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QUARTERLY TECHNICAL PROGRESS REPORT

SNAP AEROSPACE SAFETY PROGRAM

JULY – SEPTEMBER 1962

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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NUCLEAR TECHNOLOGY – AEROSPACE SAFETY
PROPULSION SYSTEMS AND
ENERGY CONVERSION
56 PAGES

# QUARTERLY TECHNICAL PROGRESS REPORT

# SNAP AEROSPACE SAFETY PROGRAM

JULY – SEPTEMBER 1962

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.
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## FIGURES



This is the first in the series of SNAP Aerospace Safety quarterly progress reports.

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PROJECT ENGINEER'S QUARTERLY REPORT

**Program:** SNAP Aerospace Safety

**Project Engineer:** L. I. Moss

**Reporting Period:** July-September 1962

## I. PROGRAM OBJECTIVES

The objectives of the SNAP Aerospace Safety Program are to provide, through experiment and analysis, the ability to assess the consequences of various postulated accidents and to develop criteria to guide in the design of inherently safe SNAP systems. These objectives encompass ultimate safety precautions throughout the factory-to-flight sequence which includes handling, transportation, assembly, launch, flight, and reentry.

The SNAP Aerospace Safety Program consists of a series of tests, with supporting analytical effort, derived from a review of the various accidents postulated in the factory-to-flight sequence. The various accidents are categorized and tests are conceived to assess the consequences of these accidents.

## II. PROJECT ENGINEER'S SUMMARY

The July-September quarter was a period of intensive design activity within the Aerospace Safety Program. The requirements of several projects, conceived in the latter half of the previous fiscal year, demanded the design of several test models. The major efforts were concentrated on the SNAPTRAN 2/10A-1 and -2 machines and the models for the Reentry Flight Demonstration (RFD-1).

The SNAPTRAN machine posed some difficult design problems primarily due to the nuclear characteristics of the assembly. The short, prompt neutron lifetime ($\sim 6\ \mu$sec) necessitated the design of unusually rapid-acting control devices to insert and remove reactivity in the super-prompt critical region. The demands of an experimental program capable of providing the data necessary for an understanding of reactor behavior resulted in some further design complications. This was particularly true in the areas of instrumentation and external temperature control.

The analysis effort in the quarter was primarily concerned with developing the analytical tools required for interpreting and understanding the data acquired or to be acquired from the experiments. The effort was also concerned with providing the capability of predicting the consequences of conditions other than those simulated by experimental means. A computer code, RESTORE, was written for the purpose of calculating reentry trajectories. Another code, TAP, performs a thermal analysis of various configurations of interest, given a certain heat input. Preliminary calculations have been performed, but no results can be stated with confidence until the spatial distribution of incident heat is known more accurately. Some of this data will be obtained from the "hot shot" tunnel tests planned for the next quarter.

For interpretation of the SNAPTRAN tests, the computer code, COMPOST, is being developed to solve the reactor kinetics equations, given the neutron flux and temperature history of a transient. The more usual type of kinetics calculation, i.e., solving for flux given an input reactivity, was also under development. This will incorporate the effects of loss of hydrogen and core disassembly on the termination of the transient.

Planning of the SNAPTRAN experimental program was undertaken. The desired objective is an optimization of the experiments which will be performed in close coordination with the analysis. Due to the nonrepeatable nature of some of the experiments, rapid and accurate data analysis and interpretation is imperative if the program is to be successful.

The majority of the Phase I Mechanical and Thermochemical Effects Test Program, conducted at Holloman AFB, was completed during the quarter. Perhaps the most significant conclusion is the fact that the fuel element array can survive and remain intact from both a 100 ft drop to a concrete pad and a terminal velocity (550 ft/sec) impact on water.

Some technical difficulties associated with the fission product release experiments, conducted by General Dynamics, were successfully resolved. A few releases were conducted.

The water immersion critical experiment was planned in detail. Necessary test apparatus was designed and fabricated. The initial objective will be the demonstration of an adequate shipping sleeve design.

In the next quarter, major emphasis will shift to fabrication of test articles.

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QUARTERLY PROJECT PROGRESS REPORT

| | |
|---|---|
| **Program:** SNAP Aerospace Safety | |
| **Project:** Reactor Separation and Fuel Element Ejection | |
| **Responsible Engineer:** R. D. Elliott | **Project Engineer:** L. I. Moss |
| **Reporting Period:** July-September 1962 | **AEC Category:** 04-60-50-01.1 |
| **General Order:** 7611 | **Subaccount:** 2061 |

## I. PROJECT OBJECTIVES

The objective of the SNAP reentry program is to investigate by analytical and experimental means the separation and dispersion of the reactor fuel upon reentry from a satellite orbit. To achieve this objective, it is first necessary to determine the mode of reactor breakup and release of the fuel elements. A reentry safety program, divided into two phases, has been initiated. The first phase, described in this section of the report, is concerned with events leading up to release of the fuel elements from the reactor vessel. The second phase, which is being carried out concurrently under Subaccount 2067, is concerned with the melting and/or breakup of the fuel elements and dispersion of the resulting particles.

For the reactor separation and fuel element release project, the principal objective is to establish the mode of breakup of the reactor and associated structure when subjected to reentry heating. Two approaches will be taken in this investigation. The first will be to analyze the mode of reactor and vehicle breakup and fuel element release by application of aerodynamic and thermodynamic theory, incorporating the data from tests conducted by AI and by other agencies where such data are applicable. The second approach will be to collaborate with other contractors in the conduct of ground and flight tests of instrumented reactor mockups (nonnuclear) to determine heating parameters and modes of failure in the upper atmosphere.

## II. MAJOR ACCOMPLISHMENTS IN FISCAL YEAR 1962

The primary accomplishments during FY 1962 were the establishment of a plan for analysis of reactor breakup and of plans for the experimental programs. The design of the reactor mockups for flight test was initiated and construction of some components was started.

## III. PROGRESS DURING THE REPORT PERIOD

It was evident early in this program that it would be necessary to have a computer code available for the calculation of trajectories and heating functions on reentering bodies. Such a code has been developed and adapted to the special needs of the project. One way in which these needs are somewhat unique is in the expectation of reentry causing the mass of the reentering body to diminish significantly by ablation and breakup. This expectation is not particularly attractive to those who write codes for reentry of manned vehicles, and thus is of little interest to them.

The computer code has been named RESTORE, an acronym which stands for "Reentry of Satellites to an Oblate, Rotating Earth." The computations are performed by integration of the equations of motion in rectangular Cartesian coordinates in inertial space, although the inputs and outputs may be expressed in polar coordinates (latitude, longitude, and altitude). This eliminates a difficulty with polar orbits which is inherent in some other trajectory codes that were considered. Several test problems have been run with this code and the results compared with those of other codes from reliable sources. The agreement was extremely close.

The trajectory code has thus far been applicable only to the calculation of the motion of a point-mass having drag but no lift. Future development will extend its capability to calculation of the tumbling of a body with the aerodynamic and inertial parameters of the body as inputs.

Some progress has been made in estimating the local heating rates on various portions of the reactor and vehicle by the use of aerodynamic theory, but the confidence level of these estimates is very low due to the lack of experimental data to support the estimates. The Sandia Corporation has run some wind tunnel tests on a scale model of the reactor and is planning to run more tests on a full-size reactor vessel. Atomics International has furnished them with some of the components for their test model. Their tests are being run primarily in support of the flight-test program (to be described later), and are all at low angles of attack.

Information has been obtained from Lockheed regarding the center of gravity and the aerodynamic coefficients of the SNAP 10A and Agena-B combination. These data indicate that the aerodynamic trim angle may be as high as 27 degrees off axial and that the vehicle will be oscillating while it is descending. Anomalies in the vehicle configuration due to structural failure in reentry might cause unpredictable oscillations and tumbling.

Preliminary calculations of the melting and breakup of the coolant pipe, coolant pump, and the core vessel lip have been made for the assumed case of zero angle of attack. The system was assumed to be empty of coolant for these first calculations. The effect of the NaK coolant will be considered in the next series of calculations. Because of the low confidence in the external heating parameters, it is not useful to quote estimated failure altitudes at this time. However, the thermal models employed have been checked and will be rerun when better input data are available.

The design of reactor mockups for the Reentry Flight Demonstration tests (RFD-1) was nearly completed. All drawings were released except the instrumentation details and the final assembly drawing. Many components were fabricated; those remaining are on order for delivery early in the next quarter.

These flight tests (RFD-1) are scheduled to be conducted over the Atlantic ocean off the coast of Virginia during the latter part of this fiscal year. Atomics International is building four mockups for this program. The first two will be subjected to an extensive series of vibration, shock, and other environmental tests to qualify the design while the second two will be subjected to a series of acceptance tests to qualify them for flight. At the present time two test flights are planned, but, if the first test is successful, the second test may not be flown. These tests will be conducted in conjunction with the Sandia Corporation.

These reactor mockups consist of full-sized reactor vessels equipped with dummy coolant pumps (prototype fins but neither thermoelectric elements nor magnets). To save weight and thus gain extra velocity within the capability of the booster rockets (Blue Scout), the beryllium reflectors are replaced by hollow aluminum shells and the fuel rods are omitted from the core. Twenty thermocouples and six switches are used in the mockup to indicate temperatures of critical parts and to signal events during breakup. The mockups will not contain NaK coolant because its presence would complicate the analysis of the results as well as interfere with the transmission of telemetered data.

## IV. EVALUATION OF EFFORT TO DATE

The progress in the analytical effort has centered in the development of methods for computation of transient heating in various components of the reactor. Dry runs of these methods, utilizing several representative cases, has prepared us to analyze the failure modes of the components once data is obtained on the relative aerodynamic heating rates on the outside of the reactor and system at various angles of attack.

The progress in the manufacture of instrumented mockups for the Reentry Flight Demonstration test has been satisfactory. While it appears that delivery of the first item may be a few weeks behind schedule, this slippage is not expected to delay the scheduled flight test.

## V. NEXT REPORT PERIOD ACTIVITIES

Work will begin on a study of vehicle attitudes and oscillations expected during reentry from satellite orbits. The studies of shock wave patterns and local heating intensities on the reactor and vehicle will be continued with the use of data from tests run by Sandia.

Typical reentry trajectories will be calculated by the use of the RESTORE code. An investigation will be made to determine whether the oblateness of the earth and its atmosphere tends to cause satellites to impact in certain zones on earth with a higher probability than in other zones, and whether this would have an effect on the safety problem.

The first two mockups for the flight test program will be completed and sent to Sandia. The last two mockups will be nearing completion within the next quarter and will be ready for shipment early in the third quarter. Estimates of the weight, center of mass, and moments of inertia of the mockups will be made.

Analysis of the aerodynamic heating and modes of failure of the reactor and vehicle will be continued. Preparations will be made for the reduction of the data from the flight tests and relating them to the prediction of heating and breakup during reentry from orbit. The thermodynamic aspects of the coolant (NaK) remaining in the vessel and pipes during reentry will be studied.

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QUARTERLY PROJECT PROGRESS REPORT

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|---|---|
| **Program:** SNAP Aerospace Safety | |
| **Project:** Reactor Transient and Excursion Tests | |
| **Responsible Engineer:** L. Rash | **Project Engineer:** L. I. Moss |
| **Reporting Period:** July-September 1962 | **AEC Category:** 04-60-50-01.1 |
| **General Order:** 7611 | **Subaccount:** 2062 |

## I. PROJECT OBJECTIVES

This project is investigating the behavior of SNAP systems under various nuclear accident conditions. The response characteristics of SNAP reactors to varying reactivity insertions will be determined. Inherent shutdown mechanisms, such as prompt negative temperature coefficient and hydrogen release from the fuel moderator material, will be evaluated. A mathematical model of the reactor will be developed. Both beryllium- and water-reflected assemblies will be studied, and the effect of differences in the effective prompt neutron lifetime will be determined. The ultimate shutdown mechanisms will be demonstrated by observing the response of the reactors to reactivity insertions large enough to cause irreversible reactor shutdown. The reactivity associated with the reactor in various possible accident conditions is being determined experimentally by the critical configuration tests. From these tests it is necessary to translate the reactivity data to an excursion or energy release in order to properly evaluate the consequences of an accident. Determining the energy release in a postulated excursion by analytical means is a difficult task, since detailed knowledge of the hydrogen release mechanism is required. Consequently, experimental studies are being conducted to increase the accuracy of the analytical calculations.

## II. MAJOR ACCOMPLISHMENTS IN FISCAL YEAR 1962

The design of the machines to be used for beryllium controlled reactivity insertions (SNAPTRAN 2/10A-1 and 2) was started. Also, the hardware procurement for the machine was initiated. Investigations to determine the most practical fuel and/or core instrumentation were performed; the instrumented fuel element design was fixed. The Safety Analysis Report (SAR) was started. Phillips Petroleum Company was chosen by the AEC to conduct the transient tests at the NRTS.

The hydrogen release rates during the fuel heating experiments were shown to be limited by power input rather than diffusion rates. This applied for a power input which was slow, relative to that which is expected during the reactor period resulting from a large reactivity input.

## III. PROGRESS DURING REPORT PERIOD

A topical report (NAA-SR-7398) on the electrical resistance heating tests was published. This report included an analysis of energy input, temperature, and hydrogen release. In view of the advisability of further pulse tests utilizing higher heating rates, equipment that will provide an order of magnitude increase in the heating rate was investigated.

The current series of KEWB pulse heating experiments was completed; various analytical evaluations are now in progress. These include an analysis of the fuel grain structure and an analysis of the number of fissions produced in each sample. The latter analysis will be used for energy balance calculations.

A new computer code is being developed to perform "backward" kinetics calculations to determine compensated reactivity from reactor transient experiments. This code, COMPOST (Computations on SNAP Transients), will be used to analyze the digital data provided by the Phillips Petroleum Company at the NRTS. Since Phillips has not yet specified the nuclear instrumentation to be used in the tests, the preparation of the input sections of the code has been delayed until a later date. A "forward" kinetics computer code is also being developed to incorporate both the nuclear and the mechanical shutdown characteristics of the SNAP reactor. Mechanical shutdown models have been formulated by utilizing the experimental data obtained from the electrical heating and KEWB experiments.

The Safeguards Analysis Report (SAR) was prepared and reviewed by Phillips and AI personnel. Phillips decided to make a major revision to the report to include substantially more detail in the areas of reactor design and operation. Atomics International prepared a table of reactor characteristics, a drawing showing a cross section of the core and reflector, typical drum reactivity worth curves, and a process and instrumentation diagram and description to add to the report.

Except for the drum drive mechanisms, the design of the SNAPTRAN 2/10A machine was completed during this period. Figure 1 is a cutaway drawing of the SNAPTRAN 2/10A-1 machine. Phillips had a full-scale model fabricated and assembled for use in planning future hot cell operations. In addition, the model was expected to prove helpful in noting machine interferences.

The operating console for the actual SNAPTRAN machine is being built by Phillips. The plans to ship the console to AI were completed; Phillips will supply personnel to assist AI in the hookup and operation of the console as well as the checkout of the machine.

The SNAPTRAN Reactor Manual of Checkout, Operation, and Maintenance Procedures is being prepared by AI. A checkout procedure for internal use is also being prepared. This procedure will be used during the acceptance check of the SNAPTRAN machine.

The pilot run for the instrumented fuel element progressed well. The holes for the thermocouples were successfully drilled into the first model element. This element was then assembled into a can to test the special sealing technique. Later, a modification was incorporated into the design. The modification is intended to improve the transient response of the thermocouples without adversely affecting their reliability.

The thermal envelope door heater failed during heating due to a failure of the mounting material. The failure apparently occurred after the shutdown of the heater since adjacent coils were touching at several places but no shorting effect was observed during the operation. A new mounting device will be fabricated utilizing fibrefrax insulation. Also, the Blue M heater, which is a 480-v, single

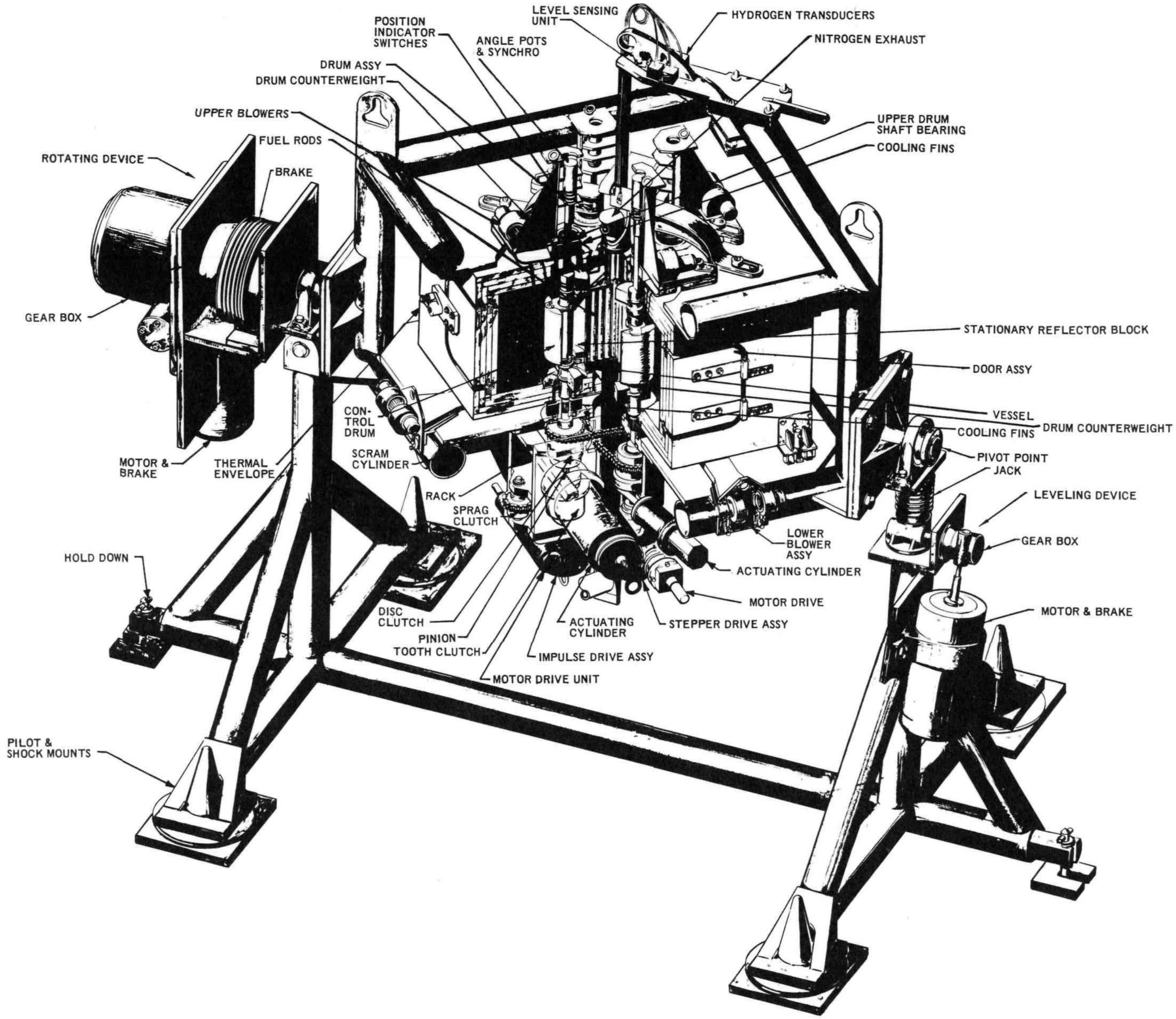


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Figure 1. SNAPTRAN 2/10A-1 Machine

phase heater, was received and is being tested for possible application as the thermal envelope heater.

## IV. EVALUATION OF EFFORT TO DATE

The progress in the design, fabrication, procurement, and assembly of the machine has been less than expected. Based on the present design status, and using typical procurement time spans, it appears that the machine should be mechanically tested and ready for delivery to Idaho during the latter part of the third quarter of this fiscal year. This is approximately three months later than originally anticipated.

Analytical efforts are proceeding at a satisfactory pace that is compatible with current design, procurement, fabrication, and assembly progress. The digital computer codes for the analysis of SNAPTRAN transients will be available during the third quarter; therefore, progress in this area is more than adequate.

## V. NEXT REPORT PERIOD ACTIVITIES

It is expected that the report on electrical resistance heating will be released as well as the results of the KEWB pulse heating tests. The SAR report revision should be completed and the report ready for publication by the end of the period.

The design and detail drawings of the SNAPTRAN machine will be completed; fabrication and assembly will be started prior to the end of the second quarter. The operating console that Phillips is building for the SNAPTRAN machine should arrive at AI early in this period. It will be installed and the checkout of the console completed. The computer code program development will continue. The "forward" kinetics code is not expected to be completed during this period but COMPOST may be completed if Phillips is able to specify the input data that is to be used.

Destructive fuel element tests will be undertaken to investigate fuel element failure as a function of temperature. The data obtained will be used to define the temperature limitations for later nondestructive tests.

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QUARTERLY PROJECT PROGRESS REPORT

| | |
|---|---|
| **Program:** SNAP Aerospace Safety | |
| **Project:** Reactor End-of-Life Shutdown Devices | |
| **Responsible Engineer:** J. Lampl | **Project Engineer:** L. I. Moss |
| **Reporting Period:** July-September 1962 | **AEC Category:** 04-60-50-01.1 |
| **General Order:** 7611 | **Subaccount:** 2063 |

## I. PROJECT OBJECTIVES

The objective of this project is to develop a reliable end-of-life shutdown device that operates independently from the reactor or power conversion system.

It is desirable to incorporate into the reactor design a reliable device that will cause reactor shutdown or destruction after the useful life of the reactor system has been achieved. Such a device may incorporate such things as a corrosion barrier or radioisotope that, after a finite length of time, will trigger a mechanism that will either release the reflectors or set off an explosive charge. Various such devices have been postulated and are being investigated for use as an end-of-life shutdown device in operational SNAP systems.

## II. MAJOR ACCOMPLISHMENTS IN FISCAL YEAR 1962

During FY 1962, the effort was directed primarily toward analytical studies of possible devices to determine those most suited for the proposed application. This investigation included such things as determining ways that a radioisotope decay or corrosion barrier could be used to trigger a charge or release a mechanism. In addition, reaction times and possible isotopes for use in a device were studied.

## III. PROGRESS DURING REPORT PERIOD

Two devices presently intended for operational SNAP systems are an explosive projectile device and a chemical reaction pressure-producing device, both of which effect destruction of the reactor and dispersal of the fuel elements (see Figures 2 and 3). A single command box incorporating five different command signals is being designed for both of these devices (see Figure 4).

### A. EXPLOSIVE SHUTDOWN PROJECTILE

Two bids for a feasibility study of the explosive projectile were received and evaluated. The command box (Figure 4), which incorporates all five initiating commands, was designed.

### B. CHEMICAL REACTION SHUTDOWN

A series of tests were conducted to obtain reactions of metallic fuels and oxides above 1350°F. Reactions that were initially successful produced the following combinations:

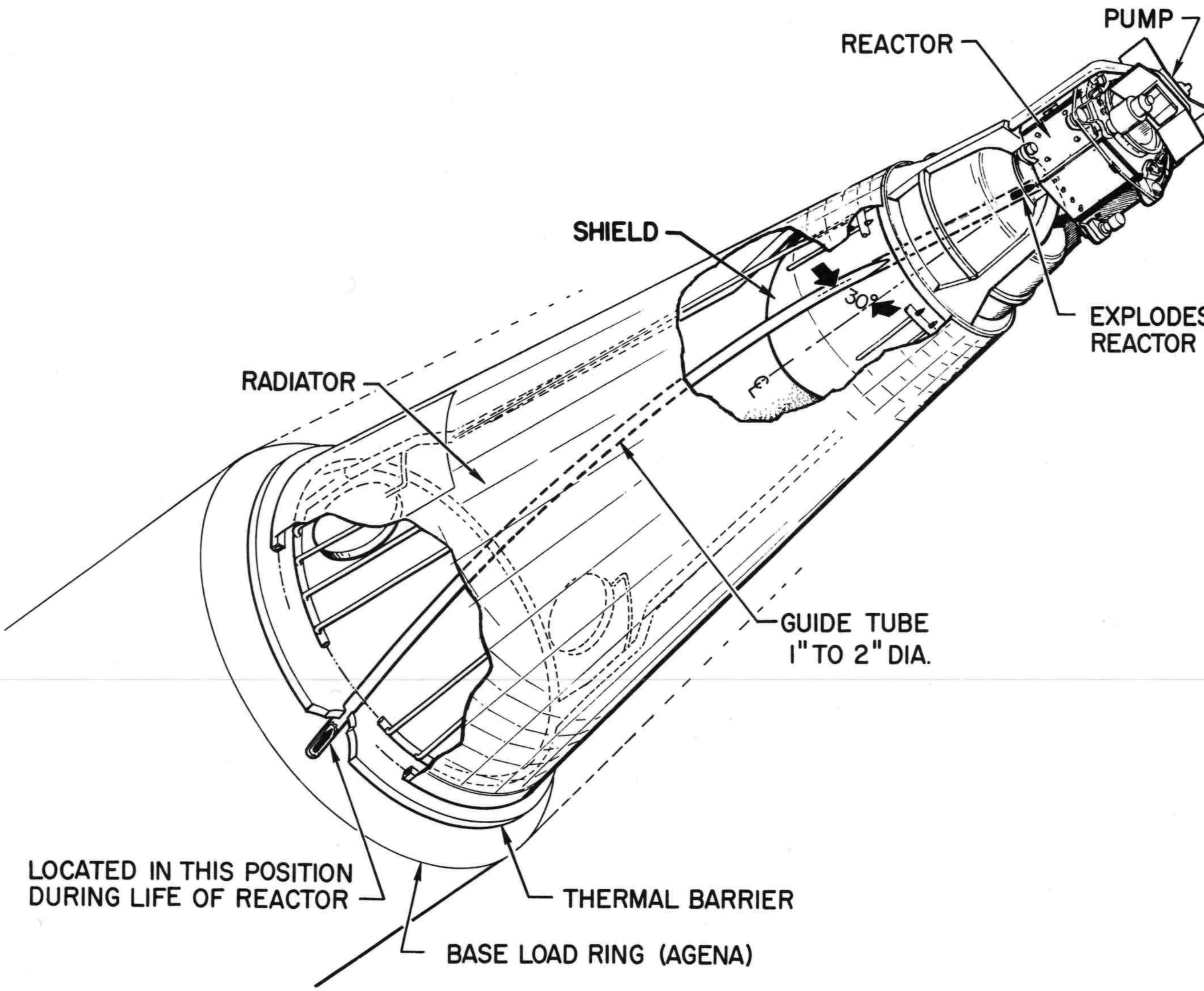


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Figure 2. Explosive Shutdown Device

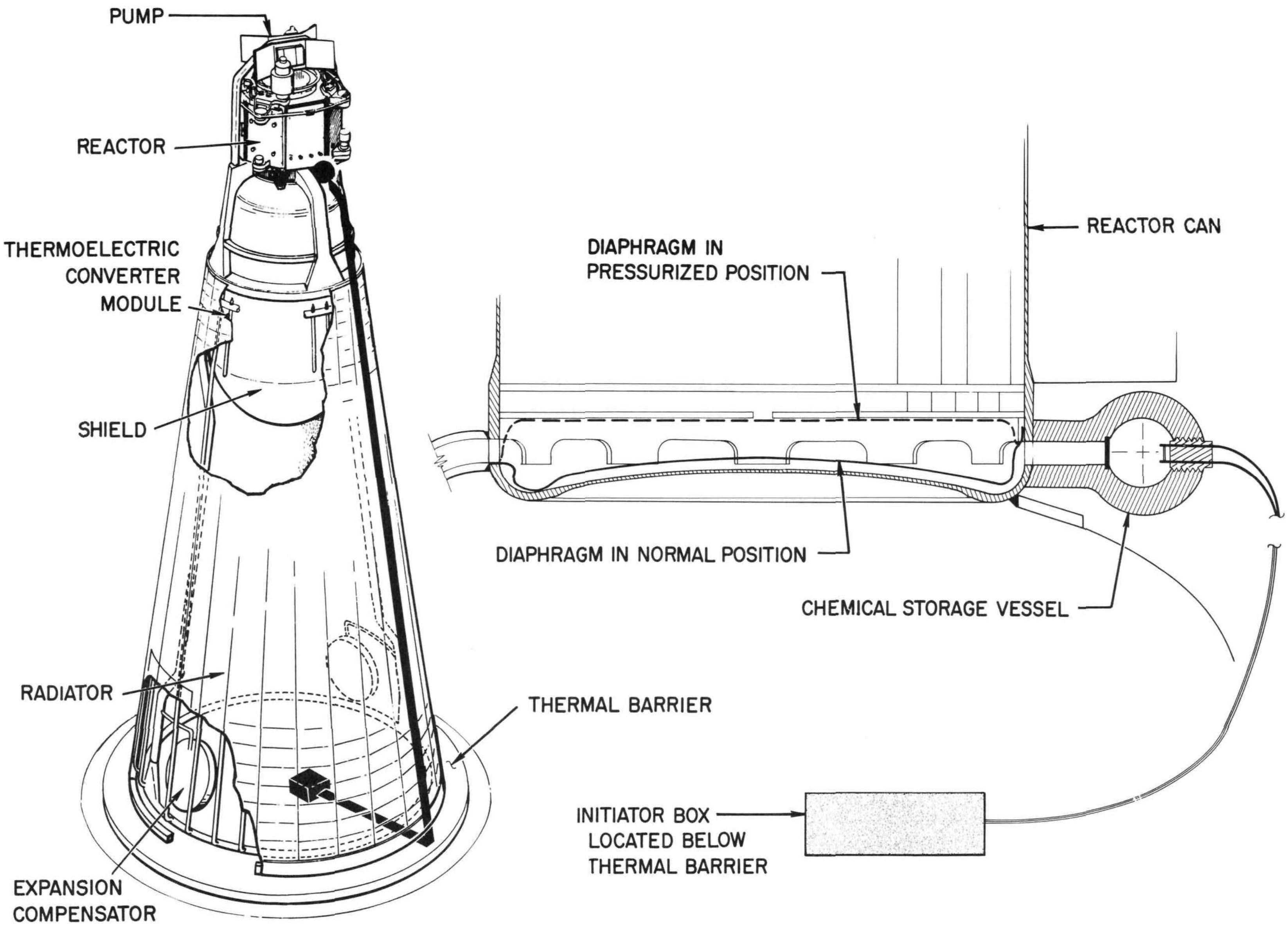


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Figure 3. Chemical Reaction Shutdown Device

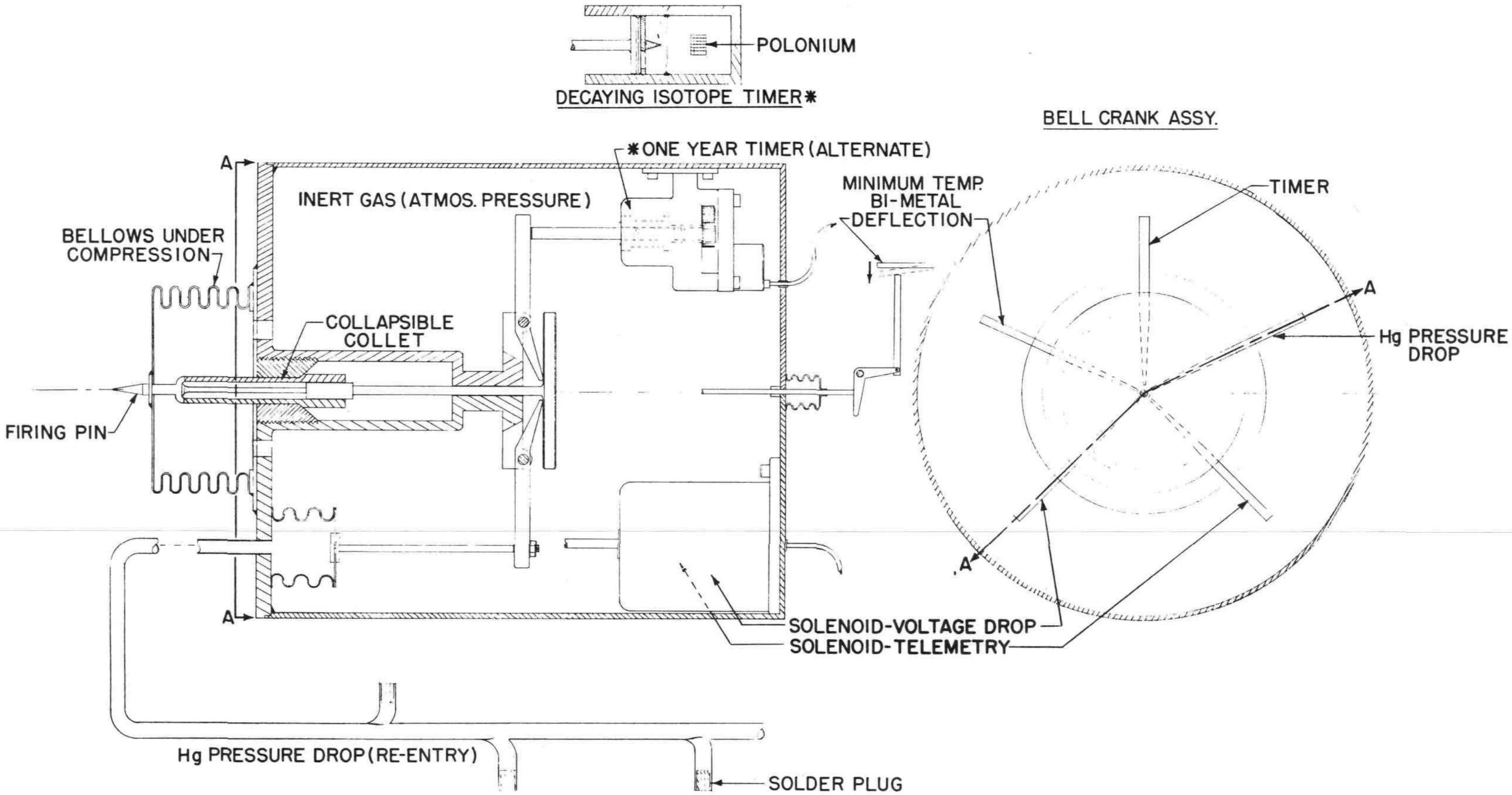


Figure 4. Command Box for Explosive Destruct Charge

| Fuel | Oxidizer Gas Producers |
|---|---|
| Mg | $+Fe_2O_3 + C$ |
| Ca | $+SnO_2 + C$ |
| Be | $+Zn_2P_2O_7 + C$ |
| Be | $+SnO_2 + C$ (with BeO covering Be) |
| Al | $+ZnO + C$ |
| $Al_4C_3$ | $+Fe_2O_3 + C$ |
| SiC | $+Ba(NO_3)_2$ |
| Zr | $+Mn_2O_3$ |
| $CaC_2$ | $+Zn_2P_2O_7$ |

These reactions will have to be checked after exposure to temperature and irradiation to determine their long term stability.

All the tests were conducted in a closed 700-cc crucible inside an air-evacuated chamber under a helium atmosphere; the reaction was initiated with a heated tungsten filament.

## IV. EVALUATION OF EFFORT TO DATE

### A. EXPLOSIVE SHUTDOWN PROJECTILE

The bids for the feasibility study for this project indicate that the approach taken by the vendors is within the present state-of-the-art, and should prove successful.

The command box design itself appears feasible and the force analysis shows that the margin of safety for functioning is adequate.

### B. CHEMICAL REACTION SHUTDOWN

In this project, there was a very broad effort to determine the usefulness of pyrotechnics under specified environmental conditions. More tests of these compounds and stability tests are required before any definite recommendations can be made.

## V. NEXT REPORT PERIOD ACTIVITIES

### A. EXPLOSIVE SHUTDOWN PROJECTILE

The command box design will be completely detailed and checked; bellows specification control drawings will be released for purchase. A study will be made to determine the optimum location of the projectile guide tube to minimize the irradiation dosage in the instrument compartment.

## B. CHEMICAL REACTION SHUTDOWN

Reactions with Al and $Sr(NO_3)_2$, utilizing several catalysts, will be conducted. Reactions will also be conducted with Ca, Zr, Be and $Sr(NO_3)_2$; Ca and $CaCO_3$; Ca and $SrCO_3$; Ca with $SrCO_3$ and $Na_2CO_3$; Al, $PbO_2$ and C; and $Li_3N$ and $Na_2CO_3$. These reaction studies will be conducted at the environmental temperature of 1100°F which has now been established as the SNAP 8 environment.

After conducting stability tests with the most promising pyrotechnic compounds, large volume reactions will be conducted to determine the actual pressure rise for the conditions required to rupture the reactor vessel.

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QUARTERLY PROJECT PROGRESS REPORT

| | |
|---|---|
| **Program:** SNAP Aerospace Safety | |
| **Project:** Fission Product Release Studies | |
| **Responsible Engineer:** W. M. Cegelski | **Project Engineer:** L. I. Moss |
| **Reporting Period:** July-September 1962 | **AEC Category:** 04-60-50-01.1 |
| **General Order:** 7611 | **Subaccount:** 2064 |

## I. PROJECT OBJECTIVES

The primary objective is to accurately determine the radiological consequences of a nuclear excursion. To do this, it is necessary to know the fission product release from the core. Unfortunately, the release of fission products from any solid material is a complicated process combining the effects of microscopic cracking, gross diffusion, lattice defects, thermal spikes, and other solid-state phenomena. Therefore, it is not possible to accurately extrapolate data on the release of fission products from materials other than the particular material being studied (in this case a hydrided zirconium-uranium alloy). It has been shown that, even for very similar alloys which have undergone slightly different fabrication processes, the release of fission products may vary by an order of magnitude. It is difficult, if not impossible, to extrapolate available data for diffusion of a light gas, such as hydrogen, to gross fission product release through the same material. Thus, it is necessary to experimentally obtain fission product release data for the actual fuel element.

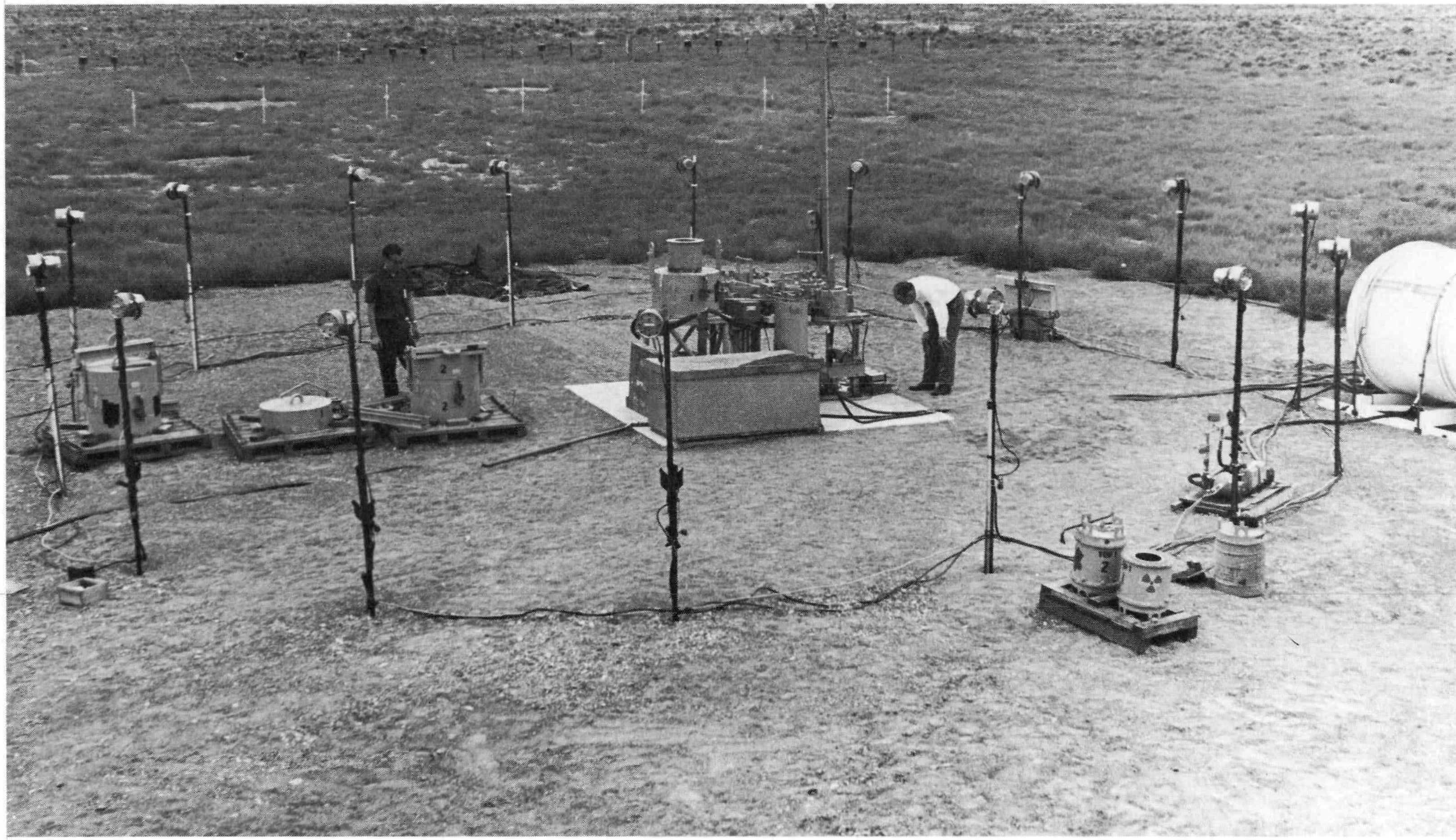
## II. MAJOR ACCOMPLISHMENTS IN FISCAL YEAR 1962

In the second half of FY 1962, AI subcontracted the actual performance of the tests at the NRTS (National Reactor Testing Station), Idaho, to General Dynamics-Fort Worth. Twelve fuel element samples were irradiated in the MTR in preparation for heating in an induction furnace to temperatures of 1500 to 4500°F. The residue from these furnace tests were to be analyzed for iodine 131, cesium 137, barium and lanthanum 140, strontium 89 and 90, total rare earths, uranium, rubidium 86, and tellurium 129. Continuous monitoring and collection of iodine, krypton, and xenon was to be done during the tests. The radiochemical analysis at the NRTS was subcontracted to Phillips Petroleum Company. At the end of FY 1962, the test apparatus was in the final stages of assembly and checkout at the NRTS.

## III. PROGRESS DURING REPORT PERIOD

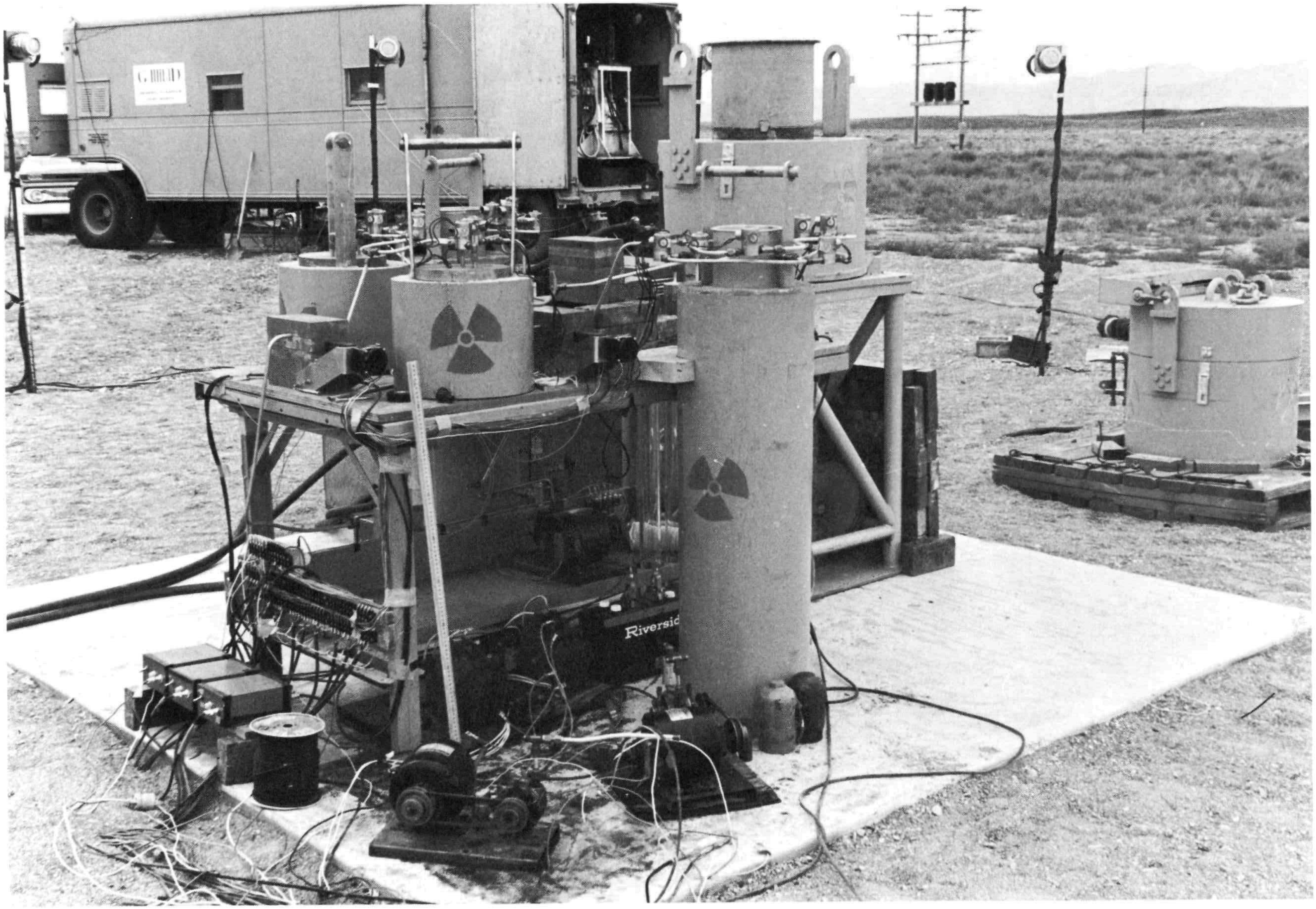
After the system to be used in the test program was assembled (see Figures 5 and 6), pressure drops across sections of the system were measured by the use of a manometer. Using soap suds as a detector, small leaks were found and sealed as the system was brought to operating conditions.

The gas activity monitor system was checked by using krypton 85 gas. This gas was introduced into the furnace with helium in order to provide an inert atmosphere. Then the furnace was brought to ~2000°F to simulate operating conditions, and about 0.1 curies of the gas was introduced over a period of about ten minutes. After it was collected in the gas trap, the liquid nitrogen level



7611-5015

Figure 5. Overall View of Fission Product Release Test Site




7611-5016

Figure 6. Fission Product Release Tests — Furnace and Counting Apparatus

around the trap was lowered and the gas was transferred to a second gas trap. This second trap can be disconnected from the system to facilitate radiation spectrum analysis. While making this transfer, some of the gas was lost due to low back-pressure in the remote operation solenoid valves. These valves were later replaced with mechanical valves.

A later checkout of the gas collection apparatus revealed persistent leaks in the bottom of the gas collector tubes. These leaks were detected by passing radioactive krypton through the system. The caps were welded and rewelded until the leaks were stopped.

It was decided to use only helium as the inert gas in the furnace region. Previously, argon flow was maintained around the crucible and graphite susceptor, and helium above the crucible. The system was found to be blocked; it was suspected that the argon was liquifying in the small valve passages in the liquid nitrogen region. To prevent further blockage, helium was substituted around the crucible and susceptor. Later, in the interest of simplification, the helium flow above the crucible was discontinued. The temperature recalibration runs showed that there was no significant temperature effect due to replacing the argon with helium.

Melting points of fuel samples and the furnace calibration were determined by heating nonirradiated fuel samples. It was found that unclad elements melted at 3500 ± 50°F. Increasing the temperature to about 3800 to 4000°F resulted in the tantallum crucible alloying with the fuel. Clad samples melted at 2550°F due to an alloying effect between the fuel and the Hastelloy N cladding.

The first active release utilized an unclad fuel sample that was maintained at 2800°F for several hours. During this test, some restriction of gas flow was observed within the system. This was traced to blockage in the water trap (dryer), which is a 3-in. diameter by 3-ft long cylinder containing dessiccant crystals. This restriction was eliminated after repairing a leak that resulted due to excessive chemicals in the iodine trap.

The second release test was performed using a fuel sample with standard cladding and bonding. The sample was maintained at 3500°F for 20 minutes to ensure complete melting. During the test, the monitors indicated that evolved gas activity was ~30 times the activity observed during the first release.

The third test was delayed until the fission product gas system could be modified. A considerable period of time was necessary to transfer the collected gases into a second collector unit. This unit was then taken from the system and gamma-scanned. This process was simplified by designing a single unit to fulfill both functions.

After the modification was completed, the third release test was performed. The test plan was to heat a clad sample to 3500°F; then the temperature was to be reduced to 2000°F for fifteen minutes. This would simulate a nuclear excursion followed by a rocket fuel fire. Soon after the test began, the radiation pyrometer, which views the bottom of the graphite susceptor through a channel in the bottom of the furnace, ceased to function properly. The test was then terminated after an estimated 3450°F was reached. Following the test, significant beta activity was detected below the furnace. A coolant water leak in the induction furnace coils in the region just outside the graphite susceptor allowed active material to be "washed" down to the pyrometer and the surrounding region below the furnace. The pyrometer glass was covered with material and this caused its malfunction. Also, it was found that some of the active gases were bypassing the collector system during the tests. This required a minor modification to correct the situation.

Due to delays in the program it was necessary to reirradiate some fuel samples to ensure that their fission product activity was high enough to give good results. Also, some difficulty was encountered in dissolving the fuel element residue for analysis. This required modification of equipment at Phillips' Chemical Processing Plant. Analysis then proceeded satisfactorily.

## IV. EVALUATION OF EFFORT TO DATE

Many problems were encountered and overcome while establishing a system for the tests that was essentially leak-tight. The furnace and activity detection equipment had to be properly calibrated. Several modifications were necessary before the system could perform successive tests fairly rapidly and give accurate data. These necessary tasks were accomplished by the end of the report period.

The initial tests indicated that, after a few final modifications, the data obtained from the program will be useful in determining the radiological consequences of a nuclear excursion. By the end of this report period, sufficient progress had been made such that the nine remaining tests in the series could be performed successfully within the next few weeks.

## V. NEXT REPORT PERIOD ACTIVITIES

All of the remaining closed release tests will be completed. The radiochemical analyses of fuel element residue and evolved particles and gases will continue. Complete data should be available on at least half of the tests by the end of the next reporting period. The analysis of the data at AI will be initiated. The computer codes that have been developed for this purpose will be employed.

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QUARTERLY PROJECT PROGRESS REPORT

| | |
|---|---|
| **Program:** SNAP Aerospace Safety | |
| **Project:** Critical Configuration Tests | |
| **Responsible Engineer:** D. G. Oliver | **Project Engineer:** L. I. Moss |
| **Reporting Period:** July-September 1962 | **AEC Category:** 04-60-50-01.1 |
| **General Order:** 7611 | **Subaccount:** 2065 |

## I. PROJECT OBJECTIVES

In order to estimate the energy release in a nuclear excursion, it is necessary to determine the reactivity associated with the reactor when it is subjected to various accident conditions. This reactivity can be calculated numerically, but poor accuracy would result, especially where a water moderator and reflector are involved. Consequently, experimental methods are necessary to obtain results usable for an accurate hazards evaluation. It is the objective of these critical configuration tests to determine the reactivity of SNAP reactors when they are subjected to various water immersion configurations.

## II. MAJOR ACCOMPLISHMENTS IN FISCAL YEAR 1962

The SNAP 2/10A reactor was subjected to various critical configuration tests with a water moderator. The test apparatus for the series consisted of a removable water reflector which was physically separated into three regions and which surrounded the core. Each region could be remotely filled or emptied with water. The specific objectives of the test included the determination of the following: (a) the number of fuel rods necessary to achieve criticality with water both filling and surrounding the core, (b) the reactivity of the core with a full loading of fuel and reflected by water, (c) the reactivity of the core with a full loading of fuel and with water surrounding the core and in the core, and (d) the effect on the preceding reactivities as a result of poisoning the core vessel and the grid plates.

Initial (Phases I and II) tests were performed in the SETF (SNAP Environmental Test Facility). Regarding reactor safeguards, the main conclusion drawn was that a poison sleeve surrounding the core would prevent criticality upon water immersion. However, if the core is then flooded, criticality would occur.

Following this series, the test machine was transferred to the SNAP critical facility and installation was begun for further (Phase III) SNAP 2/10A tests and the initial water tests of the SNAP 8 core.

## III. PROGRESS DURING REPORT PERIOD

The proposed Phase III Experimental Program was reviewed and approved by the AI Compact Reactor Safeguards Committee. However, start of the tests was delayed pending AEC approval of the Building 012 Facility Safeguards Report. The approval was not forthcoming during this reporting period.

Earlier phases of the SNAP 2/10A water immersion experiments have shown that the water reflected bare core is supercritical. Poison sleeves (containing boron) surrounding the core will prevent criticality when the core is immersed in water. However, if the core is then flooded, criticality occurs. For safety reasons, it is desirable to prevent criticality upon both water immersion and flooding.

The Phase III series of SNAP 2/10A tests will investigate the effects of surrounding voids and surrounding void-poison combinations on the bare core after it is immersed and flooded. Voids as large as a 4-in. annulus will be studied. Some of the poisons to be investigated are amorphous natural boron powder canned in stainless steel, $Sm_2O_3$ powder (also canned), and binal (a dispersion of $B_4C$ in aluminum). The tests will also investigate the reactivity effect of immersing the beryllium-reflected core in water as well as methods of reducing this reactivity.

The test objectives will be to demonstrate that sleeve and filler block designs are adequate to prevent criticality upon water immersion and flooding and upon water immersion, respectively. The main purpose will be to develop the ability to analyze a general poison-void sleeve design, with the objective of eliminating the need of experiments to evaluate each new sleeve design.

Fifteen configurations (see Table I) will be studied with critical loading or criticality determined where appropriate for analysis. The reactivity effects of necessary structural material in the sleeve designs will be determined. This experimental program is designed to provide information to permit a general evaluation of different sleeve designs in reducing core reactivities in water.

In addition to specifying the test procedures, support equipment was purchased and/or fabricated as required. This included the completion of the hardware design for the SNAP 8 tests and the start of procurement and fabrication. Both are expected to be completed early in the next reporting period. In addition, the critical assembly machine was completely checked. The various poison and void sleeve containers were each assembled around the bare, unloaded core to detect any assembly problems. All the equipment for the bare core test was assembled and is now ready for the start of the Phase III tests. During this period, photographs were taken (see Figures 7 and 8) of the bare core test equipment and of the various surrounding sleeve configurations. Motion pictures were also taken to show the operation of the equipment.

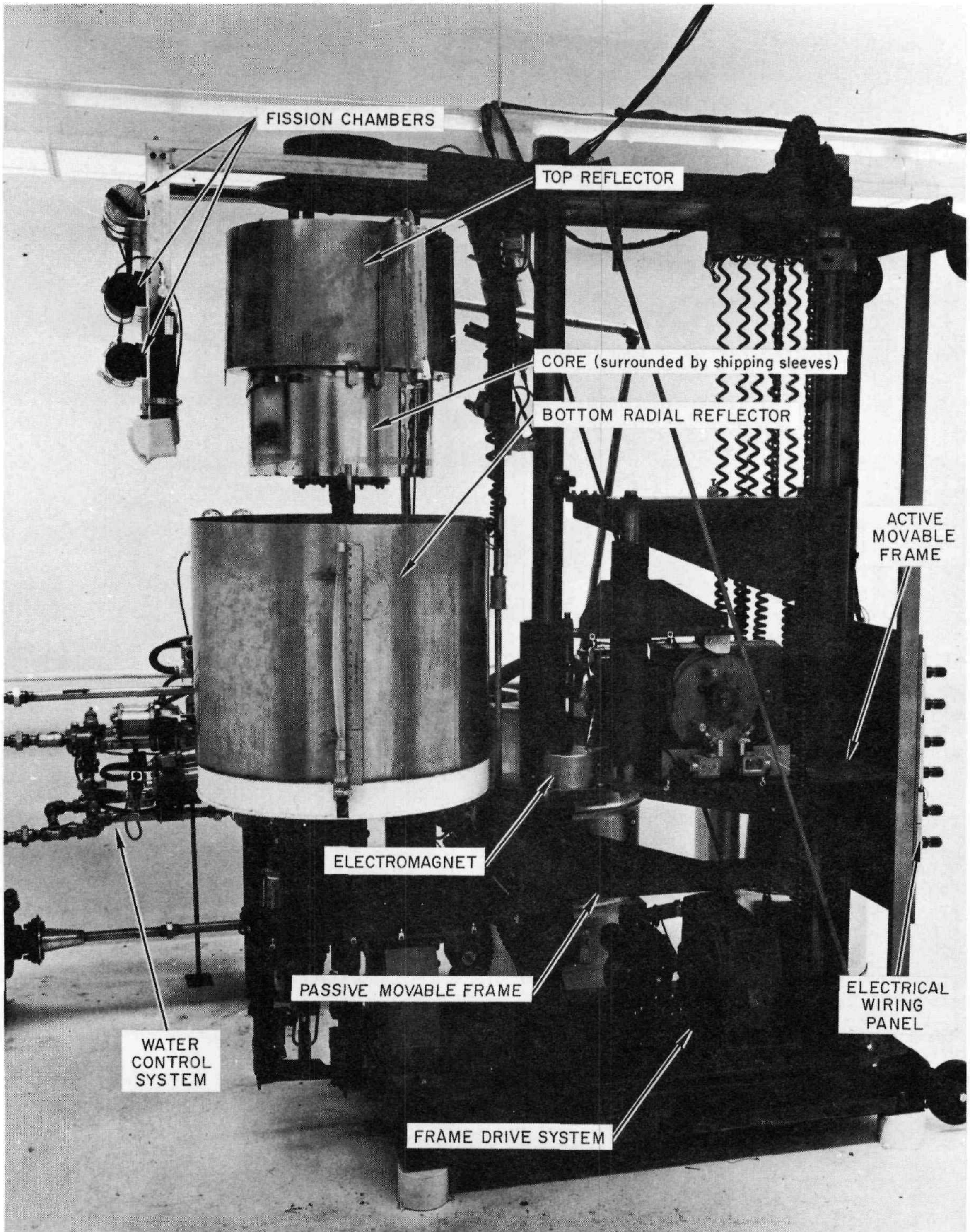
The SNAP 8 tests will determine the reactivity effect of water immersion and water flooding on the SNAP 8 core. Poison-void sleeves and/or poison fuel rods will be tested in an effort to prevent criticality from water immersion and flooding. Start of this test program has been delayed pending AEC approval of the facility hazards report. For scheduling reasons, the SNAP 2/10A program will be interrupted to conduct SNAP 8 tests. SNAP 2/10A tests will then be continued. To obtain evaluation of the adequacy of the poison-void sleeve design, tests 1, 2, 8, 14, and 15 of the Phase III Test Program (Table I) will be conducted prior to the SNAP 8 tests.

TABLE I

SNAP 2/10A PHASE III TEST PROGRAM

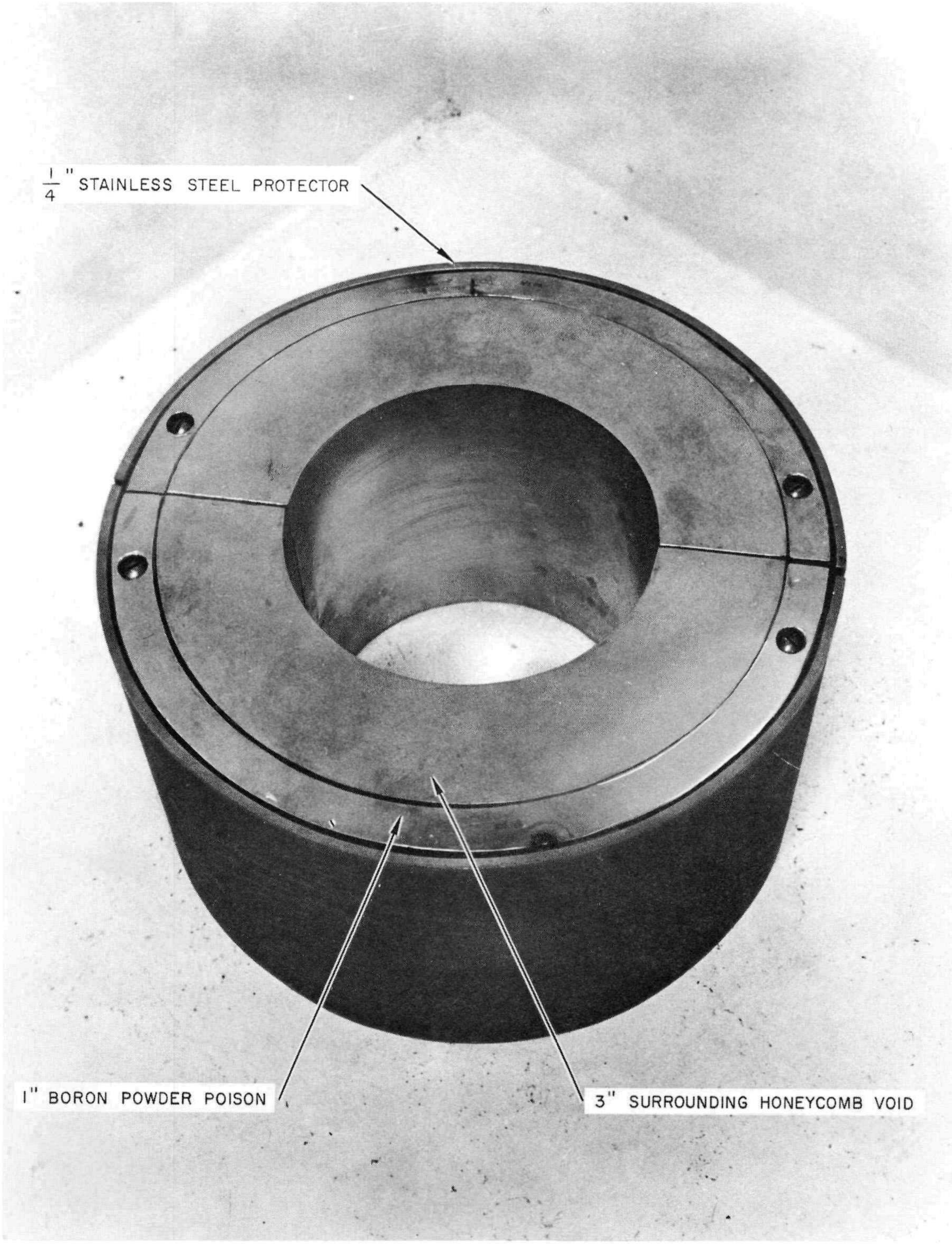
| No. | Core | Reflector Region | | | | Measurement |
|---|---|---|---|---|---|---|
| | | First | Second | Third | Fourth | |
| 1. | Water flooded | - | - | - | - | $K_{eff}$ |
| 2. | Water flooded | Water | - | - | - | $K_{eff}$ |
| 3. | Water flooded | Air | - | - | - | $K_{eff}$ |
| 4. | Water flooded | 1 in. air | Water | - | - | $K_{eff}$ |
| 5. | Water flooded | 3 in. air | Water | - | - | $K_{eff}$ |
| 6. | Water flooded | 4 in. air | Water | - | - | $K_{eff}$ |
| 7. | Water flooded | 3 in. air | 1 in. boron | Air | - | $K_{eff}$ |
| 8. | Water flooded | 3 in. air | 1 in. boron | Water | - | $K_{eff}$ |
| 9. | Water flooded | 3 in. air | 1 in. $Sm_2O_3$ | Water | - | Critical loading |
| 10. | Water flooded | 1 in. A | Water | - | - | Critical loading |
| 11. | Water flooded | 3/4 in. Binal | 3 in. air | Water | - | Critical loading |
| 12. | Water flooded | 3 in. air | 1 in. boron | 1/4 in. steel | Water | Critical loading |
| 13. | Water flooded | 3 in. air | 1 in. boron | 1/2 in. steel | Water | Critical loading |
| 14. | Air | Be | Water | - | - | $K_{eff}$ |
| 15. | Air | Be | 1/2 in. boron Filler blocks | Water | - | $K_{eff}$ |

7611-5001




1-21-63 7611-1827-A

Figure 7. Water Immersion Critical Machine




1-21-63 7611-1824-A

Figure 8. Shipping Sleeve Configuration

## IV. EVALUATION OF EFFORT TO DATE

No experiments were conducted during this period. The equipment has been installed and checked out for SNAP 2/10A operation. The test series will begin upon receipt of AEC approval of the facility hazards report. All SNAP 2/10A equipment was delivered.

The SNAP 8 design was completed and fabrication started. Equipment procurement is progressing at a satisfactory rate; therefore, no delays are expected from this source.

## V. NEXT REPORT PERIOD ACTIVITIES

The design and the fabrication of the water immerson hardware for the Phase III tests will be completed. The SNAP 8 tests and the Phase III test series will be started. Data compilation and analysis will begin as soon as each test is completed.

ATOMICS INTERNATIONAL

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QUARTERLY PROJECT PROGRESS REPORT

| | |
|---|---|
| **Program:** SNAP Aerospace Safety | |
| **Project:** Mechanical and Thermochemical Effects | |
| **Responsible Engineer:** L. I. Moss | **Project Engineer:** L. I. Moss |
| **Reporting Period:** July-September 1962 | **AEC Category:** 04-60-50-01.1 |
| **General Order:** 7611 | **Subaccount:** 2066 |

## I. PROJECT OBJECTIVES

The principal objective is to initiate and complete a series of tests so that data and information will be available to evaluate the hazards that may occur before, during, and after the initial flight test.

During the factory-to-orbit sequence, the reactor and its related systems will be subjected to various handling, transportation, and launch conditions. From these conditions, potential accidents, such as impacts, chemical interactions, explosions, and fires, can be postulated. In order to analyze these potential hazards, it is necessary to evaluate the effect of these mechanical and thermochemical changes on the SNAP system. To perform this evaluation, a series of tests are necessary whereby full-scale mockup reactors and systems would be subjected to conditions similar to those which would occur in the various postulated accidents.

## II. MAJOR ACCOMPLISHMENTS IN FISCAL YEAR 1962

Fourteen tests were proposed; four were run at Holloman Air Force Base prior to the end of FY 1962. The choice was difficult to make because of the almost infinite number of accident conditions, attitudes, and geometries that could be postulated to occur. Where possible, a limiting condition was selected in each test. The tests were divided into three categories: (a) chemical interaction, (b) fire and explosion, and (c) impact. These tests are summarized as follows:

### A. CHEMICAL INTERACTION TESTS

Three chemical interaction tests were performed to determine the gross effects of various simulated accident conditions.

Test No. 1 consisted of exposing a reactor vessel and internals to a liquid oxygen (LOX) deluge. There was no damage either external or internal to the core vessel. The purpose of the test was to measure the rate of heat transfer throughout the reactor and to observe the general behavior of the reactor for evidence of structural failure due to thermal stress, differential contraction, or loss of ductility. This test was planned to simulate the falling of the reactor intact on the launch pad and subsequently being exposed to the LOX deluge from an Atlas fuel tank.

Test No. 2 simulated the condition whereby the vessel or piping was ruptured and the NaK was exposed to the LOX spray. This test consisted of exposing the NaK at the two inlet nozzles and the outlet nozzle to a LOX deluge. The purpose of the test was to determine the effect of a chemical reaction on the reactor vessel and what effects, if any, occurred due to explosions generated by a LOX-NaK interaction. The LOX spray quickly froze the NaK; no reaction occurred.

Test No. 3 consisted of exposing the NaK at the two inlet nozzles and the outlet nozzle to $H_2O$ after the reactor was immersed in a container of $H_2O$ (see Figure 9). The reaction was so violent that the water tank was ruptured (see Figure 10). The subsequent rapid loss of the water from the tank minimized the reaction; therefore, it was decided to rerun this test at Sandia at a later date. However, the mockup reactor was not rendered into a configuration that would have been subcritical, as the fuel element array and the core vessel remained intact.

## B. FIRE AND EXPLOSION TESTS

One fire (Test No. 4) and one explosion (Test No. 5) test were planned to simulate environmental conditions arising from a launch pad abort. The explosion test consisted of exposing a reactor vessel and reflector assembly to an explosion with a resulting over-pressure of 415 psi. The reflectors were ejected but the core vessel was not significantly damaged. The purpose of the test was to observe the behavior of the reactor for evidence of structural failure and distortion due to the externally applied pressure. This did not occur in a manner necessary to affect the fuel element array. The fire exposure test was not conducted in FY 1962; it is discussed in Part III.

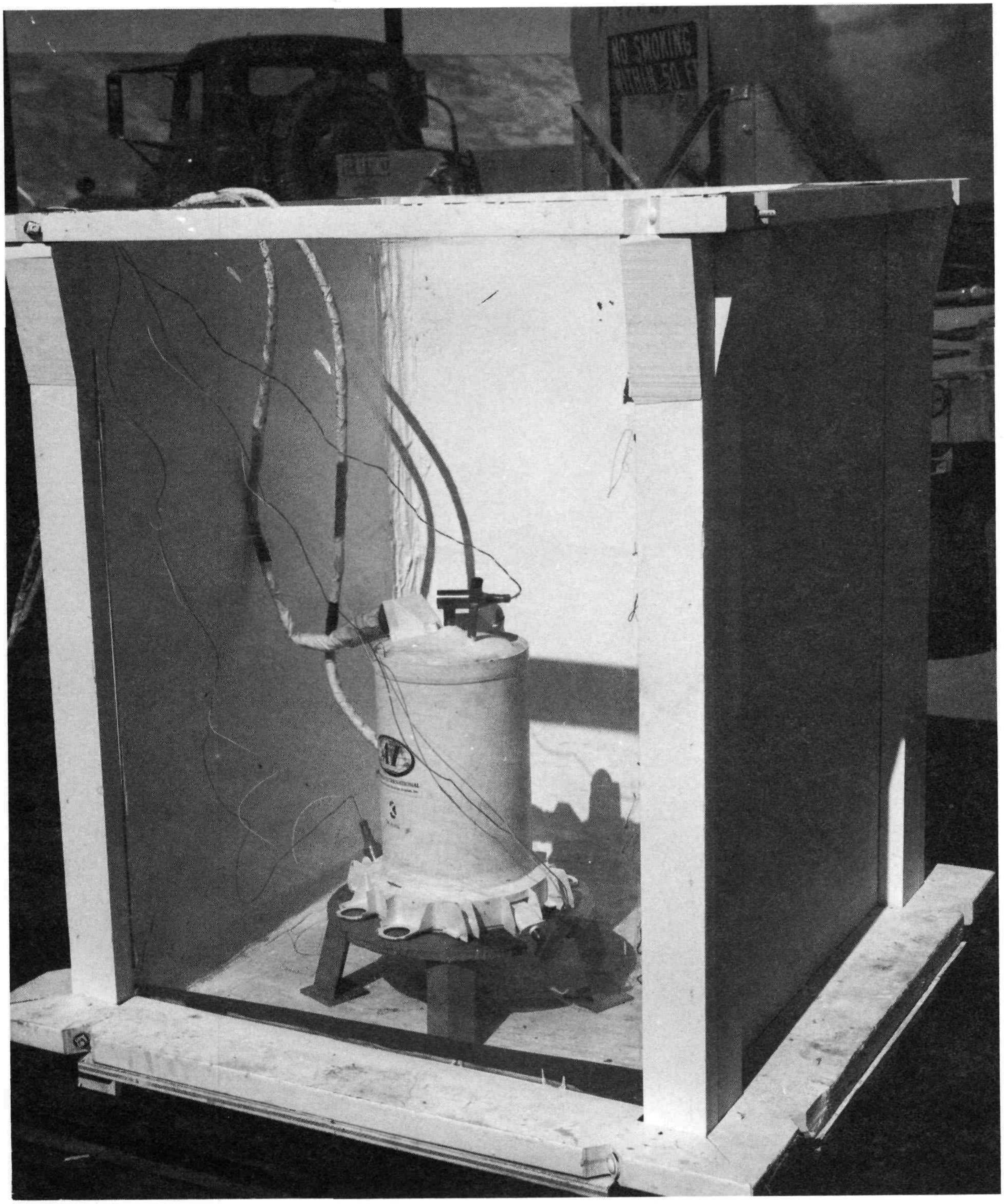
## C. IMPACT TESTS

Nine impact tests (six sled tests and three drop-tower tests) were initiated; a test assembly was prepared for each test. The purpose of these tests was to determine the mode of failure of the test assemblies when subjected to severe shock loads. In the terminal velocity tests, the mode of ejection of the fuel rods and their subsequent physical state and dispersion are of prime importance.

The three drop-tower impact tests were initiated to simulate the system falling from the Atlas-Agena vehicle. These tests were planned for an impact velocity of 80 ft/sec. Pump end, converter end, and side attitude impacts were planned.

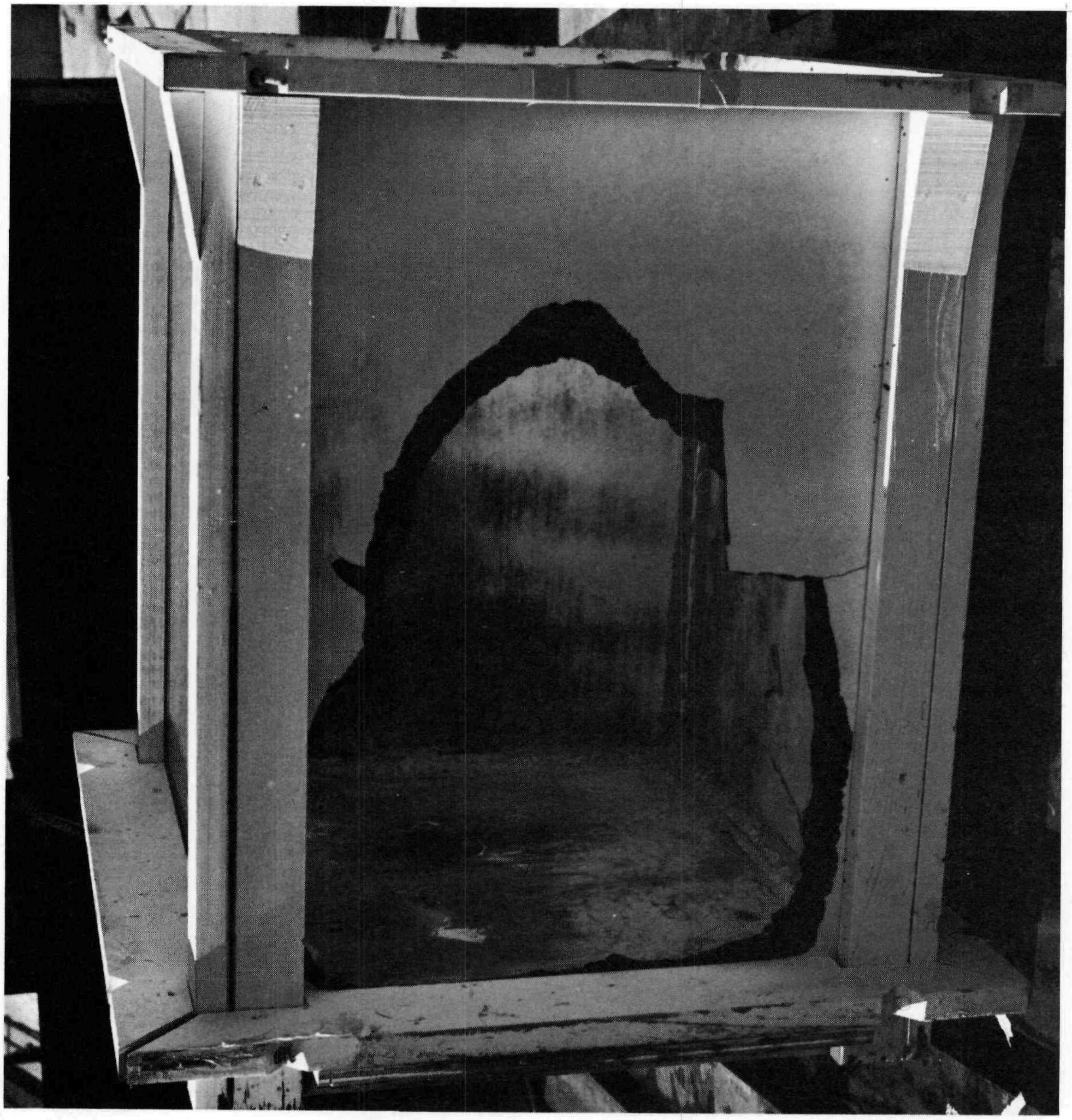
Four water and two concrete impact tests were scheduled. The first three water tests were planned for a velocity of 550 ft/sec and the fourth at 750 ft/sec. The impacting of the lower velocity tests was to be done for three different attitudes: (1) impact on the pump end of the reactor, (2) impact on the shield end of the reactor, and (3) impact on the side of the reactor. The higher velocity impact was to be done at pump end attitude and would include, in addition to a simulated reactor vessel, reflector, and shield, a simulated converter.

Instrumentation for all the tests included pressure transducers, strain gauges, and accelerometers. In addition, high speed colored motion picture coverage was to be provided for all impacts.




7611-5002

Figure 9. NaK-$H_2O$ Interaction Test Assembly



7611-5003

Figure 10. NaK-$H_2O$ Interaction Test Results

# III. PROGRESS DURING REPORT PERIOD

Test numbers 4, 6 through 9, and 11 through 13 were completed during the reporting period. Test No. 10 was cancelled and Test No. 14 will be completed during the next reporting period.

The fire exposure test (No. 4) consisted of exposing a reactor vessel and simulated reflector to a high temperature fire of 3700°F for the first 2.2 sec, followed by 1500°F for the next 15 min. The reflector braze band parted and ejected the reflector (see Figure 11). The core itself was not damaged The purpose of the test was to observe the behavior of the reactor for evidence of structural failure and distortion due to thermal stress or differential expansion. No such distortion occurred, no doubt due to the excellent thermal coupling from core vessel to the high heat capacity core interior.

The next series of tests (No. 6, 7, and 8) were the drop-tower tests (see Figures 12, 13, and 14). In each of the tests, the reflector retaining band failed. Thus, the reflectors were separated from the core vessel in all the tests (see Figure 15). An examination after the side-on drop showed that one control drum had rotated to the in position. It was not possible to determine if this rotation occurred before or after the ejection of the reflectors; therefore, further drop tests have been scheduled as part of the Phase II program.

Test No. 9 was the impacting of a concrete-faced monorail sled upon a stationary reactor — reflector test article. The velocity of the sled at impact was 560 ft/sec. The test article was completely destroyed upon impact; the debris that was recovered accounted for only about 10% of the pre-impact test article. The remainder of the debris was well scattered over the test area. The three pictures (Figures 16, 17, and 18) show the test article prior to shipment, prior to impact, and after impact.

Test No. 10 was to be similar to Test No. 9 except that a mockup shield and converter structure were to be added and the impact velocity was to be increased to 750 ft/sec. However, the destruction in Test No. 9 at the lower velocity was obviously sufficient to ensure subcriticality. Test No. 10 was therefore cancelled.

Test No. 11 was a high velocity, head-on impact of a reactor-reflector assembly into a tank of water. The test assembly was traveling at ~580 ft/sec at the time of impact. It passed through the tank of water and came into contact with a mound of earth ~20 ft beyond the tank (see Figure 19). Prior to contacting the earth, the test article lost its reflector assembly, the NaK pump, the upper head, and the upper grid plates. The reactor vessel was essentially intact after the impact. The fuel rods were displaced longitudinally into a spherical boundary at the upper and lower grid plates. The lower vessel head was displaced in a similar fashion. Figure 20 shows the debris recovered after impact.

Test No. 12 was a high velocity, tail-on impact of a reactor-reflector assembly into a tank of water. The test assembly velocity was 594 ft/sec at the time of impact. The test article passed through the tank of water and impacted into the earth mound 20 ft beyond the tank. The bottom of the core vessel was ripped off and two fuel rods were ejected from the core can. Two other fuel rods were longitudinally displaced 10 in. The remaining 33 rods were longitudinally displaced in such a manner as to form an approximate tilted plane (over a 6 in.

vertical projection) as an upper boundary. (See Figure 21.) Estimates indicated that this fuel rod array would be supercritical if it were flooded with water.

Test No. 13 was similar to Tests No. 11 and 12, except the impact was side-on. In this case, as with all of the impacts, the reflectors came off.

Test No. 14, the last test of the Phase I series, was scheduled to be run early in the next reporting period.

Plans for the Phase II Test Program were submitted to Sandia. After discussion between AI and Sandia, it was agreed that the following tests will be specified:

1) A Be fire test to evaluate BeO contamination
2) A 3-sec radiant heat test of the lockout pin squibs to evaluate the possibility of self-ignition during the fall of a reactor to the launch pad, subsequent to an abort
3) A NaK-$H_2O$ interaction test, the reaction proceeding to completion
4) One high velocity compacted soil impact test
5) Four drop tests to study the time sequence of drum rotation and reflector separation.

## IV. EVALUATION OF EFFORT TO DATE

The tests conducted to date have provided information regarding the gross behavior of the reactor assembly in certain abort environments. The approach employed in specifying these tests has been that of (a) demonstrating the adequacy of a theoretical result and/or (b) establishing the credibility or incredibility of some postulated behavior difficult for analytical solution. It has not been considered advisable to execute a program of statistical testing of all possible occurrences, since this would involve a great number of tests in order to establish probabilities with a high confidence level.

Thus far, the tests have verified that: (a) representative thermal and explosive environments have no effect on the fuel element array, (b) all impacts tested produce reflector ejection, but only the terminal velocity concrete impact conclusively demonstrated core disassembly. It has been shown that in a terminal velocity water impact, it is credible that the fuel element array remains in a configuration that is supercritical when flooded with water.

## V. NEXT REPORT PERIOD ACTIVITIES

The last of the Phase I series (Test No. 14) will be run at Holloman Air Force Base. The design and the start of fabrication of parts for the Phase II drop tests will be initiated.

Phase II tests scheduled to be completed during this period are: (a) the NaK-$H_2O$ interaction test (with the reaction permitted to proceed to completion), (b) the Be fire test, (c) the terminal velocity (550 ft/sec) soil impact test, and (d) the 3-sec radiant heat test of the lockout pin squibs.


7611-5004

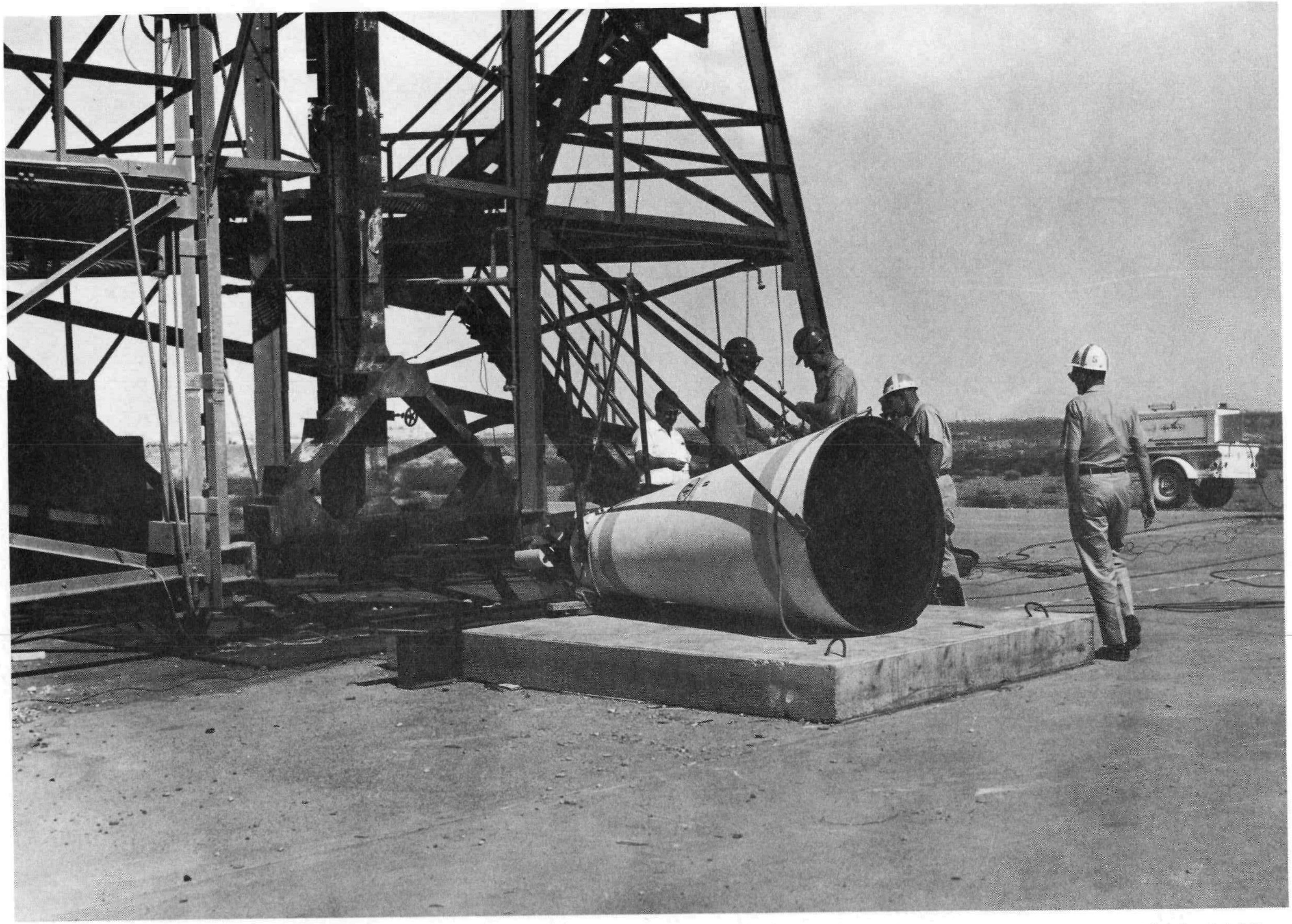
Figure 11. Fire Exposure Test Results


7611-5005

Figure 12. Drop-Tower Test, Pump-End Impact

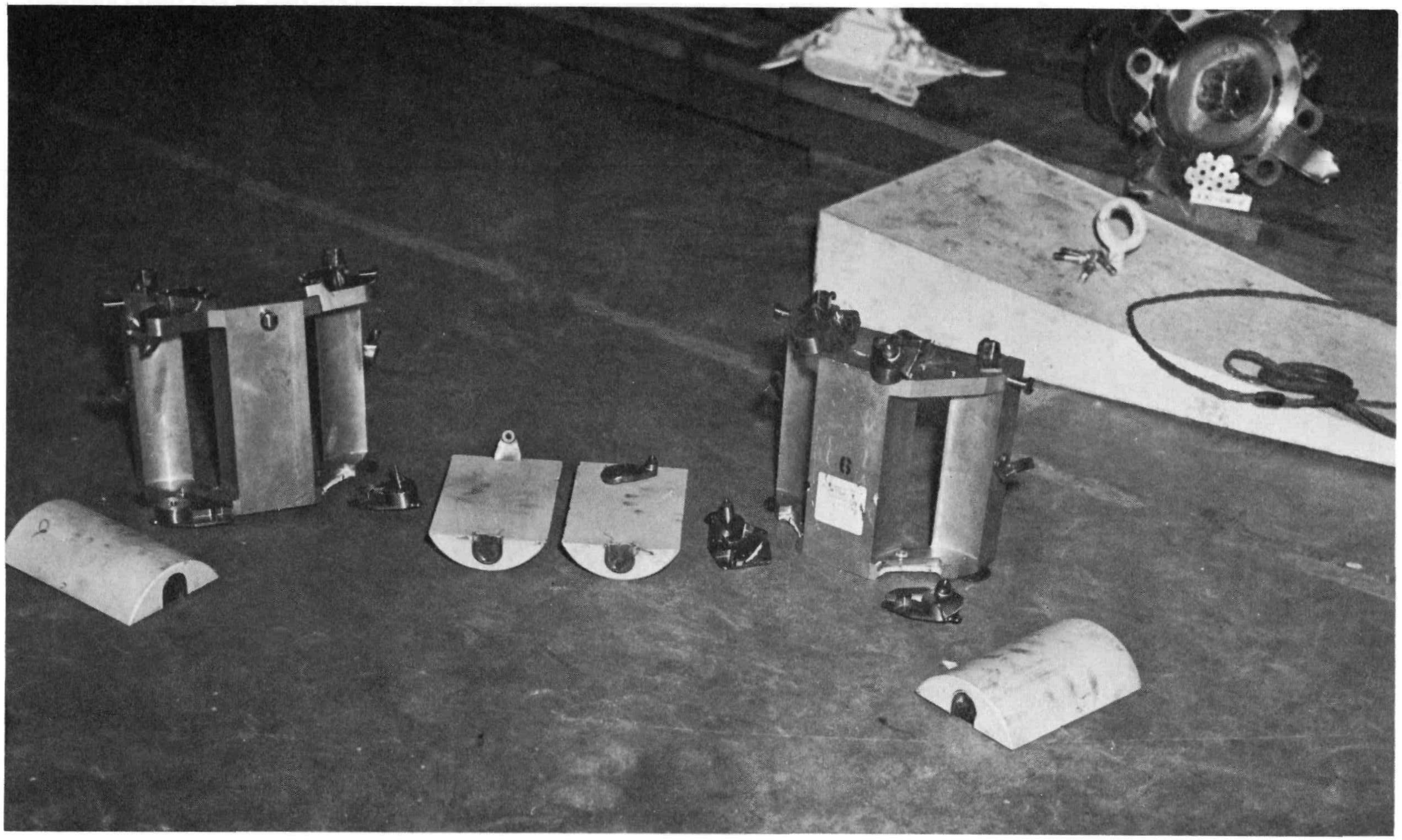
7611-5006

Figure 13. Drop-Tower Test, Converter-End Impact



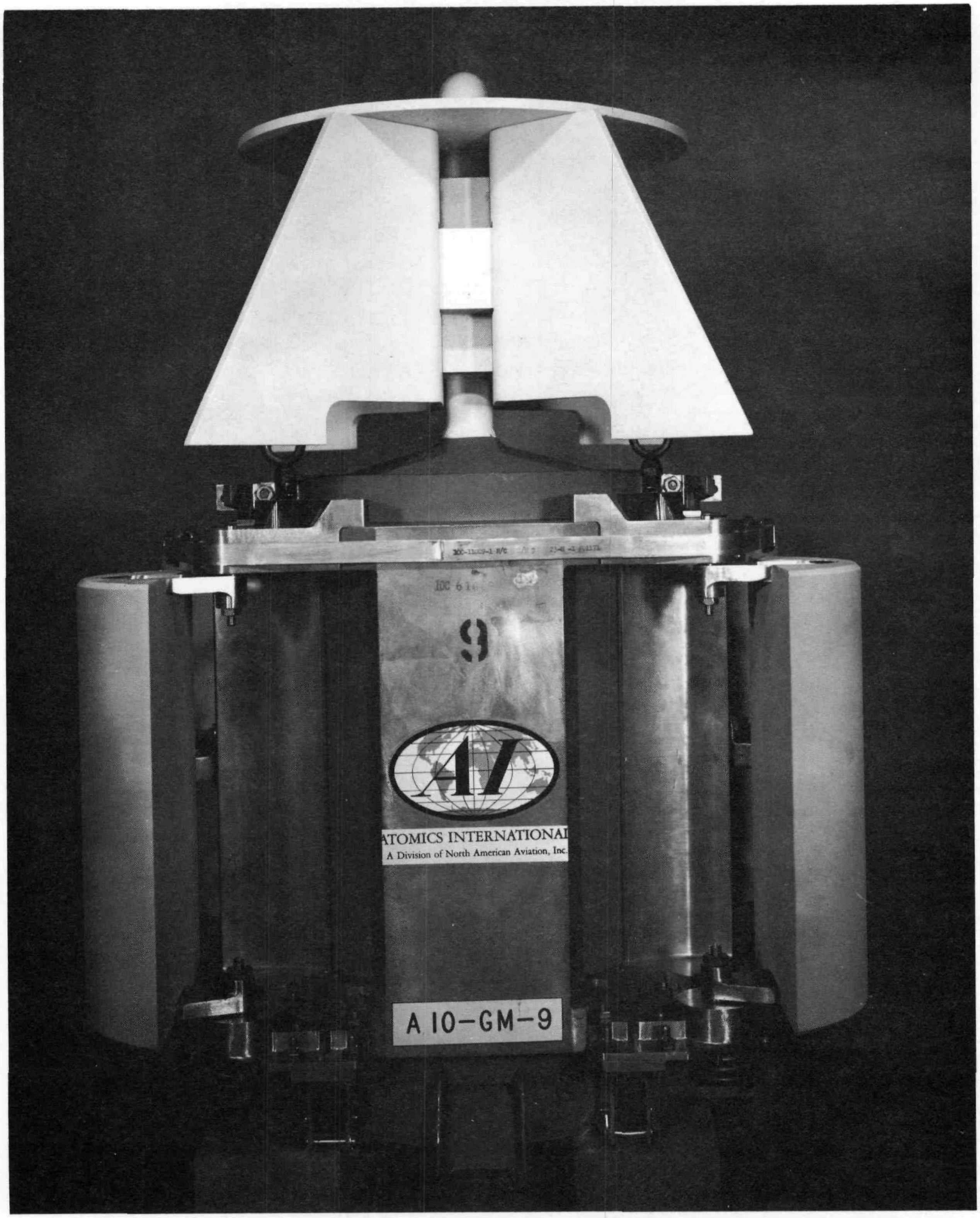
7611-5007

Figure 14. Drop-Tower Test, Side-Attitude Impact



7611-5008

Figure 15. Drop-Tower Test, Typical Results




7611-5009

Figure 16. Concrete Impact Test Article Prior to Shipment

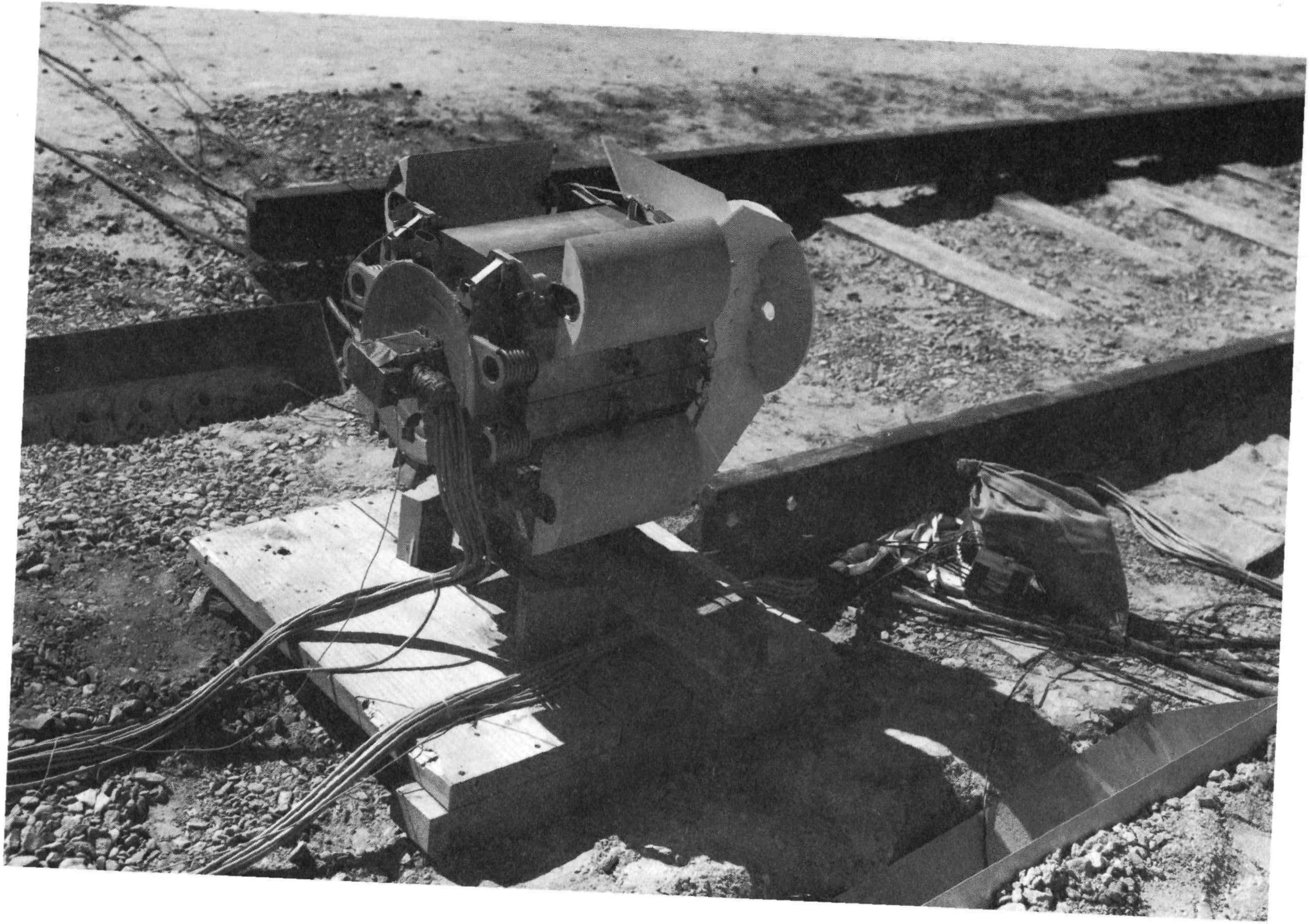
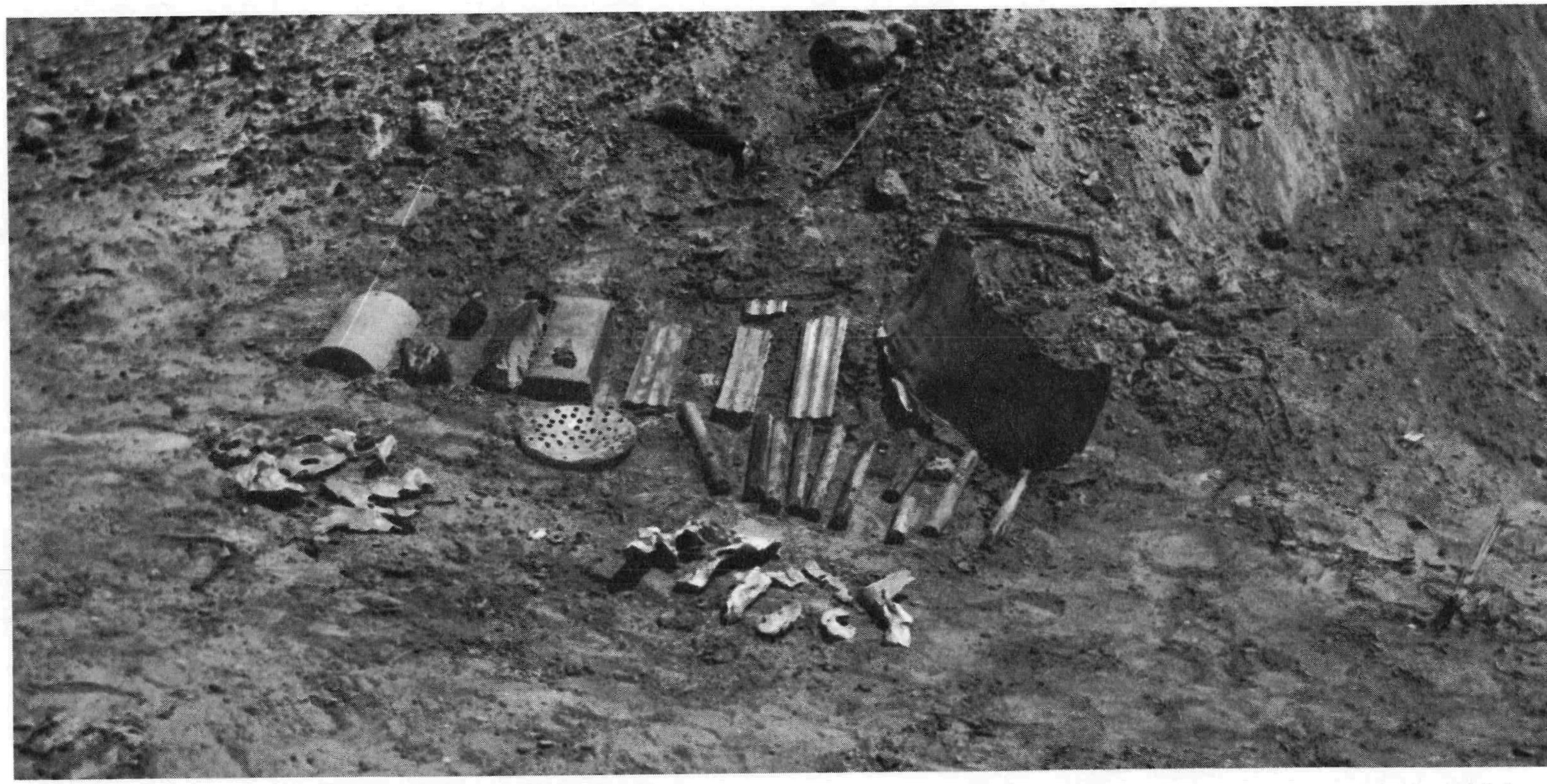


Figure 17. Concrete Impact Test Article Prior to Impact 7611-5010



7611-5011

Figure 18. Concrete Impact Test Article After Impact

7611-5012

Figure 19. Overall View of Water Impact Test Site After Impact

7611-5013

Figure 20. Debris Recovered After Head-On Water Impact

7611-5014

Figure 21. Core Vessel After Tail-On Water Impact

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ATOMICS INTERNATIONAL

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QUARTERLY PROJECT PROGRESS REPORT

| | |
|---|---|
| **Program:** SNAP Aerospace Safety | |
| **Project:** Fuel Element Burnup and Fission Product Dispersal | |
| **Responsible Engineer:** R. D. Elliott | **Project Engineer:** L. I. Moss |
| **Reporting Period:** July-September 1962 | **AEC Category:** 04-60-50-01.1 |
| **General Order:** 7611 | **Subaccount:** 2067 |

## I. PROJECT OBJECTIVES

The objectives of this project are to investigate by analytical and experimental means the burnup and dispersion of fuel element material upon reentry of SNAP reactors, and to evaluate the resultant hazards.

The analytical investigations of this project will be concerned with the development of a mathematical model which will be used to predict the physical and chemical behavior of the fuel elements in the reentry environment. This model will be validated by utilizing it to explain the results of various laboratory and flight tests of fuel elements and fuel alloy specimens.

Other objectives of this project will be to investigate possible means of enhancing burnup and dispersal of the fuel material, and to provide information which will lead to the establishment of criteria for the required release altitudes for the fuel elements.

The thermophysical properties of the fuel materials at high temperatures are not well known at the present time. Such characteristics as specific heat and thermal conductivity with hydrogen migration, liquid alloy viscosity and surface tension, thermal emissivity, and oxidization behavior have not yet been established. Previous estimates of fuel burnup have been based on some assumed parameters and on a limited number of ablation tests on zirconium-hydride without uranium. Diverse conclusions have been reached by various investigators ranging from assurance of complete burnup to doubt that the fuel elements would melt at all. Therefore, an essential part of this project will be to determine, by experimental methods, the thermophysical properties of fuel alloys.

Experimental investigations will be made of the behavior of the fuel alloys in simulated reentry environments by the use of arc-heated air jets. Finally, tests will be conducted in flight in the upper atmosphere, using actual fuel alloys, but without radioactive fission products present.

## II. MAJOR ACCOMPLISHMENTS IN FISCAL YEAR 1962

An analytical study was performed to evaluate criteria for safe reentry of SNAP reactor materials. A study of orbital decay time for various satellite orbits was made. A review of the work on the relationship between particle size and settling time was initiated, in addition to work on computational codes for predicting reentry trajectories and heat transfer.

Preliminary measurements were made on the thermal emissivities of uranium-zirconium. Programs for arc-jet testing were prepared, and a search for an acceptable arc-jet facility was conducted.

# III. PROGRESS DURING THE REPORT PERIOD

The work done on this project falls into three categories: (a) material property determinations, (b) analytical predictions of ablation rates, and (3) planning for in-flight tests.

No material properties were measured in our laboratories during this report period, but the work of other investigators, such as those under contract to AFSWC, was reviewed and discussed. Plans were made for the testing of four specimens of uranium-zirconium hydride in the arc-jet facility at North American Aviation, Inc., Los Angeles Division, but the tests were delayed because pilot runs made with zirconium metal showed that selection of a different material for the specimen supports would be required. The zirconium specimens were held on support rods of Inconel-X and on rods of zirconium. In both cases, the rods melted prematurely and the specimens fell out of the arc. Further tests showed that tungsten support rods would be satisfactory. Tests of the fuel alloy specimens will be run early in the next report period, using tungsten support rods.

The plans for the arc-jet tests include extensive preparations for health-safety monitoring and decontamination of the facility. Two of the four specimens of fuel alloy will be of a classified modification to the material, and so physical access to them and to any of the melted particles will be limited to Q-cleared personnel. A replacement heat exchanger and filter section of the facility has been purchased by AI; the contaminated heat exchanger and filter will be removed after the test and stored in a security area at AI.

Analytical predictions of the ablation of reentering fuel elements have been made by using thermophysical properties obtained from the literature. However, it was necessary to use extrapolations to estimate the properties at the higher temperatures. Data from the series of arc-jet tests of zirconium-hydride run in 1960 have also been used as test cases for the analytical model. Trajectories of fuel elements released from the reactor vessel at altitudes of 150,000 ft, 200,000 ft, 250,000 ft, and 300,000 ft have been taken from the work of General Dynamics/Astronautics (GD/ASTRO Monthly Progress Letter 596-2-6466, dated 8 May 1962). Aerodynamic heating rates were calculated by the following formula, due to Detra and Hidalgo:

$$q_{stag} = 867.7\,(r_{eff})^{-0.5}\left(\frac{\rho}{0.00238}\right)^{0.5}\left(\frac{V}{10,000}\right)^{3.15}$$

where

$q_{stag}$ = Aerodynamic heating flux at stagnation point, $B/ft^2$-sec,

$r_{eff}$ = Effective radius of curvature of stagnation point, ft,

$\rho$ = Density of the ambient air, $slugs/ft^3$, and

$V$ = Flight velocity, ft/sec.

The effective radius for a circular cylinder normal to the direction of flight is twice the actual radius of the cylinder, whereas the true radius would be used in the case of a sphere because the constant in the preceding formula was derived for a spherical geometry. The mean heat flux on the surface of a cylinder rotating about its longitudinal axis was related to the stagnation heat flux by the factor 0.36.

The calculations of ablation were made with the use of a digital computer code which simulates a thermal analyzer network. This code, called TAP-2, was revised to make possible the inclusion of latent heats of phase change in an easier and more accurate manner.

Oxidation effects, which may prove to be important, have not been included in the results to date, but they are under consideration. The effect of hydrogen dissociation on fuel rod reentry ablation was simulated by including this process as a phase change separate and distinct (at a lower temperature) from the fusion phase change associated with ablation. The resulting effect on reentry ablation was very significant; the analytical model incorporating this effect tends to be more favorable to burnup.

Analytical results to date indicate that burnup is marginal for the nontumbling rod released at 250,000 ft, and incomplete for lower release altitudes. However, efforts to improve the program input data are continuing to allow a more accurate prediction. Once data has been received from the arc-jet tests, the analytical model will be further improved.

Results of experiments conducted by Dr. Littman of the Stanford Research Institute were received. His experiments concerned the oxidation of uranium-zirconium hydride in an arc-image furnace. He duplicated the heating rates and gas pressures calculated by General Dynamics for the same trajectories that we have been using in our analyses; he failed to melt any of the material. Several of his test specimens show the formation of an oxide layer. The oxidation is more severe when the simulated trajectory corresponds to early exposure of the alloy, since the initial heating intensity is not great enough to melt the surface. His results may not be directly applicable, however, since in actual reentry the atmosphere is streaming over the surface. Furthermore, the cladding on the rods will protect them from oxidation until the heating is quite intense.

A program to determine the possibility of making hollow fuel rods for insertion of flare material was undertaken during this reporting period. First, a rod was successfully machined with a 0.5-in. diameter hole in its center. This rod was then remachined to enlarge the hole to determine the minimum wall diameter which can be manufactured. Next, the results of a pilot run of the flare insert fuel element indicated that it is feasible to drill a 0.75-in. hole in the 1.20-in. diameter SNAP 2/10A fuel rod. Later, larger holes were attempted and fuel rods with longitudinal holes up to 1.0 in. in diameter were successfully fabricated. Sandia requested twelve fuel rod samples for radiant heat tests. The twelve rods made are of natural uranium-zirconium hydride, are 6 in. in length, and have longitudinal holes up to 1.0 in. in diameter. For the larger holes, this leaves the wall thickness at only 0.1 in. (See Figures 22 and 23.)

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Figure 22. Hollow Fuel Rod for Radiant Heat Test

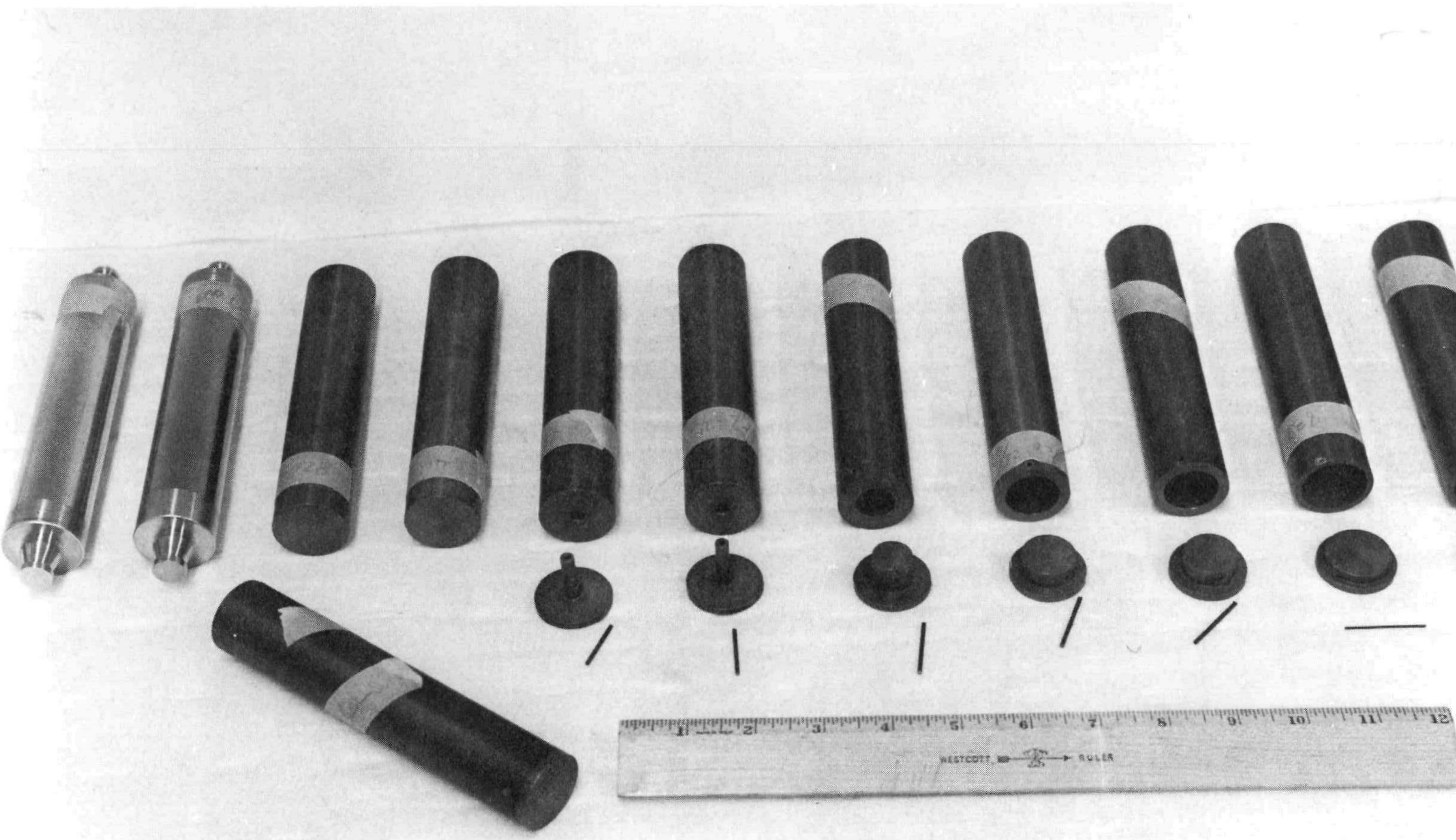

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Figure 23. Hollow Fuel Rod Configurations for Radiant Heat Tests

## IV. EVALUATION OF EFFORT TO DATE

While progress has been made toward the development of a thermal model that can be used to predict the ablation rate of materials, this model must be improved to include the effects of hydrogen migration and the effects of chemical reactions on the surface of the materials. These improvements must be based on the results of the experimental programs. At present, the mathematical tools are available but experimental data is necessary to check our calculations and improve their accuracy. Arc-jet tests and flight tests can supply this data.

The arc-jet test program has again been started. The present series of tests, which will be completed during the next report period, will comprise about four runs. These pilot tests will be used to determine whether or not the actual series of tests can be run with the unclassified fuel alloy. After this has been determined, a test plan for the actual series will be written and the program initiated.

Some studies on particle dispersion are needed in order to evaluate the hazards resulting from the settling of these particles.

## V. NEXT REPORT PERIOD ACTIVITIES

Several sample problems will be run as part of the continuing TAP-2 analytical effort.

The arc-jet tests will be performed. The results will be compared to those obtained from the analytical model as part of the continual program to improve the model.

The hollow fuel rods and their end plugs will be sent to Sandia so that they may evaluate the rods as possible specimens for later flight tests.