Run (°F)	Initial		Final		Hydrogen Evolved During Run (%)	Extent of Oxidation (mg/cm²)
				N _H	H/Zr *	N _H	H/Zr *		
340-1-5	33.3	1685	1648	6.37	1.811	4.67	1.332	26.45	3.26
340-1-6	33.3	1666	1665	6.37	1.811	4.59	1.309	27.70	4.18
336-4-6	37.8	1748	1657	6.35	1.808	4.80	1.366	24.45	2.51
336-4-7	38.2	1745	1651	6.35	1.808	4.57	1.301	28.03	2.76
337-6-1	38.1	1789	1685	6.33	1.800	4.62	1.315	26.95	3.19
337-6-2	48.4	1839	1732	6.33	1.800	3.51	1.000	44.47	4.41
337-6-3	50.6	1764	1764	6.33	1.800	2.98	0.848	52.91	4.83
337-6-4	51.1	1776	1762	6.33	1.800	2.94	0.838	53.41	4.67
337-6-5	66.0	2095	2095	6.33	1.800	1.77	0.505	71.96	8.60
337-6-6	65.3	2135	2135	6.33	1.800	1.42	0.404	77.52	9.74
340-1-2	100.4	2247	2247	6.37	1.811	1.01	0.287	84.17	13.47
340-1-4	110.3	2201	2201	6.37	1.811	1.21	0.346	80.92	13.27
336-4-3	140	2973	2973	6.35	1.808	0.20	0.057	96.83	34.08
336-4-4	140	3044	3044	6.35	1.808	0.30	0.085	95.30	31.61

*Total atom ratio, not effective atom ratio.

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The data for the unhydrided fuel sample were also reduced. The computer results, which represent data made on a single sample, are shown in Figure 13. The data below 300°C are believed to be sound; the data above 300°C require further investigation.

3. Drop Calorimeter

During final tests of the hydrogen drop calorimeter, Dynatech experienced repeated failure of the sheathed heaters on the copper receiver. The trouble was traced to two causes: (1) the method of flaring the sheath and (2) yielding of the clamp used to join the heater to the nickel power lead. Dynatech reported that these problems had been corrected and that the instrument was scheduled to be shipped early in the next reporting period.

4. AI-BMI Data Comparison Program

The data obtained on the unhydrided and 1.81 H/Zr samples were being critically reviewed on the basis of the information exchanged between AI and BMI. In general, the agreements in data were satisfactory. Detailed analyses of the various measurements were being made and will be the subject of a topical report to be issued in the near future.

B. OXIDATION KINETICS

Experimental work on the oxidation kinetics of solid SNAP fuel was completed. Although a complete analysis of the data had not yet been undertaken, preliminary results were available and are given in Tables 9 and 10 and Figure 14. The data were obtained using a total gas flow of ~300 cfh with the observed temperature transient indicated in Figure 14.* The results given for the amount of oxidation are based on the differences between the initial weights of

the samples and the weights obtained upon removal from the retort. These values are known to be high, because oxidation which occurred during cooling may represent a significant fraction of the total, particularly for the shorter runs. The values given must, therefore, be considered as extreme upper limits.

The values given for hydrogen loss were determined from the initial hydrogen content and the weight loss observed upon dehydriding the samples after oxidation. Dehydriding was accomplished by means of vacuum heating of the oxidized samples to 2350°F until no further weight change occurred (10 to 15 min). The assumption that only hydrogen is lost during dehydriding was verified by subjecting an oxidized sample (~21 gm) of nonhydrided alloy to the conditions used in dehydriding; no weight change was observed with a sensitivity of 0.1 mg. This observation coupled with the thermodynamic stability of the oxides, nitrides, and carbides of zirconium and uranium constitutes strong evidence, if not proof, of the validity of the assumption. The fact that the hydrogen-air flame surrounding the sample collapsed almost simultaneously with shutoff of the induction unit verifies the assumption that hydrogen evolution effectively ceased at that time.

Each of the three fuel rods (rod ends) used in the hydrided oxidation work produced a characteristic temperature transient for the first 35 sec; the transients are depicted in Figure 15. That the differences cannot be attributed to composition variables only is evident from the pretest analyses of the rods (see Table 11):

The differences may be related to structural variations including the distribution of carbide

*The observed transient in Figure 14 is the average of 3 different transients which are shown in more detail in Figure 15.

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TABLE 10
OXIDATION OF NONHYDRIDED FUEL ALLOY
(~300 cfh)

Sample No.	Run Duration (sec)	Maximum Temperature (°F)	Temperature at End of Run (°F)	Extent of Oxidation (mg/cm ²)
348-6-3	32.8	1895	1862	1.59
348-6-4	33.2	1901	1851	1.36
348-5-7	37.2	1882	1710	1.93
348-6-7	38.4	1970	1776	2.56
348-3-1	50.2	1950	1679	3.23
348-4-4	50.7	1923	1682	3.27
348-4-7	65.0	2059	2030	4.81
348-5-8	65.7	2068	2045	5.03
348-3-4	106.0	2317	2294	9.34
348-3-8	105.5	2294	2294	9.93
348-3-5	120.8	2551	2551	12.09
348-3-2	141.0	3151	3139	32.66
348-3-3	141.4	3166	3115	32.75

1-19-66

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Figure 14. Oxidation and Dehydriding of SNAP Fuel

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Figure 15. Characteristic Transients

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TABLE 11
PRETEST CHEMICAL COMPOSITION OF HYDRIDED
KINETIC STUDY SAMPLES

Rod	H/Zr (eff)	% H	% C	% U	% N	% O
336-4	1.829	1.756	0.13	10.21	0.0085	0.0660
337-6	1.818	1.749	0.11	10.23	0.0080	0.0630
340-1	1.833	1.758	0.14	10.26	0.0105	0.0980

"stringers." Metallographic examination, which was in progress, may reveal the cause.

A comparison of the values in Tables 9 and 10 shows that the hydrided fuel apparently oxidized to a greater extent than the nonhydrided alloy. This anomalous behavior is believed to result from two causes: (1) the calculations are based on original surface areas of the samples and do not reflect the significant increase in surface area produced by cracks during dehydriding of the hydride fuel; and (2) liberation of hydrogen from the hydrided samples during the run tended to shield the sample surface from oxygen. Thus, when the heating transient was stopped, hydrogen evolution ceased and the relatively clean sample surface was exposed to large quantities of air at high temperature. In the nonhydrided material, the sample surfaces were oxidized at the lower temperatures and this low-temperature oxide film provided some protection to reduce the amount of oxygen pickup at high temperatures.

A more precise analysis of the data will be undertaken using appropriate oxidation rate constants to determine the amount of oxidation taking place after the end of the runs. It may be possible, after the metallographic examination is completed, to estimate the area added by cracking and thus further improve the accuracy of the values.

The values reported in the progress report for the preceding period (NAA-SR-11697) for oxidation of the unhydrided fuel alloy are given in Table 12. These results were obtained using a lower flow rate (~57 cfh) and the desired temperature transient indicated in Figure 14. The differences between these results and those given in Table 9 are of the order of 30% for the longer runs. A more precise analysis of the data for Table 10 will certainly reduce this discrepancy and perhaps eliminate it. Thus, it is unlikely that significant oxygen "starvation" occurred at the lower flow rate, and the values reported in Table 12 are valid.

Equipment and materials were being prepared for the study of the oxidation kinetics of molten fuel alloy. Preliminary experiments were planned to determine the proper coil configurations to obtain levitation and heating of the samples.

C. EMISSIVITY STUDIES

The combination sample holder and concentrator coil for inductively heating samples for emissivity measurements was designed and fabricated. Initial tests on this device indicated that a uniform sample surface temperature could be maintained. Further work on this program was stopped because of program redirection. It was anticipated that this work will be resumed at the beginning of the next fiscal year (FY 1967).

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TABLE 12
OXIDATION OF NONHYDRIDED FUEL ALLOY
(~57 cfh)

Sample No.	Run Duration (sec)	Maximum Temperature (°F)	Extent of Oxidation (mg/cm ²)
348-6-5	40.8	2125	3.41 ± 0.19
348-6-8	42.8	2128	3.67 ± 0.45
348-2-1	57.4	2122	4.67 ± 0.33
348-2-2	75.7	2118	5.71 ± 0.43
348-2-3	76.8	2115	5.37 ± 0.43
348-2-4	92.8	2167	6.69 ± 0.17
348-2-5	105.0	2249	7.03 ± 0.34
348-2-6	105.4	2255	7.67 ± 0.17
348-2-7	120.2	2586	9.70 ± 0.45
348-2-8	121.2	2611	9.68 ± 0.35
348-5-1	130.4	2964	16.18 ± 1.17
348-5-2	131.4	3009	13.79 ± 0.88
348-5-3	140	3081	22.31 ± 0.44
348-5-4	140	3081	24.27 ± 1.78

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VI. REACTOR DISPOSAL PROJECTS

A. REACTOR DISPOSAL PROOF-OF-PRINCIPLE EXPERIMENT

A test plan was prepared designed to determine the residual particle size resulting from destruction of SNAP fuel rods by explosive charge detonation. Since it is possible that particles in the 1000- to 2000-micron range may not ablate during reentry, it is important to minimize the fraction of the fuel rod residue in that range which will fall. The primary test objectives were established: (1) to verify the feasibility of fuel element rupture and fuel dispersal by explosive destruct, (2) to determine fuel residue particle size as a function of explosive charge size, and (3) to optimize the explosive charge location for destruction of a fuel element bundle.

A study was begun to compile the data obtained from a literature search of the work performed by other agencies on destruct charge analyses and explosive materials evaluation.

B. ATMOSPHERIC FALLOUT EXPERIMENTS

A report⁽⁶⁾ outlining a suggested program for atmospheric fallout experiments utilizing gun-launched probes was published. In this report, an analysis of the factors affecting particle deposit concentration at the earth's surface which result from the injection in the high atmosphere of radioactive particulate is presented. The need for experimental measurements of particle cloud growth is outlined. Techniques for utilizing gun-launched probes to place selected particles at appropriate altitudes and observe the fallout are described. Finally, an experimental procedure for conducting atmospheric fallout tests is outlined and the requirements for data collection and analysis are presented.

In the preparation of a plan for the conduct of the experiments, the application of sampling

theory was made to determine the maximum and minimum sized anomalies that can be defined or resolved for a given area and the number and spatial distribution of sample points. The identification of the "best" distribution of sampling points cannot be made without first defining the size of the anomaly to be delineated. Based on a Fourier series representation of the values along a line of the parameter to be sampled, it can be shown that the smallest anomaly which can be resolved is

$$a = \frac{2L}{n-1},$$

where

a = smallest anomaly

n = number of sample points over a line, L.

For a parameter gradient ($\delta G / \delta x$) along a line, the equivalent error in the parameter, ΔG , for a given error in position Δx , is given by

$$\Delta G = \frac{\delta G}{\delta x} \times \Delta x.$$

Also, this expression can be used to express the accuracy of the measurement in terms of the parameter gradient and the spacing of the sample points. Only three sampling points are required to define the gross features of a variable along a line.

Several references were reviewed to assist in the development of a detailed plan to experimentally measure the particle cloud growth in the atmosphere. The results of Dr. P. D. Thompson's work on the optimum smoothing of two-dimensional fields is pertinent to the question of the appropriate placement of sample collectors in measuring particle

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fallout at the earth's surface. Dr. Thompson has studied the problem of smoothing nonsystematic errors in a two-dimensional field of measurements from the standpoint of finding the type of weighted area average for which the root-mean-square difference between the true field and the weighted average of the field of observations is the least.

An analysis of wind measurements was made as part of the fallout studies. This analysis confirmed that wind gusts (the difference between peak and lull speeds) are directly proportional to the value of the average wind. This specific study revealed that the range in speed is given by $R = 0.78 \bar{V}$, where $\bar{V}$ is the average wind velocity. For these data, the gusts were not symmetrically distributed about the average value. Maximum values were found to be $1.44 \bar{V}$, while minimum values were $0.66 \bar{V}$. This implies that the duration of peak values is only 77% of the duration of lulls.

The use of dye marker to measure fallout was under investigation. The U. S. Army Chemical Corps conducted drop tests to evaluate

atmospheric dispersal of bomblet clusters, using sodium salt of fluorescein dye in the ocean and in the Great Salt Lake. The open ocean and Chesapeake Bay tests were unsuccessful and the Great Salt Lake tests were quite sensitive to wind and surface conditions. Recently, personnel from Lamont Geophysical Observatory, Columbia University, were successful in using liquid rhodamine dye in the open ocean to study ocean circulation and the behavior of fluid contaminants. Aerial photographs were taken and data were obtained even though surface winds exceeded 25 mph. It appears that dye can be used in the ocean if sufficiently high concentrations are obtained.

Copies of the draft of "Radiological Aspects of Reentry Burnup of SNAP Reactors"⁽²⁾ were transmitted to the AEC for review and approval. The report recommends that for planning purposes, $1/8$ the ICRP population dose limit, 0.25 rem/30 yr, be taken as the allowable dose from SNAP reactor applications. This dose limitation would permit the use of reentry burnup for about 100 SNAP 8-type reactors per year.

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VII. REACTOR TRANSIENT PROJECTS

A. SNAPTRAN-2 EXPERIMENT

A series of tests was completed in which scrams were made on both the A and D impulse drive units from points on each side of the scram cam dead band, as well as from points on top of the cam, and from the point where the drive pistons first contact the snubbers. All scrams were satisfactory with no failures. It was also determined that the drive pistons contact the snubbers at 323 degrees on each unit, which is approximately 20 to 23 degrees before the top of the scram cam.

Three types of tests were conducted at the IET in preparation for the SNAPTRAN-2 destruct test: (1) shake tests were performed by firing the reactor control drums to note if the machine would affect EG&G and PPCo photography; various drive pressures up to 1000 psi were used on the impulse drives with steeper drive pressures being limited to 350 psi; (2) control drum synchronization tests were conducted to determine how closely drum release times could be controlled; (3) systems noise tests were conducted to determine how much interference was introduced into detector signals by firing the EG&G flash lamps; various changes in equipment grounding and shielding resulted in a 90% reduction in noise effects; the remaining noise on the nuclear temperature energy probe and strain detectors is within acceptable limits.

To improve drum synchronization, the stainless-steel coupling clutch chain was replaced with a stronger, carbon-steel chain. A mechanical method of clamping the coupling clutch was chosen instead of welding the coupling clutch closed. This will permit clamp removal for drum synchronization tests prior to the destruct test.

The impulse unit tooth clutch splines were lubricated with graphite in an attempt to shorten the tooth clutch release times on the impulse drive unit. This improved the release times, but the graphite caused the tooth to release at lower drive pressures. The clutch-holding voltages were increased to 30 volts, but the clutches still would not hold at drive pressures greater than 980 psi. Work on this problem was continuing.

The loading of the SNAPTRAN-2 fuel elements was completed according to the approved test series proposal. Several control circuit changes were made on the control system. Tests were conducted to verify proper machine performance following these changes. Installation and hookup of wiring for the instrumentation and detectors associated with the destruct test were completed. Flux wires were inserted into the -2 core and a power calibration test was conducted. The control drum shim configurations tests were initiated and the Drum-A vs Drum-D calibration was completed.

Installation of additional shielding material on the EG&G camera dolly was completed, and the final alignment of mirrors was performed for both the EG&G and PPCo photography. Instrument and detector installations and hookups were completed, including installation of the LASL capsule.

Transient testing of the SNAPTRAN-2 reactor was initiated at the IET by performing coupled drum step test No. 329. The reactivity insertion was \$1.03. Tests No. 330 and 332 were also performed. Each had \$1.03 reactivity insertion.

A planning meeting was held to discuss the SNAPTRAN-2 destruct test and proposed dry-run test. Installation of fuel element displacement detectors and other instrumentation was completed by both EG&G and PPCo personnel.

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A \$1.03 steptransient test was performed in conjunction with the dry-run test. Results of this test, No. 334, were as follows:

Peak power	12.6 Mw
Energy to peak power	0.38 Mw/sec
Energy total	0.80 Mw/sec
Period	18.9 msec
Reactivity	\$1.036
Average temperature	78°F
Maximum temperature	130°F

During test No. 334, it was observed that the simulation detectors of PPCo and EG&G had gross sensitivity differences, although manufacturer and design sensitivity values were used to determine calibration values. The EG&G detector saturated approximately two decades before peak power occurred. Further analysis of transient data and additional simulated tests were made to accurately determine the correct sensitivity for the EG&G detectors.

Control drum synchronization tests were performed on both of the impulse drive units. Drum synchronization within 1 msec at zero degrees was achieved with drive pressures of 100 and 500 psi.

A nonnuclear, dry-run test was performed. It was found that scram times on the impulse units were 2 and 7 msec on the A and D units, respectively. These times were taken after the machine had been exposed to an ambient temperature of approximately 2°F as may be expected at the NRTS at this time of year.

A second nonnuclear, dry-run test was conducted to evaluate the countdown procedures. All phases of the countdown were termed successful, except that premature starting of the high-vols on the radiological grid network masked the data channels on all transports. PPCo planned to perform one dry-run test every two weeks until the destruct test is performed. A minimum of one additional

successful dry-run test will be required before the destruct test.

PPCo began patchwork and continuity checkout tests on all data transports in preparation for the destruct test.

B. ANALYSIS

1. SNAPTRAN-1

The remainder of the data from the SNAPTRAN-1 test series was received and the initial data reductions and analysis were completed. These final transients were coupled drum step tests, of which several were initiated at elevated temperatures. A summary of the initial analysis of these transients is presented in Table 13. This series of tests provided temperature coefficient information at the highest core temperatures in the SNAPTRAN-1 test series.

This essentially completed the initial data reduction for the SNAPTRAN-1 test series. Emphasis was then shifted to evaluating and correlating the results. The major effort was concentrated in those areas which are concerned with understanding the temperature coefficient results.

A complete summary of the SNAPTRAN-1 results was prepared for evaluation and to assist in energy probe calibration and temperature profile studies. This included a detailed compilation of all data channels used in the analysis of each transient. Also, a summary of thermal cycling for the SNAPTRAN-1 fuel was compiled.

Several improvements and refinements were made to the data analysis portion of the COMPOST computer program. These include an improved straight-line fit to the plot of compensated reactivity ($\Delta\rho$) vs average core temperature change (ΔT). This gives a more accurate average temperature coefficient. Also, a plot of P/T was added to give heat capacity.

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TABLE 13
INITIAL RESULTS FROM FINAL COUPLED STEP TESTS SERIES

Test No.	Drum-Inserted Reactivity (\$)	Stable Period (msec)	Peak Power (Mw)	Total Energy Release (Mw-sec)	Initial Temperature (°F)	Maximum Average Core Temperature* (°F)	Temperature Coefficient† (¢/°F)
249	1.50	1.6	1500	10.6	212	702	-0.20
250	1.37	2.1	840	8.5	705	1040	-0.19
251	1.20	4	380	6.6	935	1148	-0.20
252	1.17	5	270	5.4	1110	1285	-0.20
253	1.7	1	2280	11.2	95	790	-0.20
254	1.39	2	781	8.0	690	1031	-0.18
255	1.20	4	350	6.2	935	1142	-0.19
256	1.15	5	250	5.7	1110	1285	-0.20

*This is the maximum temperature just after the power burst. It does not include the effect of delayed gamma heating.

†Temperature coefficients based on volume-weighted average core temperature change obtained from energy probe data.

Due to the improvements in analysis techniques and input parameters, a new analysis of several prompt critical transients from the initial step test series was performed. This was done primarily to allow the comparison of all prompt critical step tests on an equal basis. The main improvements, besides those described above, included changing the prompt neutron lifetime from 6.25 to 6.60 μ sec, elimination of those energy probes which appear to be giving erroneous results, and not allowing the temperature coefficient calculation to go as far beyond peak power. The changes in temperature coefficients brought about by this new analysis is summarized in Table 14.

As can be seen from the table, the corrections had the largest effect on the higher reactivity steps, since the lifetime correction is more important in these. The corrected results can now be compared on an equal basis with results from recent step tests, such as those given in Table 13.

Since the temperature coefficient results depend directly on the energy probe calibration,

TABLE 14
COMPARISON OF ORIGINAL AND IMPROVED TEMPERATURE COEFFICIENT RESULTS FROM ORIGINAL STEP TEST SERIES

Test No.	Stable Period (msec)	Original Temperature Coefficient* (¢/°F)	Improved Temperature Coefficient (¢/°F)
128	8.2	-0.15	-0.13
131	5.3	-0.14	-0.14
133	3.3	-0.15	-0.15
136	2.4	-0.16	-0.15
138	2.4	-0.14	-0.15
140	2.0	-0.15	-0.17
142	1.7	-0.15	-0.16
144	1.7	-0.15	-0.16
159	1.3	-0.14	-0.16

*All temperature coefficients based on volume-weighted average temperature from energy probe data.

an extensive investigation of energy probe behavior and calibration was initiated. The energy probes from which good data were available in the SNAPTRAN experiments varied somewhat in the different series of tests. As a result, the

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same probes were not used in the temperature coefficient analyses of all transients. The temperature coefficient was found to vary over a large range (from -0.13 to -0.20 $\epsilon/^\circ\text{F}$). To determine whether some of this variation resulted from the use of different groups of energy probes, a second analysis of the temperature coefficient was made using data from a single probe common to a number of the transients. The results were found to be in excellent agreement with those previously obtained. It is concluded that the temperature coefficient determined with energy probe temperatures does vary from test to test and the variation is not a strong function of the particular group of probes selected for analysis.

A post-test metallurgical examination of the energy probes used in the SNAPTRAN-1 test series was being conducted. Numerous probes were disassembled and examined. All the probes of the metal-trough design (all of the probes built after the first few were of this design) appeared to be intact except for the 0.5-mil thermocouple wire on some probes. It was difficult to remove the MgO which surrounds these wires without disturbing them; however, this may account for the damaged condition of some disassembled probes.

Fuel samples from several representative probes were being photomicrographed. From these, the phase, general condition, amount of surface contamination, etc, of the fuel samples can be determined. These photomicrographs will include polished cross-sections, made at the positions where the thermocouple wire is attached to the fuel; and they will aid in evaluating the microscopic heat transfer between the fuel and thermocouple wire.

The response time constant of the energy probes used for temperature measurements in the SNAPTRAN-1 experiments was analytically

estimated to be in the range of $100\mu\text{sec}$ or less. The maximum fuel heating rate in these experiments was about $500,000^\circ\text{F}/\text{sec}$. At this heating rate, the error in the temperature coefficient, computed directly from energy probe data, would be small and would not explain the apparent shift to larger temperature coefficients (-0.13 to -0.20 $\epsilon/^\circ\text{F}$) as the peak power increased. The good linearity between energy obtained from power data and energy from probe data also verifies that temperature lags are small.

The standard deviation of energy densities from the energy probe data to the theoretical fission density distribution was found to be in the range of 10 to 13%. The agreement of data from the different types of energy probes is shown in Table 15. The data shown are for a representative time during transient 142.

TABLE 15
MEAN FUEL ENERGY DEPOSITION FROM
ENERGY PROBES DURING
TRANSIENT 142

Type of Energy Probe	Number of Probes of This Type	Mean Fuel Energy Deposition (Btu/lb)
5 wt % U-Zr	8	$50.7 \pm 6.4^*$
5 wt % U-Zr-H _x	4	$48.4 \pm 4.8^*$
10 wt % U-Zr-H _x	9	$50.4 \pm 6.5^*$
10 wt % U-Zr	1	42.8^*
0 wt % U-Zr-H	1	2.6

*Corrected to represent mean energy generation in SNAPTRAN fuel (10 wt % U-Zr-H_x)

The uncertainty in calculating mean fuel temperature from energy probe data in this particular test is thus expected to be in the range of 13% when heat transfer and flux depression effects are not important.

A detailed investigation of the temperature profile was being conducted using the SCRAP computer program. This program fits the energy probe data to the theoretical profile and plots the results at specified times throughout

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the transient. This allows both evaluation of the theoretical profile and isolation of probes which produce anomalous results.

The analysis of the control drum interaction experiments was completed. A difference of about 3% was found in the worth of inserting two opposite drums vs two adjacent drums. A smaller amount of interaction attributed to drum-to-drum scattering was also observed. Some interaction effect in drum calibration due to the method of calibration was found, primarily in the region beyond the 90-degree angle (nearly full out). The errors observed are expected to lead to errors considerably smaller than 3% in the actual SNAPTRAN experiments, thus, these errors are expected to be of no consequence.

A system for combining SNAPTRAN transient data on a master storage tape was completed. The transients are stored in files containing about 5 transients each, with about 5 files per tape. The master tape was checked out and is directly usable by COMPOST. This development makes possible permanent storage of the SNAPTRAN transient data, using only a small number of tapes.

2. SNAPTRAN-2

Data from SNAPTRAN-2 transient No. 332 were received and the initial analysis was completed. The transient was initiated by a \$1.03 coupled step reactivity insertion. A peak power of 9.5 Mw was attained, with a total energy release of 1.04 Mw-sec. The average core temperature rise was 78°F. A prompt temperature coefficient of $-0.13\text{¢}/^\circ\text{F}$ was calculated. This result is generally in agreement with those obtained from similar transients in the beginning of the SNAPTRAN-1 test series, but is significantly lower than the result of the later -1 tests run at higher reactivities.

AI personnel attended a meeting at the NRTS to discuss the SNAPTRAN-2 destruct test. The

drum shimming configurations to be employed in initiating the destruct test were discussed. Specific information was obtained concerning the time history of impulse drum positions expected during such a destructive experiment. Based on this information as well as certain criteria established at the meeting, a series of calculations was performed to determine what shimming configurations should be employed.

Several SNAPKIN-VI transients were calculated to determine whether or not the impulse drums should be shimmed during the SNAPTRAN-2 destruct test. X-Y plots of impulse drum position vs time were obtained from mechanical checkout runs of the destruct drum drive mechanism. These traces were used in conjunction with appropriate drum calibration curves to determine reactivity insertion traces for input to SNAPKIN.

In the calculations, the impulse drum motion was assumed to start just after the shimmed stepper drums were stepped to their full-in position. The reactivity was taken to be \$0.85 with the stepper drums full in. Initial powers of 0.1 and 1.0 mw were considered.

These calculations indicate that for the shimmed case, the full reactivity cannot be inserted before sensible heat generation ensues. All but a few cents of the full reactivity can be inserted, however, with the impulse drums unshimmed. The addition of the shims not only increases the total reactivity being inserted by about \$0.50, but broadens the input reactivity pulse near the full-in position.

The power excursion from the \$3.60 reactivity insertion in the SNAPTRAN-3 experiment resulted in complete core disassembly. The prompt neutron lifetime in the case of a beryllium-reflected flight reactor (SNAP 10A) is about half that in the water-reflected case. As a result, it is expected that a step insertion of about \$2.50 is needed to cause a similar excursion

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in the beryllium-reflected reactor. Computations with the SNAPKIN code show that reactivity insertion rates on the order of \$80/sec are required to achieve \$2.50 prior to fuel heating and reactivity feedback effects. The last \$1.50 of reactivity insertion would have to occur in a time interval of about 20 msec.

Subsequently, a partially shimmed configuration was decided upon. In this configuration, the stepper drums are fully shimmed and the impulse drums are partially shimmed. Criticality measurements and drum calibrations were performed with the following results:

Shutdown margin (all drums full out):	-\$4.28*
Total excess reactivity (all drums in):	\$4.96*
Worth per drum:	\$2.31

The fact that the fully shimmed stepper drums had the same worth as the partially shimmed impulse drums is apparently due to the impulse drums being slightly closer to the core than the stepper drum. The drum calibrations were made with the drums coupled.

Preliminary calculations were completed to evaluate the new SNAPTRAN-2 drum configuration. These calculations indicate that all the reactivity (\$4.90) can be inserted before any significant temperature rise has occurred. The calculations were based on starting powers of both 0.1 and 1.0 mw. It also appears that this reactivity insertion can be accomplished if the impulse drums are as much as 1 msec out of synchronization.

The Fuch-Nordheim-Scalletar (FNS) model was applied to the SNAPTRAN-2 transient to check existing computer calculations. The results compared well with the FNS model, giving somewhat higher peak power than the SNAPKIN-VI

computer code. This was as expected because of the assumptions in the FNS model of linear variation of heat capacity with temperature, which is thought to overestimate heat capacity at high temperature.

A SNAPTRAN-2 assembly in-hour plot was prepared using current data and a correction for reflector thermalization delays. The periods (τ) resulting from several reactivities (ρ) of interest are shown in Table 16. The error that would result if these data were analyzed without the reflector correction was also determined. If the period (τ) was observed in an experiment and was analyzed without the reflector correction, the reactivity (ρ_6) would be calculated. The difference ($\Delta\rho$), as tabulated, would be the error resulting from ignoring the reflector thermalization delay.

TABLE 16
ERROR INCURRED IN REACTIVITY
CALCULATIONS BY IGNORING
REFLECTOR EFFECTS

Reactivity, ρ (\$)	Period, τ (msec)	Calculated Reactivity, ρ_6^* (\$)	Difference in Reactivity, $\Delta\rho$ (\$)
4.10	250	4.22	0.12
4.20	242	4.34	0.14
4.50	221	4.67	0.17
4.90	197	5.10	0.20
5.10	187	5.32	0.22
5.50	170	5.77	0.27

*Period analyzed without reflector correction.

The error at \$4.10, approximately the highest reactivity reached in the impulse tests, does not add significantly to the uncertainty in drum calibrations, estimated at about 5%. The error, however, at \$4.90 or \$5.10 would be of some concern. It would be especially significant in the analysis of the temperature coefficient from the -2 results, since most of the error would apply to the ~\$2 compensation by temperature

*These values include an additional 11¢ introduced by the presence of the LASL test capsules.

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before core disassembly begins. This indicates that a spatially dependent neutron kinetics analysis may be of some significance in the analysis of the -2 results, as well as the -3 results.

The code which computes the energy released during disintegration of a spherical reactor core

was modified to include adiabatic cooling of the expanding hydrogen gas. Using values of the input parameters appropriate for the SNAPTRAN-2 test, the calculated energy releases were 47.2 Mw-sec with cooling and 45.6 Mw-sec without cooling.

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VIII. CRITICAL CONFIGURATION PROJECTS

DTF-II calculations of the worth of axial water reflector above the SCA-4B core indicate a difference of about 5% between the 37-rod assembly and the 31-rod, 6-lucite-rod, assembly. The latter was the experimental configuration used for measuring the worth of this water. Since the upper tank water is worth a total of only about \$1.50, the 5% represents only a negligible correction to the experimental results. This correction would probably be even smaller for the sea water experiments. Corrections to the pulsed source experiment might be more important when radial water is being added (bottom 4 in. of the upper tank). This was being investigated.

The DTF-II calculations indicate that the reactivity worth of the entire upper-tank water used for the SCA-4B experiments is only slightly dependent on the core loading. (The upper tank provided top axial reflection and radial reflection of the top 1/3 of the fuel array.) The calculated difference between the worth of this water for the case of 31 fuel rods and 6 lucite rods and that for the case of 37 fuel rods and no lucite rods is only 35¢.

In a water environment, the bare S8DS reactor was calculated to be \$4 more reactive than S8ER. This increased reactivity is primarily due to the increased fuel length and the increased concentration of U^{235} . Based on a \$6 excess reactivity measured for the S8ER core in a water environment, the S8DS core will be \$10 supercritical in water.

The relationship between core diameter and core length which ensures subcriticality in water was determined for a core of SNAP 8 material compositions. These vary from a 10-in. length for the present SNAP 8 core diameter of 9 in. to a 22-in. length for a core diameter of 7.5 in. The reactivity in water is relatively insensitive to increased core lengths above ~25 in.

Calculations were also completed to determine subcritical core geometries with 4.0, 3.2, 2.0, and 1.0 in. of BeO axial reflector and with SNAP 8-type fuel compositions.

A computer program was developed to assist in determining the weight penalty associated with intrinsically subcritical (in water) SNAP 8-type reactors.

Critical core lengths, as a function of radii, were calculated for the core geometry study experiments (see Figure 16). These are experiments with the SCA-5 fuel in an infinite

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Figure 16. Estimates of Critical Dimensions for Core Geometry Study Experiments

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water environment. The experimental design limits the maximum core dimensions to 24 in. in length and 11.3 in. in diameter. The available fuel limits the variation in critical dimensions within these geometries. The present study shows that within the framework of these limitations, the critical fuel length may be varied by 70%. This variation in core geometry is greater than that expected in planned SNAP-type reactor designs. The pre-experimental analysis of the geometry study experiments was extended to the study of reactivity effects of BeO axial reflectors of 1.0, 2.0, and 3.0 in. in length. The purpose of this analysis is to provide a general outline for the experimental program.

The incremental reactivity worth of water height on the SCA-5 fuel assembly was estimated for the purpose of establishing test procedures in the water immersion experiments. These experiments are limited to a 2¢/sec rate of increase in reactivity. A simple model was used which assumed the incremental worth to be proportional to $\cos^2$ over the fuel length. Incremental worths of ~\$3.2/in. and \$5.5/in. were calculated for 26- and 9-in.-long fuel arrays, respectively. These numbers estab-

lish the maximum water fill rate allowable in these experiments.

As a check on the validity of recently reported water reflector worth calculations for SNAP 10A-type (SCA-4B) cores, radial bucklings were calculated as a function of bare core height for a number of heights in the range of interest. It was found that the bucklings are independent of the assumed bare core height. Therefore, the reported calculations, which assumed constant radial buckling for small changes in the water reflector height, do not contain serious errors.

Hardware for the core geometry study experiments was assembled. Delivery of the BeO axial reflectors was delayed, but a partial shipment was delivered so that the experiments could begin the first week of December as scheduled.

The loading of 9 in. of SCA-5 fuel pellets into the fuel tubes for the SCA-4B critical assembly was completed and loading approach to critical was initiated (see Figures 17 and 18). A 12-in.-diameter array was found to be somewhat supercritical in a water environment. Removal of fuel pellets was initiated to determine the critical fuel height.

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Figure 17. SCA-4B Machine Modified for Core Geometry Experiments

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Figure 18. Partial Fuel Tube Array for Core Geometry Experiments

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IX. END-OF-LIFE SHUTDOWN PROJECT

A comparison of the dissociation pressures of $\text{ZrH}_{1.66-1.80}$ and $\text{ZrH}_{1.57-1.71}\text{T}_{0.09}$ was made. Additional dissociation pressure data were obtained for ZrH_x and ZrT_y (using 97% pure tritium). The methods and equipment employed in these experiments have been described in previous progress reports.^(1,7,8) The results of these tests are given in Tables 17 and 18, and are graphically represented in Figures 19 and 20.

Figure 19 is a plot of the data for $\text{ZrH}_{1.66-1.80}$ and $\text{ZrH}_{1.57-1.71}\text{T}_{0.09}$ (~5% tritium). As depicted by the dotted curve, the ZrH-T sample apparently has a slightly higher dissociation pressure over a portion of the range of the temperatures investigated. The remainder of the points fall on a single smooth curve.

Figure 19. Dissociation Pressure vs Temperature Curves for $\text{ZrH}_{1.66-1.80}$ and $\text{ZrH}_{1.57-1.71}\text{T}_{0.09}$

Figure 20 represents the dissociation pressure and calculated isochore data obtained for ZrH_x and ZrT_y . The dotted curves represent the data from which the isochores were derived. The tritium gas employed in these tests was analyzed during and at the conclusion of these measurements and was found to be 97% tritium (remainder hydrogen). No attempt was made to correct the data to 100% tritium.

The isochore plots included in Figure 20 for H/Zr and T/Zr ratios of 1.70 show that ZrT_y has about a 40% higher dissociation pressure than ZrH_x when $x = y$. At the recommended tritium concentrations, (9, 10) ~0.01 to 1.3% of the total hydrogen, this difference will be insignificant. This conclusion is supported by the dissociation pressure comparisons made on ZrH_x and $\text{ZrH}_{x-y}\text{T}_y$ with tritium concentrations of

Figure 20. Dissociation Pressure vs Temperature Curves for ZrH_x and ZrT_y (including 1.70 isochore)

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TABLE 17
COMPARATIVE DISSOCIATION PRESSURE
DATA FOR $ZrH_{1.66-1.80}$ AND $ZrH_{1.57-1.71}T_{0.09}$

Temperature (°C)	Pressure (mm Hg)	H/Zr	(H + T)/Zr
577	42.2	-	1.805
596	56.6	1.803	-
620	106.1	-	1.788
643	144.5	1.779	-
682	265.4	-	1.742
684	269.0	1.743	-
691	288.8	1.739	-
714	358.7	-	1.716
768	534.8	-	1.666
776	547.2	1.666	-

1 and 5%.⁽¹⁾ The bodies of data for the hydride and the tritide samples (see Figure 20) provide a good comparison of their dissociation pressures. The hydride data, however, do not agree with those of J. W. Raymond.⁽¹¹⁾ An argument could be presented to explain this difference on the basis of high concentrations of interstitial impurities present in the zirconium used by Raymond. But this is felt to be of minor importance in view of the objective of this work, which is to compare the dissociation pressures of ZrH_x , ZrT_y , and $ZrH_{x-y}T_y$.

Table 19 is a compilation of the results of 1500°F annealing tests that were conducted on a series of zirconium - 10 wt % uranium fuel samples containing 0.15 wt % carbon. Experimental methods have been described in a previous quarterly progress report.⁽¹²⁾ Briefly, sample preparation consists of hydriding and tritiding SNAP fuel specimens and subsequently allowing the tritium to decay to 3_2He prior to annealing. When annealed at elevated temperatures, the 3_2He can possibly migrate, collect as small gas pockets, and exert a significant gas pressure on the surrounding metal. If this pressure should exceed the strength of the metal matrix, deformation of the fuel body will

TABLE 18
DISSOCIATION PRESSURE DATA
FOR ZrH AND ZrT

Temperature (°C)	Pressure (mm Hg)	H/Zr	T/Zr
608	163.1	-	1.799
654	272.3	-	1.748
678	318.0	-	1.726
693	346.1	-	1.712
716	391.1	-	1.691
625	145.7	1.807	-
658	224.0	1.770	-
682	269.8	1.749	-
707	322.1	1.725	-
737	383.1	1.695	-
675	204.8	-	1.703
700	255.2	-	1.680
730	319.5	-	1.651
646.6	130.7	1.745	-
675	174.6	1.726	-
722	263.2	1.691	-

occur. The extent of this deformation can be measured by means of density techniques.

As indicated by Table 19, only small amounts of swelling occurred in these samples. The recommended tritium concentration⁽¹⁰⁾ (1.6×10^{19} atoms/cc uniformly distributed in all fuel rods within the SNAP 8 core) would form considerably smaller quantities of 3_2He , after several years of reactor operation, than used in these tests. Therefore, the conclusion has been reached that at the temperatures used in these tests, 3_2He concentrations as high as 3.5×10^{19} atoms/cc will contribute little to gas-induced fuel swelling.

As noted, samples 1, 2, 4, 5, and 7 were previously annealed at 1300°F. The remainder of the samples were "aged" at room temperature until the desired 3_2He concentration was obtained. Samples 12, 13, 15, and 16 cracked during the 1500°F annealing cycle. Visual examination prior to annealing indicated that

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TABLE 19
RESULTS OF 1500°F ANNEAL OF FUEL-SWELLING SAMPLES

Samples *	(H + T)/Zr	$^2\text{He}^3$ Concentrations at Time of Anneal (atoms/cc $\times 10^{19}$)	Total Time at Temperature (hr)	Cumulative Change in Density (g/cc $\pm$ 5 mg/cc)
1	1.68	1.5	21	+0.006
2	1.68	1.5	21	0
4	1.68	3.5	21	-0.010
			87	-0.009
5	1.68	3.5	21	-0.006
			87	-0.005
7	1.68	3.1	21	-0.002
			87	-0.003
9	1.63	1.6	42	-0.005
			91	+0.002
10	1.63	1.6	42	-0.007
			91	0
11	1.63	1.6	42	-0.002
12	1.37	3.5	22	(cracked) -0.009
13	1.37	3.5	22	(cracked) -0.011
15	1.63	3.5	22	(cracked) -0.001
16	1.63	3.5	22	(cracked) -0.004

*Samples 1, 2, 4, 5, and 7 were annealed ~900 hr at 1300°F prior to annealing at 1500°F.

SAMPLE 13

SAMPLE 15

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Figure 21. Photomicrographs of Samples 13 and 15 After a 1500°F Annealing Cycle (8X)

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they were free of surface cracks. Photo-macrographs of the polished sections of Samples 13 and 15 are shown in Figure 21; these are typical of the cracking which also occurred in Samples 12 and 16.

No conclusions had been reached in determining why these samples cracked. Additional tests will be performed to study this occurrence.

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REFERENCES

1. "SNAP Aerospace Safety Quarterly Progress Report, April-June 1965," NAA-SR-11497 (CRD) (March 15, 1965)
2. C. A. Willis, "Radiological Aspects of Re-entry Burnup of SNAP Reactors," NAA-SR-11761 (to be published)
3. M. Hock, M. Nakata, and H. L. Johnson, "Vapor Pressure of Inorganic Substances XII, Zirconium Dioxide," J. Am. Chem. Soc., Vol 76, 2651 (May, 1964)
4. M. Nakata, R. L. McKisson, and B. D. Pollock, "Vaporization of Zirconium Oxide," NAA-SR-6095 (April 15, 1961)
5. L. S. Nelson, "Combustion of Zirconium Droplets Ignited by Flash Heating," Presented at the Combustion Institute, Western States Section, Salt Lake City, Utah, October 26 and 27, 1964 (August 30, 1964)
6. C. V. Hendricks and C. A. Willis, "A Suggested Program for Atmospheric Fallout Experiments," NAA-SR-MEMO-11551 (December 1, 1965)
7. "SNAP Aerospace Safety Quarterly Progress Report, July-September 1964," NAA-SR-10497 (CRD) (November 15, 1964)
8. "SNAP Aerospace Safety Quarterly Progress Report, October-December 1964," NAA-SR-10797 (CRD) (February 15, 1965)
9. D. G. Oliver and C. A. Willis, "Evaluation of an End-of-Life Shutdown Device for Nuclear Reactors," NAA-SR-9231 (CRD) (March 15, 1964)
10. L. I. Maki, "Inherent Shutdown Mechanism for SNAP 8," NAA-SR-MEMO-10488 (CRD) (September 28, 1964)
11. J. W. Raymond, "Equilibrium Dissociation Pressures of the Delta and Epsilon Phases in the Zirconium-Hydrogen System," NAA-SR-9374 (May 31, 1964)
12. "SNAP Aerospace Safety Quarterly Progress Report, July-September 1965," NAA-SR-11697 (CRD) (August 15, 1965)

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