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QUARTERLY TECHNICAL PROGRESS REPORT
SNAP AEROSPACE SAFETY PROGRAM
OCTOBER–DECEMBER 1962

AEC Research and Development Report

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.

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NUCLEAR TECHNOLOGY-AEROSPACE SAFETY
PROPULSION SYSTEMS AND
ENERGY CONVERSION
40 PAGES

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A DIVISION OF NORTH AMERICAN AVIATION, INC.
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The previous Quarterly Technical Progress Report for the SNAP Aerospace Safety Program was NAA-SR-7797.

I. PROJECT ENGINEER'S SUMMARY

A. REACTOR TRANSIENT AND EXCURSION TESTS

During this quarter, the design of the SNAPTRAN 2/10A-1 and -2 machines was essentially completed, although certain of the assembly drawings required further work. Fabrication of the major components was well underway, primarily at outside vendors' facilities. Fabrication of many of the minor items is being done at AI.

The scheduled shipping date of April 1, 1963, for the first machine leaves little contingency for extension of the vendors' promised completion dates. AI expeditors are, therefore, maintaining close contact (daily in the case of critical parts) with these vendors in an effort to resolve problems as quickly as they arise.

In order to help define the operating limits for the nondestructive experiments, five fuel rods were heated to the point of cladding failure. Four of the rods developed inelastic yielding of the cladding in the temperature range of 1375 to 1400°F, followed by failure of the cladding integrity in the range of 1400 to 1425°F. The fifth rod demonstrated anomolous behavior (failure of the cladding integrity at 1485°F), but this can be correlated with the observed high leak rate of this particular element, since this higher rate results in a lower internal hydrogen pressure.

In these fuel rod experiments, various strain gages were tested in an attempt to find one suitable for SNAPTRAN instrumentation. A flame-spray bonded gage appears to give satisfactory data up to at least 1425°F. Further testing is planned to establish the reliability and accuracy of this strain gage.

Fuel temperature information is to be provided by the specially designed thermocouple fuel rods. A pilot instrumented rod was fabricated. It was found to be within acceptable limits when it was tested for hydrogen leak rate (at high temperature).

Fabrication of the first SNAPTRAN fuel loading (37 rods) was completed. This fuel is being stored, for the present, at AI.

Procedures for the SNAPTRAN low power tests have been specified. Only those tests which provide necessary preliminary information for the transient tests have been indicated.

At the request of Phillips Petroleum Company, AI has provided further information for the Safeguards Analysis Report. The presently indicated completion date of February 1, 1963, for the report may not be consistent with the April 1 shipping date for the machine unless AEC approval of the report can be expedited. It is expected that the preliminary discussions that have been held with AEC personnel will assist in obtaining the necessary approval in a timely fashion.

B. FISSION PRODUCT RELEASE STUDIES

The fission product release tests at the NRTS were completed during this quarter. The radiochemical analyses of the residues are in progress and preliminary results should be available before the end of the next reporting period.

C. END-OF-LIFE SHUTDOWN DEVICES

In the development of a satisfactory end-of-life shutdown device, some progress was made in the design of the explosive shutdown projectile. Also, further chemical reactions were investigated as shutdown devices. The experimental work has been temporarily halted, however, and a thorough reexamination of criteria and methods has been initiated. A redirection of effort might possibly be indicated before experimental work on this project is continued.

D. CRITICAL CONFIGURATION STUDIES

The critical configuration tests have demonstrated that a shipping sleeve of practical design will maintain the SNAP 2/10A assembly in a subcritical condition, even if the assembly is immersed in and flooded with water. This was shown in the case of the reactor without the beryllium reflector. This corresponds to the condition of the reactor during the time of shipment from Santa Susana to Vandenburg AFB. Another nuclear protective device (void filler blocks) has been shown to be effective in preventing criticality from human body reflection. In this case, the beryllium reflector was in place and the drums were in the withdrawn position. This testing program is being continued into the next period.

E. MECHANICAL AND THERMOCHEMICAL EFFECTS

The Phase I Ground Test Series at Holloman Air Force Base was completed during this period. These tests demonstrated that the reactor maintains a configuration which would allow criticality if the reactor were immersed in water after being subjected to the following conditions:

1) A LOX deluge
2) A LOX-NaK interaction
3) An explosion
4) A NaK/water interaction
5) A fire
6) Various impacts (excluding concrete at terminal velocity).

Impact on concrete at 560 ft/sec does result in complete disassembly and dispersal of the reactor.

Phase II testing to date has developed information which supports the conclusions drawn from the Phase I test results. Further Phase II tests will be conducted during the next reporting period.

F. REACTOR SEPARATION AND FUEL ELEMENT EJECTION

Comparison tests utilizing the computer code, RESTORE, have shown that the code is excellent for the calculation of reentry trajectories. Angles of attack other than zero remain to be considered as a part of the analytical work on the predictions of reactor burnup. Thermal analyses to date have indicated the significance of the coolant remaining in the vessel and pipes upon reentry. Further investigation is required in this area.

The extensive effort expended in the production of the flight test articles resulted in shipments (to Sandia) of three of the four articles this quarter. The remaining article will be completed and shipped early next quarter.

G. REENTRY BURNUP OF FUEL ELEMENTS

The calculation of fuel rod heating and ablation, utilizing the latest version of the Digital Thermal Analyzer Program, has resulted in an improved and more elaborate analytical model. Efforts have been continued in this direction with the meaningful objective of improving the thermal model, primarily by including such considerations as the heats of chemical reactions.

The analysis of the arc-jet tests made by Sandia has verified that mathematical models for ablation of fuel materials must be quite complex if reliable predictions of ablation are to be made. Results of Sandia arc-jet tests performed at the NAA-LA Division facility were factored into the RFD-1 Flight Test Program and the fuel element flare experiments were accepted for the flights. It is probable that additional arc-jet tests will be made before the end of this fiscal year to obtain additional data.

II. REACTOR TRANSIENT AND EXCURSION TESTS

A. FUEL ELEMENT TESTING

The preliminary tests on a stainless steel control sample were unsuccessful. The strain gages failed at a temperature between 1100 and 1200°F. The failures occurred at the bond between the gage and the steel. There was a possibility that bonding to the Hastelloy-N of the actual fuel rod would be more successful. One fuel element was tested with the same attachment techniques. However, the bond failed at a temperature below 1200°F. Due to the low temperature at failure, the element was not damaged.

Since the ceramic-bonded strain gages did not prove successful for measurements at temperatures above 1100°F, a different testing approach was planned. Two of the four elements were tested by heating them in 25°F increments from 1250°F to failure. The temperature was stabilized at each level and hydrogen permeation measurements were made. Following this, the element was cooled, and a dimensional check was made.

The two fuel elements without strain gages were examined after they had been cyclically heated to 1375°F. No deleterious effects were observed. During the cooling process, the hydrogen leak rate was measured when the elements were at 1200°F. The leak rate had increased approximately 20%. A negligible amount of physical distortion was observed on one of the elements. The thermal cycling was then continued until the two elements failed at temperatures in excess of 1400°F. At the time of failure, both elements showed large strains which would result in serious interferences in a core vessel.

The two remaining elements were instrumented with strain gages attached by a metallic flame spray bond. This attachment technique had been successfully employed by the General Electric Company. Also, the control coupons were instrumented in a similar fashion. The two elements were then heated to failure in the hydrogen permeation testing furnaces. Each element was heated in 25°F increments, with leak rates and strain measurements being allowed to stabilize at each temperature.

One of the two elements failed at a temperature above 1400°F. Like the previous two elements, it showed large strains which would result in interferences within the core vessel. The fourth element was still undergoing tests at the end of this reporting period.

Prior to testing the elements, Hastelloy-N coupons were instrumented to act as control samples. This was done so that quantitative data could be obtained from the strain gage measurement.

When the latter two fuel elements were heated to 1000°F, it was found that the instrumentation lead resistance to ground was too low. The original ceramic insulation was bonded to the wire but it tended to crack as the wire was flexed. It was necessary to use ceramic insulation to avoid outgassing since the fuel elements were heated in a vacuum furnace during the tests. The problem was solved by using a ceramic sleeve that fitted over the wire and could be flexed without damage.

The strain data accumulated to date are being analyzed. Additional results will be available next quarter after this analysis has been completed.

B. SNAPTRAN

Two views of the SNAPTRAN model are shown in Figures 1 and 2. The interference problems which became apparent through assembly of the model were reviewed with Phillips personnel at the NRTS. All the interferences noted were corrected by design changes.

The 2700-ft^2 shop area that will be used for SNAPTRAN assembly and testing was cleared, and the necessary work benches were installed.

One complete fuel loading was fabricated. It is being stored at AI and will be shipped to the NRTS during the next quarter.

The pilot-run instrumented fuel elements were fabricated utilizing the new instrumented fuel element design. The first fuel element had a poor weld, as indicated by the helium leak rate check; hydrogen permeation testing was therefore not performed. The second element successfully passed the permeation test. This indicated that the new design is acceptable with respect to hydrogen leak rates.

Two tests with the Blue-M radiant heater were conducted. The heater was tested first in a horizontal position. Although the backing, which is used for support, appeared sound after the test, a second test was planned with the heater mounted vertically. This test was also satisfactory.

The Phillips console arrived and was located in the shop area. Phillips personnel uncrated and inspected the console during the week of October 29.

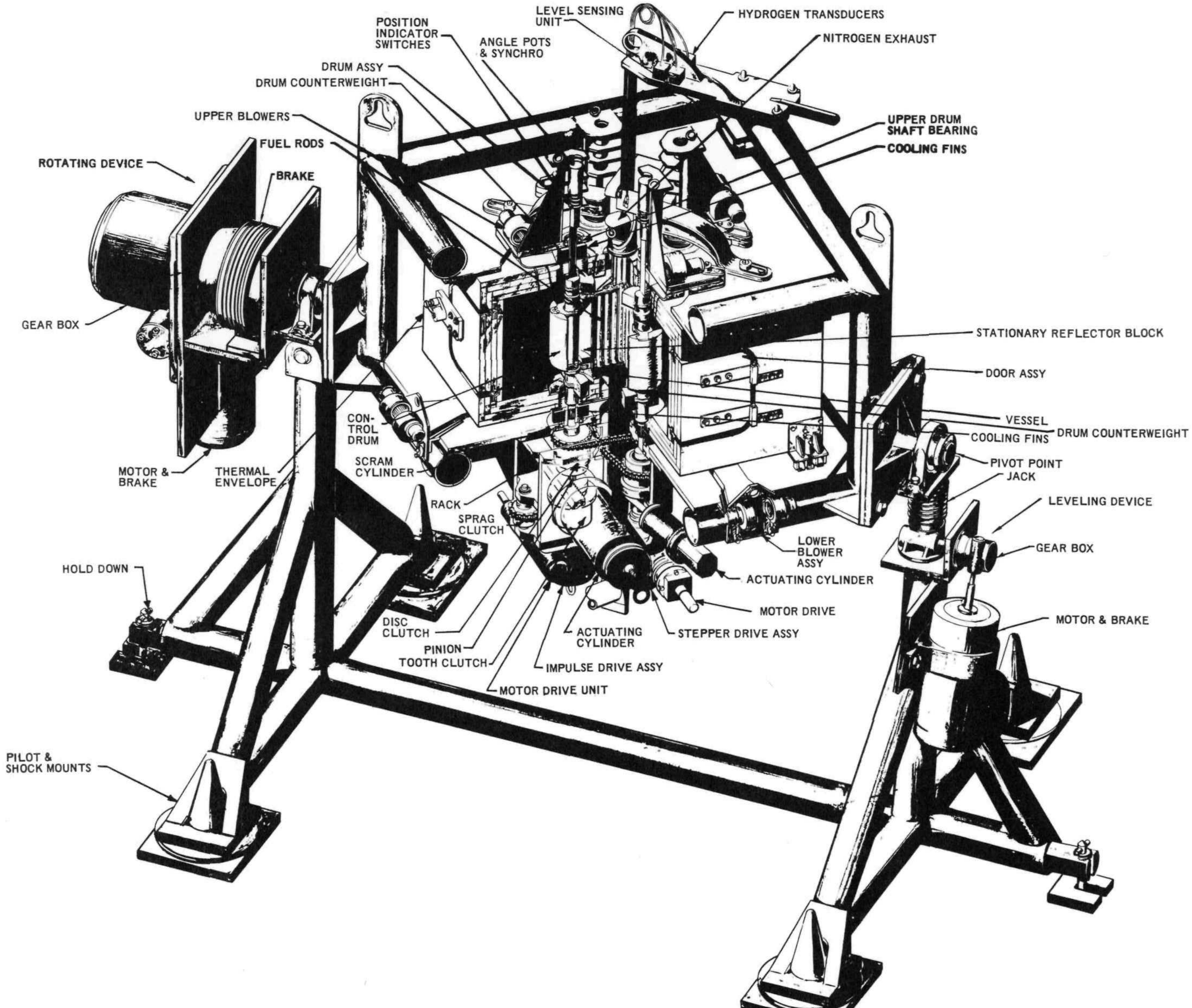

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Figure 1. SNAPTRAN 2/10A-1 Machine Schematic

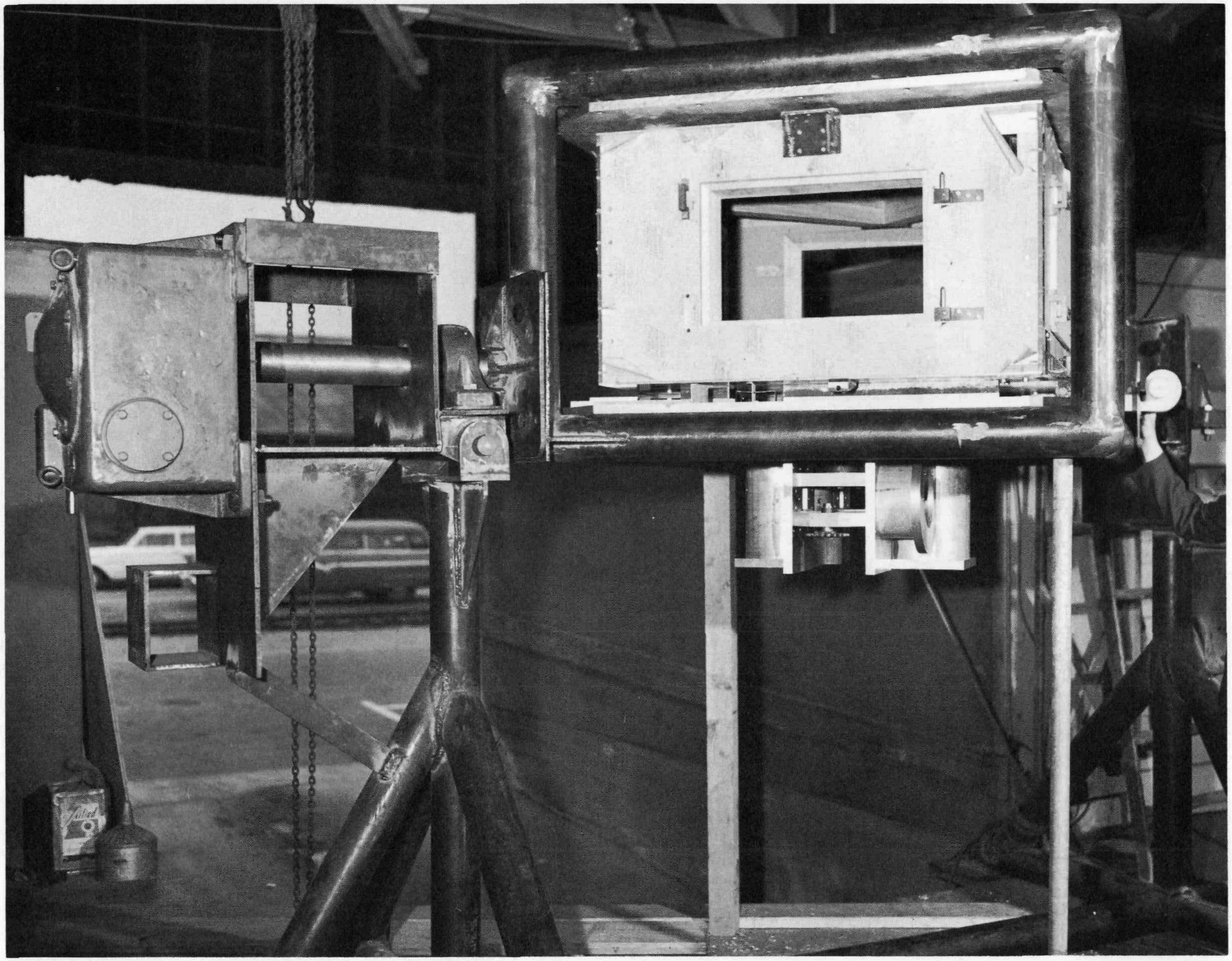

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Figure 2. SNAPTRAN 2/10A-1 Model

Motion pictures were taken of the Phillips console in the AI shop. Phillips completed the motion picture sequence requested by AI which shows the model being assembled piece by piece. A copy of this film will be used by AI to further document and improve our film record of SNAPTRAN. Also, some motion pictures have been taken of parts of the SNAPTRAN 2/10A-1 machine. Coverage will be continued when assembly is started.

Test procedures for experiments at the NRTS were reviewed and revised. These procedures were general to the degree that no discussion was included as to how any particular test, such as step tests or isothermal temperature defect measurements, would be conducted. Preparation of the detailed procedures to be followed for each different test was in progress at the end of this report period.

The Safeguards Analysis Report was reviewed at the NRTS in December. As a result of the review, AI is preparing an insert to the report describing the results of our calculation of reactor disassembly. In addition, the calculated impulse drum insertion time, as a function of initial pressure, will be provided. Also, a rough draft of the SNAPTRAN Reactor Manual of Checkout, Operation, and Maintenance Procedures was completed and is being reviewed, as are the operating test procedures for the low power tests. The low power test procedures will be provided to Phillips Petroleum as the AI recommendations for the tests to be conducted.

The design of the SNAPTRAN 2/10A-1 machine was completed and the assembly of the machine was started during this period. Approximately 50% of the parts have been received and an additional 40% are being fabricated. Several potential problem areas developed, since certain major parts were behind schedule. These delays hampered subassembly work. The rotating cube structure, which was originally scheduled to be delivered December 22, was rescheduled for delivery on January 10. This delay resulted from the many manufacturing errors made by the subcontractor. Likewise, fabrication errors delayed the chain-cross plate, which was originally scheduled for delivery November 30. It was rescheduled for delivery on January 10. It was apparent at the end of this period that potential delays could also occur in the fabrication of the impulse drive cylinder. In the cases of the critical components, an average of four full-time AI expediters have been assigned to the fabricators to prevent further delays in the delivery of the machine parts.

III. FISSION PRODUCT RELEASE STUDIES

A. ANALYSIS

The first three tests in this series were performed in the previous quarter. Test No. 4 was performed on October 9. An unclad sample was maintained at 2800°F for 3-1/2 hr in an attempt to repeat Test No. 1 (see Figure 3).

An unirradiated sample (ZrH_x - natural uranium with standard cladding and bonding) was heated and visually monitored to determine its behavior. It was found that, at approximately 2800°F, the bottom section of the cladding had melted and allowed the upper half to slide upward, presumably driven by hydrogen evolution. A further temperature increase would have caused this slipped cladding (which also had fuel adhering to it) to melt and be deposited around the top of the crucible and the graphite susceptor.

Inspection following the aforementioned test indicated that the fuel had also melted at about 2800°F. The melting point of unclad fuel has been found to be 3450°F. The probable reason that the clad sample melts at a lower temperature is because the nickel and chromium in the Hastelloy cladding alloy with zirconium at 2000 to 2300°F.

A second unirradiated clad sample was then heated and visually monitored. It was maintained at 2300°F for 10 min without melting the cladding. The temperature was then raised to 2500°F. After about 1.5 min, the cladding was observed to slide upward. It was restrained at the top of the crucible by steel wires installed for that purpose. After the sample was cooled and inspected, it was brought from 2300°F to a maximum temperature of approximately 3200°F in steps of 200°F. The end cap and upper section of the cladding did not melt, however, since they were in a region of the crucible that was decoupled from the induction coils of the furnace. The crucible was observed to be sinking in the graphite susceptor, indicating melting near the bottom. The test was terminated at this point. In the subsequent tests with active clad samples, steel wires were projected into the crucible from the top to hold down the fuel sample in the hot part of the crucible. This was done so that the cladding would melt without spewing over or lodging in the upper part of the crucible.

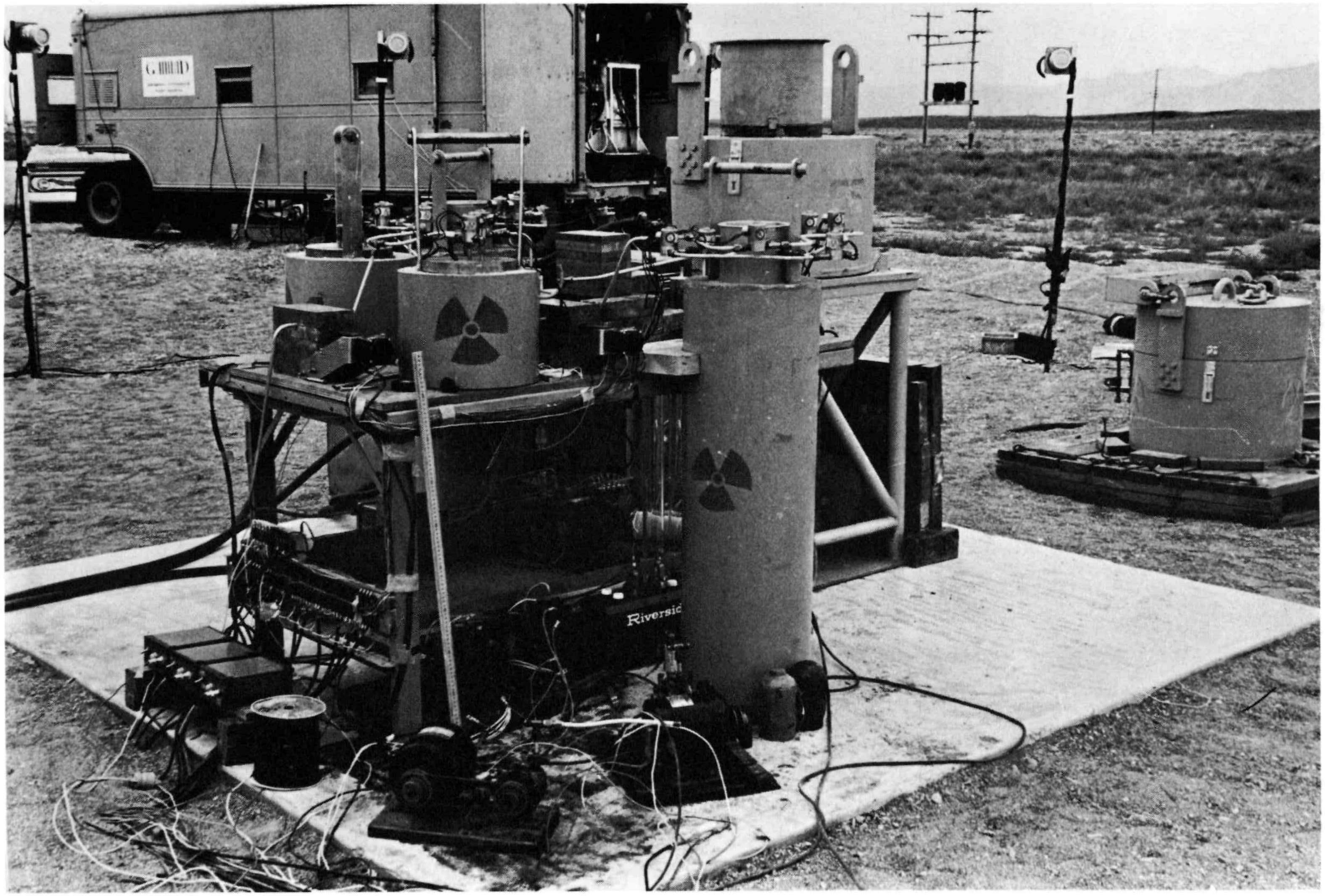

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Figure 3. Fission Product Release Tests — Furnace and Counting Apparatus

Some modifications to the fission product gas collection system were made to reduce the blockage which was previously observed. This was believed to arise from emission of oil vapor from the oil-impregnated graphite susceptors upon heating in the furnace. To correct the situation, the susceptors were preheated to drive off the vapor prior to the actual runs.

The fifth release was performed on October 24. A clad sample was heated to 3500°F, allowed to cool to 2000°F, and then maintained at that temperature for 15 min to simulate an excursion followed by a rocket fuel fire. The test was successful. The wires that were installed to prevent the fuel cladding from sliding up and spewing out of the crucible were effective. There was little residue around the top of the crucible following the run.

Test No. 6, a clad sample maintained at 2400°F for 1 hr, was performed on November 9. Test No. 7, an unclad sample maintained at 2000°F for 8-1/2 hr, was performed on November 13. Very little activity was released during Test No. 7, as evidenced by a radiation level of about 20 mr/hr near the fission product gas collector. Test No. 8, an unclad sample at 3200°F, was run on November 15. However, since the furnace coil leaked, the test was repeated.

Test No. 9, a clad sample heated to 2800°F, was run on November 19. Unfortunately, a water leak developed in the furnace coil after about 1 hr. This made it necessary to terminate the test, and much of the data obtained were useless. This was the third test that had been unsuccessful due to leaky furnace coils. Whenever a leak occurred, the steam reacted with the fuel sample under test (zirconium-water reaction) and also carried iodine out of the iodine trap. The moisture soon clogged the fission product gas trap; therefore, after a leak is detected, a test must be terminated.

On November 21, an unclad sample was maintained at 3200°F for 7 hr, satisfactorily completing Test No. 10. On November 23, a clad sample was held at 2000°F for 7 hr. Test No. 12, an unclad sample maintained at 2500°F for 6 hr, was performed on November 27. These three tests ran smoothly, and are expected to yield valuable data. They were the last tests in the series.

B. POSTTEST ACTIVITIES

After the tests were completed, AI retained possession of the 12 total effluent collector bodies and stored them at the NRTS. They can be reused in future release programs after they have been refitted with new filter elements. The General Dynamics personnel dismantled their equipment and shipped it to Fort Worth prior to their leaving the NRTS.

A movie script is being prepared for the motion picture coverage of the test program. The motion picture coverage was completed at the same time as Test No. 12, the last test in the series.

The initial analysis of the tests is being performed at the Phillips Chemical Processing Plant. Dissolution of residue was temporarily suspended while the quartz apparatus was replaced with special linear polyethylene containers. The quartz was being dissolved by the heated nitric acid-hydrofluoric acid solution used on the fuel residue. The linear polyethylene containers were tested and found to be much more suitable.

The radiochemical results for the first two tests were received from Phillips Chemical Processing Plant. The fission product inventory fuel monitor samples for these two tests were also analyzed. Reduction of the data at AI is now in progress and will continue into the next quarter.

IV. END-OF-LIFE SHUTDOWN DEVICES

An interim report summarizing the progress to date was in preparation at the end of this reporting period. After this interim report is completed, the project will be evaluated and may be reoriented before the experimental work is resumed.

A. CHEMICAL REACTION SHUTDOWN

During this period, reactions were conducted using Al, Be, Ca, and Zr as reducing agents and Sr $(NO_3)_2$ as an oxidizing agent with SiO_2 as the catalyst. These reactions were successful, but a thermal stability test of Al and $Sr(NO_3)_2$ with SiO_2 proved unsuccessful.

A reaction of Zr + $Sr(NO_3)_2$ with SiO_2 as the catalyst was successful at 400°C. Other successful reactions occurred with Ca and $SrCO_3$, Ca with a fused mixture of $SrCO_3$ and Na_2CO_3, and SiC and $Ba(NO_3)_2$. These gave good temperature and pressure yields. The next series of successful reactions were conducted with Al and PbO and C at 1100°F, but stability tests at this temperature indicated that a slow reaction takes place, thus reducing the output of the final reaction. SiC and $Ba(NO_3)_2$, with small additions of SiO_2, gave a good pressure increase. Reactions of Al and $Sr(NO_3)_2$, with Al_2O_3 as a catalyst, also showed a good pressure increase, even after short thermal stability tests.

Unsuccessful reactions were made with Ca and $CaSO_4$, $SrSO_4$, and $BaSO_4$. The reactions with Zr + MnO_2 + C, Al + Ph_3O_4 + C, Be + $Zn_2P_2O_7$ + C, and FeS + CuO were unsuccessful. A combination of Ca + $CaCO_3$ was tried with varied success. Reactions of Ca + $SrCO_3$ were not successful, while Al_4C_3 + SnO_2 gave fair pressure and temperature increases. Reactions of Be and Na_2CO_3, Be and SnO_2, Ca and K_2CO_3, Ca and PbO, Ca and SnO + C, Zr and PbO + C were not considered successful.

B. EXPLOSIVE SHUTDOWN PROJECTILE

The revised assembly drawing of the command box was reviewed. A few changes were made and the detailed design of the assembly was changed accordingly.

V. CRITICAL CONFIGURATION STUDIES

A. ANALYSIS

A hazards analysis of the SNAP 8 core water-immersion tests with ramp insertions of reactivity from \$0.01 to \$1.50/sec was made with the aid of the BOOMER computer code. The analysis showed no significant increase over SNAP 2/10A core hazards. The maximum integrated energy release of the SNAP 8 core was calculated as 46 Mw-sec with maximum fuel temperatures of approximately 2400°F. Core rupture from internal pressures arising from hydrogen evolution would terminate the excursion. This analysis was transmitted to the AEC as additional information prior to their final approval of the SNAP 8 water immersion tests.

B. FABRICATION

The design and fabrication of the various SNAP 2/10A and SNAP 8 water immersion hardware was completed during this reporting period. Because of the difficulties in estimating the reactivity effects of the flight reactor hardware, especially in the water-reflected system, mockups were used in the final evaluation of the filler block concept. This concept is designed to prevent criticality of the beryllium-reflected assembly upon water immersion. Mockups were fabricated for the plenum chambers, NaK piping, drum position indicators, drum locks and stops, and the neutron shield.

The hardware for the beryllium-water reflector experiments was installed. Although all of these experiments were conducted with a dry core, a pumping system was necessary to provide a continuous removal capability in the event that any water leaked into the core. The designed water system proved to be inadequate; therefore, a separate water system was installed to remove this water.

Ten SNAP 2/10A type fuel rods of low hydrogen concentration (6.0 compared to 6.0×10^{22} atom/cm^3) were fabricated and delivered to the test cell. These elements were placed in the core one at a time in order to determine their effect on reactivity in a water system.

The SNAP 8 hardware was assembled and no interference problems were encountered. The hardware was installed and checked out on the critical machine in preparation for SNAP 8 water immersion experiments. The SNAP 2/10A hardware was disassembled and the fuel was transferred to the SNAP 10A dry critical experiments (SCA-4C).

C. EXPERIMENTS

The Phase III experiments were not initiated during the previous quarter due to a delay in the approval of the Building 012 Facility Safeguards Report. However, the water immersion critical machine (Figure 4) was assembled; a description is as follows.

In the critical machine assembly, the top water reflector, which contains the core vessel, and the fission chambers remain stationary. The top reflector provides 6 in. of the top axial water plus 4 in. (the upper third) of the radial water reflection. The remaining 8 in. (the lower two-thirds) of the core extends below the top reflector, as shown in Figure 4. The bottom radial reflector provides two-thirds of the radial water reflection plus the bottom axial reflection. In sleeve experiments, the bottom of the core vessel is opened so that water from the bottom radial reflector flows into the core.

To initiate an experiment, the active movable frame is raised by a chain drive. Motion is transmitted to the passive frame through an electromagnetic coupling. The bottom radial reflector, which is supported on the passive movable frame, is thus raised to surround the core vessel. For scrams, the electromagnet is deenergized, releasing the bottom radial reflector and removing two-thirds of the radial reflection, the axial reflection from one end, and the internal core water.

After the bottom reflector is raised, water is added at a slow, safe rate. To ensure adequate shutdown safety, no configuration will be tested that is critical on only reflection from the bottom radial reflector. After the bottom reflector is filled, water may then be added to the top reflector in order to obtain criticality.

The poison sleeves are shown surrounding the core. The configuration of the most effective sleeve that was tested is shown in Figure 5. The 3-in. void which surrounds the core contains a number of small compartments. On a flight hardware design, each compartment would be water-tight to prevent complete flooding of the void upon possible fracture of the sleeve. Natural boron powder is used as the surrounding nuclear poison. The steel protector will be used in the actual design to prevent damage to the sleeve if an accident occurs during shipping.

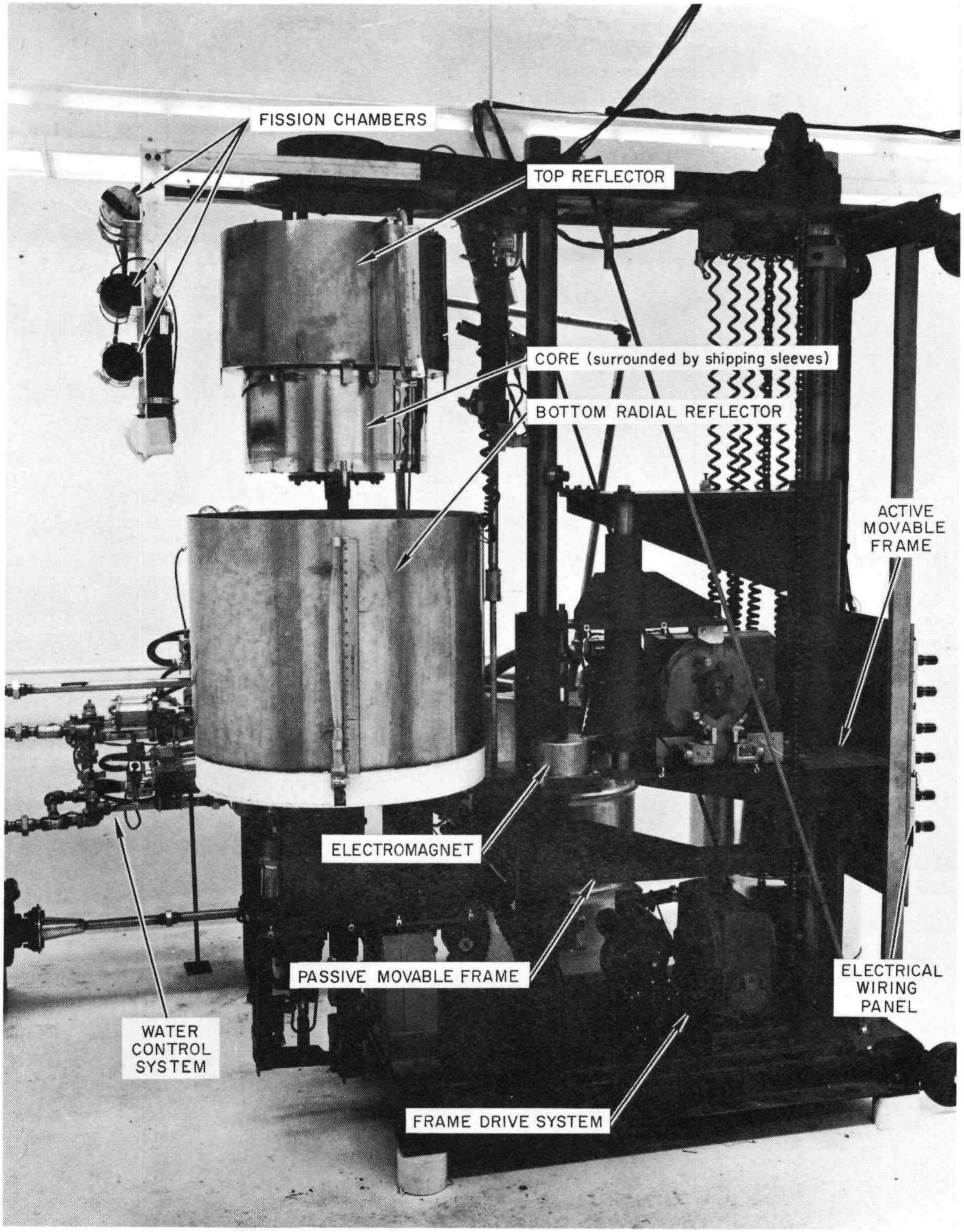

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Figure 4. Water Immersion Critical Machine

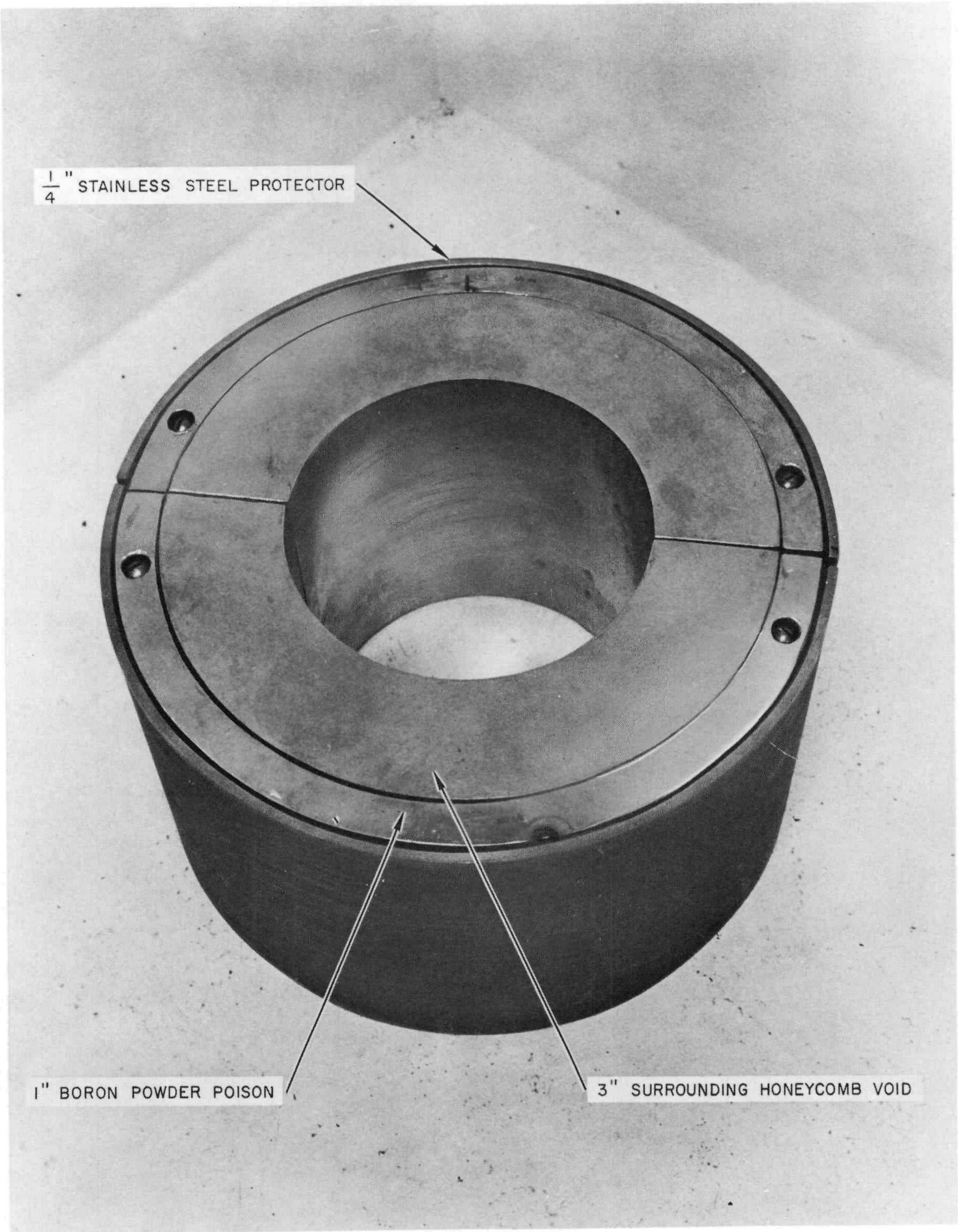

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Figure 5. Shipping Sleeve Configuration

AEC approval of the Building 012 Facility Safeguards Report was received October 15. Loading of the bare, water-reflected and flooded SNAP 10A core was initiated the following morning. Some delay was encountered because the fuel elements were slightly contaminated with alpha radiation. The source of contamination was traced to the shipping "bird cages;" all contamination was removed. The initial loading of 20 fuel rods and 17 lucite rods with full water reflection and flooding was subcritical, but noise in several of the counting chambers caused sporadic scrams. This problem was corrected and criticality was obtained October 18, with slightly less than 25 fuel rods. The critical loading agreed closely with that obtained during the Phase I and II experiments that were conducted in FY 1962.

The next tests evaluated the 3-in. void plus 1-in. boron poison shipping sleeve. The water-reflected and flooded core with this sleeve was critical with 36 rods. Next, cadmium sheets were placed over the ends of the void portions of the sleeve. This poison shielded the reactor from those neutrons scattered from the axial water through the void and thus to the core. Criticality was achieved with 37 rods and 1.5 in. of axial water reflection on one end (water everywhere else). A simulated sleeve protection structure of 1/4-in. steel surrounding the sleeve increased the reactivity by approximately 15¢.

Criticality was then achieved with the 3-in. void plus 1-in. poison plus 1/4-in. steel sleeve (no cadmium ends) with a 1-in. axial reflection on one end (water everywhere else). Four rods of low hydrogen content were then substituted to obtain a critical 37-rod loading with water both within and without the core. The flight system reactivity will be at least $1.00 less than the reactivity achieved in the aforementioned modified loading.

The important conclusion drawn from these initial experiments was that the "void-poison-protector" sleeve design will be adequate to prevent criticality of the flight reactor during water immersion. Based on these experiments, a sleeve will be designed for the flight reactor and it will be tested on a reactor of flight system reactivity.

The test apparatus was then modified prior to conducting the water experiments with the beryllium-reflected core. These experiments will be utilized to determine the effects of water on the system and to evaluate the filler block concept of reducing reactivity and preventing criticality upon water immersion.

The beryllium-water reflector tests were planned to determine the effects of water immersion only (with no water flooding). In these tests, the critical fuel loadings were obtained with nearly full or full water reflection. For safety purposes, styrofoam inserts were placed in the rod interstices to reduce the potential water volume in the core, in the event of a possible core rupture. Lucite rods were located in all the vacant fuel rod positions. Internal beryllium reflectors were installed.

The beryllium-water reflector tests were designed to provide an experimental evaluation, rather than provide comparisons for analytical studies. The filler block design prevents insertion of the beryllium control drums. The filler blocks were constructed of 0.4-in.-thick natural boron powder in a stainless steel container. They extend into the drum voids and partially cover two of the four remaining reflector faces. The surface area covered was limited by the location of the various flight hardware.

In all the experiments, the control drums were rigidly supported in the "out" position. Although this configuration makes analytical studies more difficult, it was chosen to represent the actual environment for the filler block experiments.

The first test was conducted without the poison filler blocks. Criticality was achieved with 26 fuel rods, 1-in. axial water reflector on one end, and full water reflector elsewhere.

Testing of the filler block concept on the SNAP 10A reactor was completed upon achieving a subcritical full loading of the beryllium-reflected, water-immersed reactor. However, the basic poison filler block design and basic SCA-4B experiment and reactor loading was critical with 33 fuel rods and 4 lucite rods. Successive modifications were made in the experiment to better represent the SNAP 10A flight system reactor and to improve the filler block design. Initially, the reactor plenum chambers were installed which increased the critical loading by approximately 0.5 fuel rods. The 10 rods of lower hydrogen concentration were substituted in the central core region to reduce the core reactivity to a value nearer that of the flight reactor design. This resulted in a critical loading of 36 fuel rods and one lucite rod. The filler block design was then modified by adding styrofoam behind the filler blocks to move water away from the core. This resulted in an increase in critical loading to approximately 36.5 fuel rods. A styrofoam mockup of the neutron shield volume was then installed to eliminate water from that volume. This resulted in a subcritical, full 37-rod loading with water reflector.

D. EVALUATION OF EXPERIMENTS

Calculations using experimental data indicated that the reactivity of the tested SCA-4B system with the 10 special fuel rods is comparable to SNAP 10A flight reactivity. If this is verified (in later SCA-4C experiments), it will have been demonstrated that a filler block design will afford protection against water immersion. The sequence of experiments indicated areas where possible design changes are necessary for subcriticality. Additional modifications, such as (1) placing the void between the core and the poison, (2) increasing the area of reflector covered by the filler blocks, and (3) extending the filler blocks over the axial regions of the reactor are being incorporated into the filler block design. The adequacy of this design will be demonstrated on a reactor of flight system reactivity. Additional dry critical experiments will be conducted to verify that the SCA-4B core loading contains enough reactivity to meet flight design requirements.

Two important safeguards problems were evaluated in these experiments. Without any filler block modification, the present filler blocks will provide protection against human body reflection. Depending upon the results of the dry critical experiments, the flight system SNAP 10A reactor, with redesigned filler block, is believed to be subcritical when immersed in water. However, the evaluation of the filler block design cannot be completed until the SCA-4B core reactivity has been compared to the SNAP 10A flight system reactivity. The fuel has been transferred to Building 373 so that dry critical experiments can be performed to provide the needed data.

The evaluation of the filler block concept will permit the start of the general Phase III tests on SNAP 2/10A or the SNAP 8 water immersion tests. The SNAP 2/10A tests will provide criteria for an evaluation of general sleeve designs. The effect of different thicknesses of voids and different nuclear poison and void-poison sleeve combinations will be determined. The SNAP 8 water immersion program will be an initial study of the reactivity effects of water on the SNAP 8 system. This program will (1) determine the reactivity effects of water on the S8ER core design and (2) evaluate the SNAP 10A-type shipping sleeve with regard to preventing criticality upon water flooding and immersion Poison rods (Sm_2O_3) will be loaded, if necessary, to achieve subcriticality in this water configuration. The SNAP 8 program is outlined in Table I.

TABLE I

SNAP 8 WATER IMMERSION EXPERIMENTS

Experiment	Core Region	1st	2nd	3rd	Measurement*
1	Water	Water	-	-	a & b
2	Water	3-in. void	1-in. boron	Water	a & b
3	Water-poison	3-in. void	1-in. boron	Water	c
4	Air	Water	-	-	a & b
5	Water	Air	-	-	a & b

*a. Critical loading
b. Excess reactivity fully loaded
c. Poison rods for criticality fully loaded

A full loading of lucite rods was installed in the SNAP 8 water immersion core in preparation for the experiments. The fuel loading was started immediately after receipt of AEC approval which was received at the very end of this quarter.

This experimental work on the SNAP 2/10A and SNAP 8 core systems is scheduled to be completed by April 1.

VI. MECHANICAL AND THERMOCHEMICAL EFFECTS

A. PHASE I TESTS

Twelve Phase I tests were run at Holloman Air Force Base during the previous quarter and one test was cancelled. (Refer to July-September Quarterly Progress Report, NAA-SR-7797.) The last of the series (Test No. 14) was performed during this quarter on October 10.

Test No. 14 was to consist of a reactor-reflector-shield-modified converter assembly impacting in a tank of water in a nose-first attitude at 750 ft/sec. The rocket sled did not function properly during the test. There were 12 rockets on the sled which were programmed in three stages of 2, 4, and 6 rockets each. The first and third stages functioned properly, but the second stage did not fire. This resulted in an impact velocity of only 428 ft/sec.

The sled stopping device operated properly. The test article passed through the tank and impacted on the hill of earth beyond the tank. The test article yawed slightly in the tank, giving it a lateral velocity. At the point of impact on the hill, the reactor vessel came to rest, while the shield and modified converter structure continued their flight. The shield and converter structure finally came to rest along the side of the hill. The upper and lower heads were torn from the vessel, and the upper grid plate was separated, but the fuel rod array was intact within the vessel wall.

This completed the Phase I Mechanical and Thermochemical Test Program. The program was comprised of 13 tests in which mockup SNAP 10A reactor assemblies (in some cases, including the shield and converter structure) were subjected to abort environments of thermal shock, chemical interaction, explosion, and impact. The test data are presently being analyzed.

It was noted that thermal shock due to a LOX deluge had no appreciable effect on the reactor assembly. Chemical interactions, although violent in the case of the NaK-water reaction, did not damage the core vessel. Fire, explosion, 80-ft/sec impacts on concrete, or upwards of 550-ft/sec (terminal velocity) impacts on water resulted in reflector ejection with little or no damage to the core vessel. Impact on concrete at 560 ft/sec did, however, produce complete disassembly of the reactor (see Figure 6).

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Figure 6. Test Article After Concrete Impact

A point of considerable importance is that in every test, with the exception of the 560-ft/sec concrete impact, the fuel element array did not disassemble as much as would be required to prevent criticality when immersed in water. This was true in all three of the low-velocity concrete impact tests and all four of the high-velocity water impact tests.

B. PHASE II TESTS

On October 20, a NaK-water interaction test was conducted by Sandia as part of the Phase II program. The test article was suspended in a 12-ft-diameter, water filled, steel tank 3 ft below the water surface. The inlet and outlet lines of the core vessel opened cleanly upon activation of the squibs in the lines. The initial reaction was an explosion, accompanied by a sheet of flame rising about 6 ft above the surface of the water. This was followed by a period (about 1 min) of intense turbulence in the water. There was no significant damage to the core vessel as a result of this test.

The next test conducted by Sandia was performed to evaluate the possibility of a missile-abort fire causing ignition of the SNAP 10A drum lockout pin puller squibs.

The test conditions specified an incident heat flux of greater than 360 Btu/sec-ft^2. This number was arrived at by making the conservative assumptions of (1) 5000°F flame temperature, (2) infinite flame, and (3) flame emissivity = 1.0. The test duration was specified as 3.0 sec, which is somewhat longer than the free-fall drop time of the reactor assembly from its position in the nose of the missile to the launch pad.

Two McCormick M-130 squibs were mounted in a titanium actuator assembly. Connectors were then attached to the squibs. All hardware met flight system specifications. The test article was placed in the Sandia Radiant Heat Facility to achieve the test conditions. At the end of the 3-sec period, the temperature of the actuator assembly had risen to approximately 600°F. Of the total of six squibs tested, none ignited during this period.

The duration of the heating was then extended to determine the time required for ignition. This time was found to be 8.7 sec, at which time a portion of the titanium of the actuator assembly was molten. Thus the test results indicated that the squibs would not ignite prior to the impact of the reactor assembly on the launch pad, since the free-fall time is much less than that required for squib ignition due to heating.

The significance of the test was that one of the two mechanisms that could cause premature squib ignition was demonstrated to be incredible. The second mechanism, a false signal to ignite, which in some manner bypasses the various interlocks, has not yet been evaluated. If premature ignition can be shown to be incredible or of an acceptably low probability, then the reactor assembly, at the time of impact on the launch pad, will be in a configuration with all four control drums locked out. The credibility of three of the drums rotating in, prior to the demonstrated separation of the beryllium main blocks, will be evaluated as a part of the Phase II Testing Program. Only if three of the drums rotate fully in, can the assembly be supercritical in the absence of water.

The third test performed by Sandia was to establish the condition of the SNAP 10A core vessel and fuel element array after a 550-ft/sec (terminal velocity) head-on impact on compacted soil. The core vessel survived the impact with little damage. The fuel element array was not significantly affected.

The test article included the core vessel with dummy fuel rods, reflector assembly, pump and fins, shield, and the top part of the converter structure. The target consisted of compacted soil that was in the form of a rectangular parallelepiped, 16 ft wide, 8 ft high, and 8 ft deep. The soil was tamped after each 3 in. of addition to the height in accordance with a frequently used "Sandia Standard Earth" specification. Due to the low velocity of shock wave propagation in soil, the target represented an infinite medium for the purposes of the test.

The test article was brought to a stop in the target; the target itself was destroyed by the impact. As a result of the impact, the reflector disassembled from the core vessel. Very little damage was incurred by the vessel, the most notable being a 1-in. -long opening in the vicinity of the top head weld area. The fuel element array was not significantly affected. The test indicated that the core vessel can survive a terminal velocity land impact, resulting from a launch abort.

An analysis of the dynamic characteristics of the SNAP 10A flight system control drum drive assembly has demonstrated that the moments of inertia and braking forces are such that, under conditions of impact, the drum behaves as if it were unrestrained by the drive system. Accordingly, the design of the four test articles for the drop tests is proceeding on the basis of eliminating the drive system. These articles will consist of a mockup reactor-reflector assembly. Since the converter structure and the shield will in no way contribute to the angular moments applied to the drums, they will not be provided.

The design specifications for the four test articles have been determined. These articles will be used in the concrete impact tests conducted by Sandia as a part of the Phase II program. Several of the long lead time items involved have been ordered to ensure completion of the articles by the scheduled April 1 date.

VII. REACTOR SEPARATION AND FUEL ELEMENT EJECTION

A. ANALYSIS

The trajectory code, RESTORE (Reentry of Satellites to an Oblate, Rotating Earth), was tested by comparison of calculated trajectories with those given by General Dynamics/Astronautics in their Monthly Progress Letter on SNAP Reentry Studies, dated May 8, 1962. The results agreed within 0.1%. Other trial runs made with RESTORE have shown excellent agreement with the published trajectories.

The analytical work on the predictions of reactor burnup was continued during this reporting period. Calculations were made for several initial velocities and path angles using 400,000 ft as the initial altitude. Only the case of zero angle of attack has thus far been considered, but a concurrent study was made to determine the oscillation rates and angles of attack, during reentry, of typical vehicles containing a SNAP 10A reactor system. The preliminary results of the analysis indicated that the aerodynamic trim angle for the SNAP 10A installed on an Agena-B will be about 18 to 20 degrees. Indications are that the vehicle will become nearly aligned with this angle during the orbital decay period prior to reaching its aerodynamic heating peak, although the oscillations will persist.

The thermal analysis further indicated that the reactor will separate from the shield and the APU at an altitude of about 250,000 ft. This is approximately the same altitude at which the NaK pipe is expected to fail. Subsequent failure of the vessel may occur through melting of the walls, rather than of the lip.

A theoretical study of shock wave patterns of the SNAP 10A pump and core vessel lip was made. This study was directed toward prediction of aerodynamic heating intensities in various regions. The work to date has been limited to the case of zero angle of attack since other angles are expected to require the use of experimental methods, such as wind tunnel tests.

The effects of coolant (NaK) remaining in the vessel and pipes upon reentry is also being considered. If the reactor enters with its cooling system intact, the heat required to melt the vessel would be much greater than if the coolant had previously leaked out. The thermodynamic aspects of the sudden release of the heated liquid through the first hole melted in the system are being studied.

B. FLIGHT TEST PROGRAM

The overall assembly drawing and the instrumentation installation drawings for the reentry flight test model were completed. A drawing of the modified core containing three fuel elements rigidly held between the grid plates was prepared and checked. During the assembly of the first reactor model, drawing changes were noted and the drawings were updated.

The mass and moment-of-inertia calculations were corrected for the removal of the dummy fuel rods and for a revision in the concept of the NaK pipe separation. The three configurations considered are:

1) The complete assembly

2) The assembly after the ejection of the band, reflectors, and springs

3) The assembly after the loss of the pump, top head, and NaK pipes down to the level of the top head.

The results of the calculations are shown in Table II.

TABLE II

RESULTS OF MASS AND MOMENT-OF-INERTIA CALCULATIONS

Configuration	1	2	3
Mass (lb)	77.80	51.96	32.19
Center of mass (in.)*			
x (roll)	-10.25	-10.64	-5.36
y (pitch)	- 0.06	0	0
z (yaw)	+ 0.01	0	-0.01
Moment of inertia (slug-ft^2)			
I_x (roll)	0.45	0.21	0.12
I_y (pitch)	1.27	1.05	0.31
I_z (yaw)	1.21	0.97	0.30

*The sign convections used are:
Roll axis, x, is positive rearward, measured from the mating plane (Sandia's station 13.812).
Pitch axis, y, is positive to the right-hand side, looking forward.
Yaw axis, z, is positive upward.

In all, four reactor models were built to represent the SNAP 10A reactor vessel, pump, and reflector assembly. Dummy fuel rods were not used in the core; they were omitted to save weight. Sandia is planning to use eight fuel rods mounted externally. These rods will be released at an altitude of 370,000 ft. The models utilize 21 thermocouples to indicate the rates of heating on the various components of the reactor. Also, eight switches were incorporated; these will indicate the release of the reflectors and failure of the top head and/or sides of the vessel.

The first article, which will be used for the qualification tests preparatory to the reentry flight tests, was completed on November 28 and delivered to Sandia that same day. The second article was completed December 14, while the third test article (A10FM-4), which will be used for the first flight test in the reentry program, was completed December 28. Final assembly of the fourth article was temporarily delayed pending receipt of the upper grid plate from Sandia. It will be completed and shipped to Sandia within the first two weeks of the next quarter.

C. EXPERIMENTS

On October 22, an AI-fabricated mockup of a SNAP 10A core can and top head was tested by Sandia in their Radiant Heat Facility to evaluate the mode of top head ejection. The results of this test indicated that there is a distinct possibility that the top head would not eject as expected.

In the test, the heating elements were distributed to simulate the analytically estimated spatial distribution of incident heat flux expected during reentry. An experimental verification of the heat flux distribution will not be available until the data from the "hot shot" tunnel tests are analyzed. These tests were conducted in December.

The thermocouples in and adjacent to the lip weld recorded the temperature history during the test. As expected, the highest temperatures (approximately 2500°F) occurred in the lip weld. Areas of the head and core can, immediately adjacent to the lip weld, reached temperatures of approximately 1600 and 800°F, respectively. As a result of this heating, the top head and/or the core can yielded the distance of the spring travel (0.12 in.), thereby reducing the spring force to zero. The springs, therefore, could not serve their anticipated purpose of ejecting the top head. The lip weld itself appeared to be unaffected by the heating.

A second test, similar to the foregoing, was also conducted by Sandia during this quarter. AI again supplied the test article. In the test, the top head melted through the central region before the lip failed. Further details were not available at the end of this reporting period.

VIII. REENTRY BURNUP OF FUEL ELEMENTS

A. ANALYSIS

A report (NAA-SR-TDR-7710) was issued to describe the latest version of the Digital Thermal Analyzer Program (TAP-2) which is being used for calculation of fuel rod heating and ablation.

A study (NAA-SR-TDR-7868) describing the best available methods for predicting ablation was completed. The preliminary results indicate that a release altitude of at least 250,000 ft will be required if complete burnup of the SNAP 2/10A fuel rods is to be obtained. In the study, the fuel rod ablation rates were compared by the use of two analytical models:

1) The enthalpy required for hydrogen dissociation (610 Btu/lb) was added to the enthalpy required for melting of the metal (90 Btu/lb), and the total enthalpy of phase change was assumed to be absorbed at the melting temperature (3365°F).

2) The enthalpy required for hydrogen dissociation was assumed to be absorbed at a lower temperature, such as 2000°F.

The first model was used in previous analyses of arc-jet tests, and was known to be inadequate. The second model is considered to be a first approach to a more elaborate analytical model that includes hydrogen diffusion rates.

The comparative runs made with the two models show that the start of ablation is delayed when the hydrogen dissociates at the lower temperature. However, once ablation begins, it proceeds extremely rapidly and the overall time for complete burnup to occur is less than that predicted by the first model.

A simplified explanation of the cause of this is as follows: Model 1 is ablating while the heat of dissociation (610 Btu/lb) and fusion (90 Btu/lb) are added, or while a total of approximately 700 Btu/lb is being absorbed. In Model 2, the heat for hydrogen dissociation is absorbed well below the melting temperature; thus ablation does not begin until all the hydrogen has been dissociated. Once ablation does begin, it proceeds at a much faster rate since the addition of only approximately 90 Btu/lb is required. The total time required for complete burnup to occur with a given heat flux is less for Model 2, due to the smaller radiation losses which occur because the rod is at a lower temperature while absorbing the hydrogen dissociation heat. The use of a constant temperature for hydrogen dissociation was justified by the large change in the diffusion coefficient between 1800 and 2400°F. This is a narrow range in relation to the range of 0°F to the melting temperatures of 3365°F.

As a further check on the foregoing, a study was undertaken to evaluate the effects of assuming that the hydrogen dissociation occurred at each of several given temperatures in the neighborhood of 2000°F. The results substantiated that the change in ablation behavior is not strongly dependent on assumed hydrogen dissociation temperatures within the range of approximately 1800 to 2400°F.

A sample problem on fuel rod ablation was obtained from Sandia and was solved by use of our digital code. The problem involved a fuel rod with a 0.10-in. wall thickness. It was filled with barium as a flare material and lead was added in the center to adjust the average density to that of the fuel material. The heating rates and material properties were taken to be the same as those used by Sandia for their electrical analog solution. The results agreed with Sandia's up to temperatures about 100°F below the melting temperature of the fuel. At that level, the barium and lead vaporized; the heat absorbed during this process suppressed the ablation of the fuel. Since Sandia had developed their thermal model to check their analytical methods, they did not include the second phase changes for the barium and the lead. For this reason, the solutions differed at the higher temperatures just below the melting point of the fuel alloy.

The ablation of a fuel rod having a 0.10-in. wall thickness and filled with barium flare material was then recalculated with the assumption that the hydrogen dissociates when the temperature reaches 2000°F. It was found that some of the rod material ablated before the barium vaporized, whereas the previous calculations, which were made with the entire enthalpy of phase transformation occurring at the melting temperature (3365°F), showed no ablation.

Work along these lines was continued into the next quarter with the objectives of improving the thermal model and including the heats of chemical reaction, such as those due to oxidation.

A set of calculations was made to analyze the results of some arc-jet tests made by Sandia in air and argon. The ablation rate in air was about four times as fast. This could be explained if as little as 20% of the zirconium oxidized on the ablating surface.

It appears from the foregoing analyses that simulation of reentry in an arc-jet requires control of chemical factors, such as oxygen pressure as well as control of heat rates. It also is evident that the mathematical models for ablation of hydrided fuel materials must be quite complex if reliable predictions of ablation are to be made.

B. ARC-JET TESTS

Several tests were run to develop a suitable model support. Figures 7 and 8 show two views of a zirconium rod on a tungsten support rod after exposure to a stagnation line heat flux of 340 Btu/ft^2-sec (based on the original rod diameter of 1.25 in. and on cold-wall conditions). The running time was 90 sec. The support rod successfully survived the experiment, while approximately half of the zirconium was ablated. Later, a more sophisticated model-support device was constructed which makes it possible to rotate the cylindrical samples while they are in the arc-jet. This support was developed for the Sandia tests which were run in December.

Four fuel alloy specimens were tested in the arc-jet facility at NAA-Los Angeles Division early in the quarter. The first two specimens were of the unmodified alloy; the last two were modified. All four specimens cracked in the vicinity of the tungsten support rod. The first three fell out of the jet after being partially ablated. There was substantial ablation of all three specimens.

The fourth test was terminated before the specimen fell from the support rod so that the condition of the specimen could be studied. It, too, had cracked and was heavily oxidized on the forward side. Liquid metal had broken through the oxide layer in several places.

Later, AI tested additional 1.25-in.-diameter rod specimens in the arc-jet. These specimens, some of which contained flare materials, were prepared by the Sandia Corporation from zirconium-hydride and uranium-zirconium-hydride supplied by AI. Each specimen was 2 in. long and had a nominal diameter of 1.25 in. Each was suspended and held stationary in the jet in a cross-axial position. The thermal environment in the jet core was adjusted so that the stagnation heat flux was nominally 250 Btu/ft^2-sec. This value was calculated to be representative for one point in the reentry trajectory. Three of the nine specimens were fabricated of zirconium-hydride, three of unmodified SNAP fuel, and

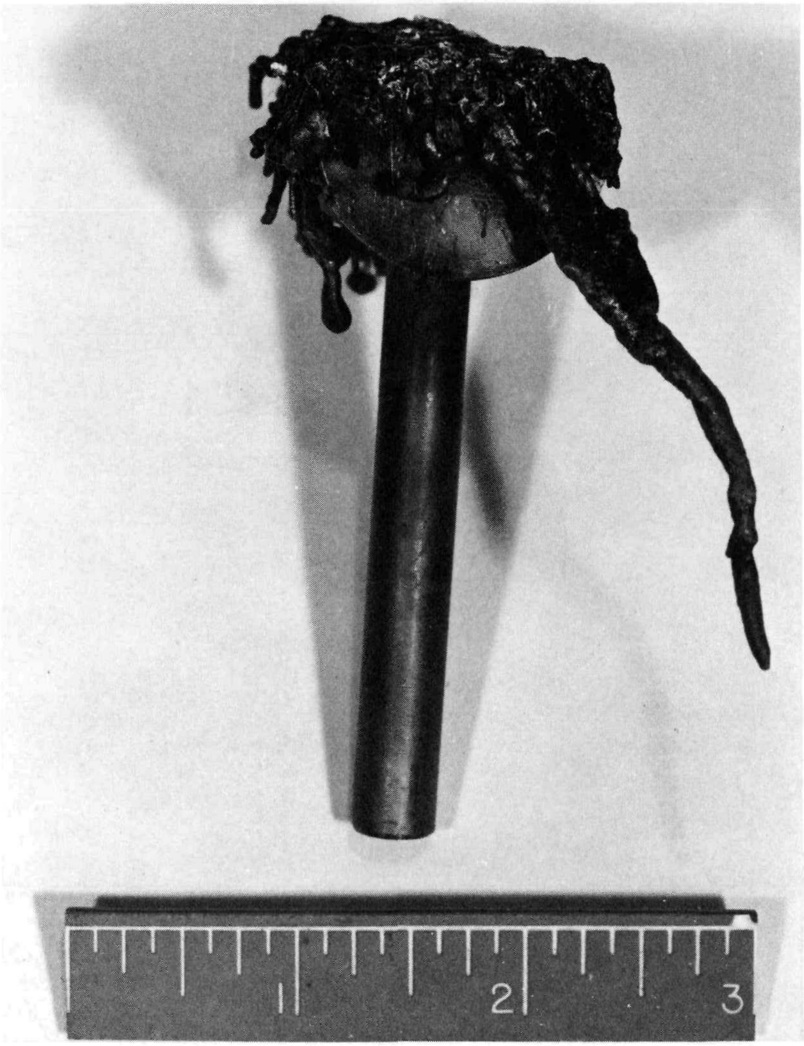

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Figure 7. Arc-Jet Test Rod — Side View

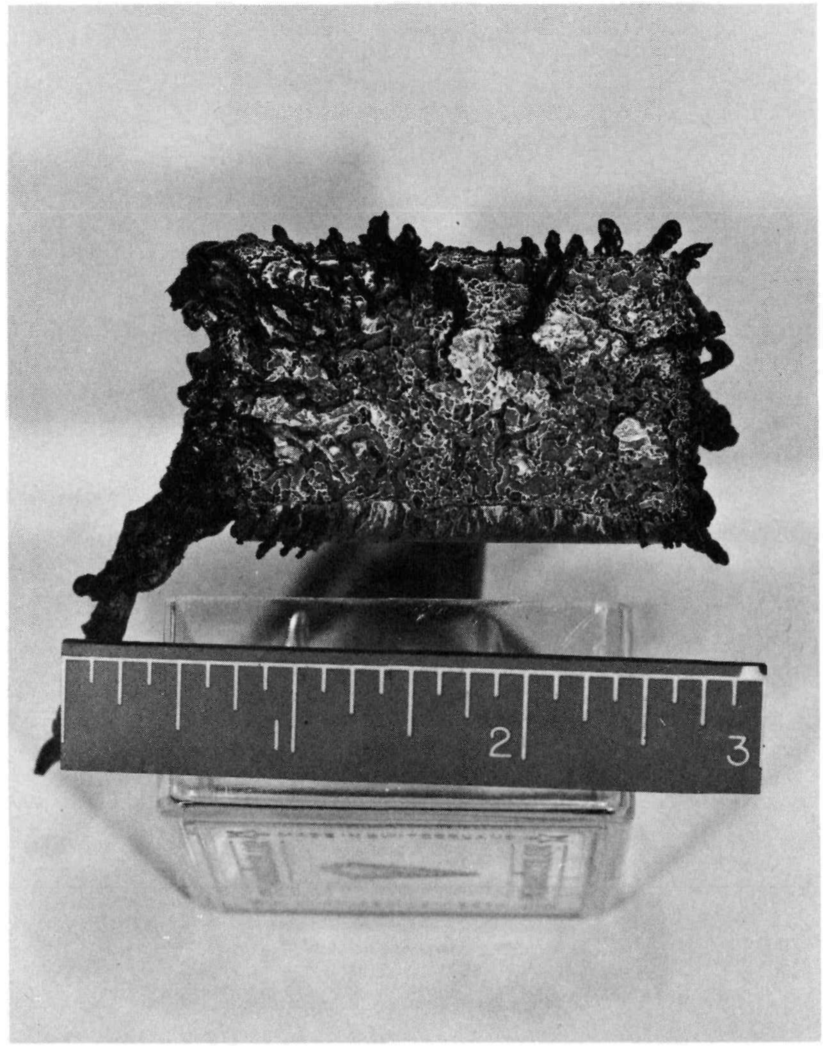

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Figure 8. Arc-Jet Test Rod — Zirconium End

the remaining three of modified SNAP fuel. These tests were run to check the information gained as a result of the October tests.

Twelve fuel alloy flare specimens (Figure 9) were sent to Sandia on November 2. Eight of these were hollow with end caps. The end caps were plugs of the fuel alloy. Since it was found to be impractical to thread these plugs, they were held in place with cross-pins. Two of the solid specimens were clad and fitted with end caps of the SNAPTRAN type. Sandia had planned to test these in their radiant heating facility, but they later decided to run the tests at the NAA-Los Angeles Division arc-jet facility. AI managed the tests in the same manner as was done for their earlier tests, supplying health physics and decontamination services. The tests were conducted in mid-December so that the results would be factored into the RFD-1 flight test program.

As a result of these tests, the fuel element flare experiments, utilizing clad fuel elements, were accepted for the RFD flights. Plans were made to fabricate the full-size flare elements and fabrication will take place during the next quarter. In addition, fixed fuel rod samples (1.75 in. long) will be fabricated for installation at the reactor base ring. There will be two of these samples for each flight.

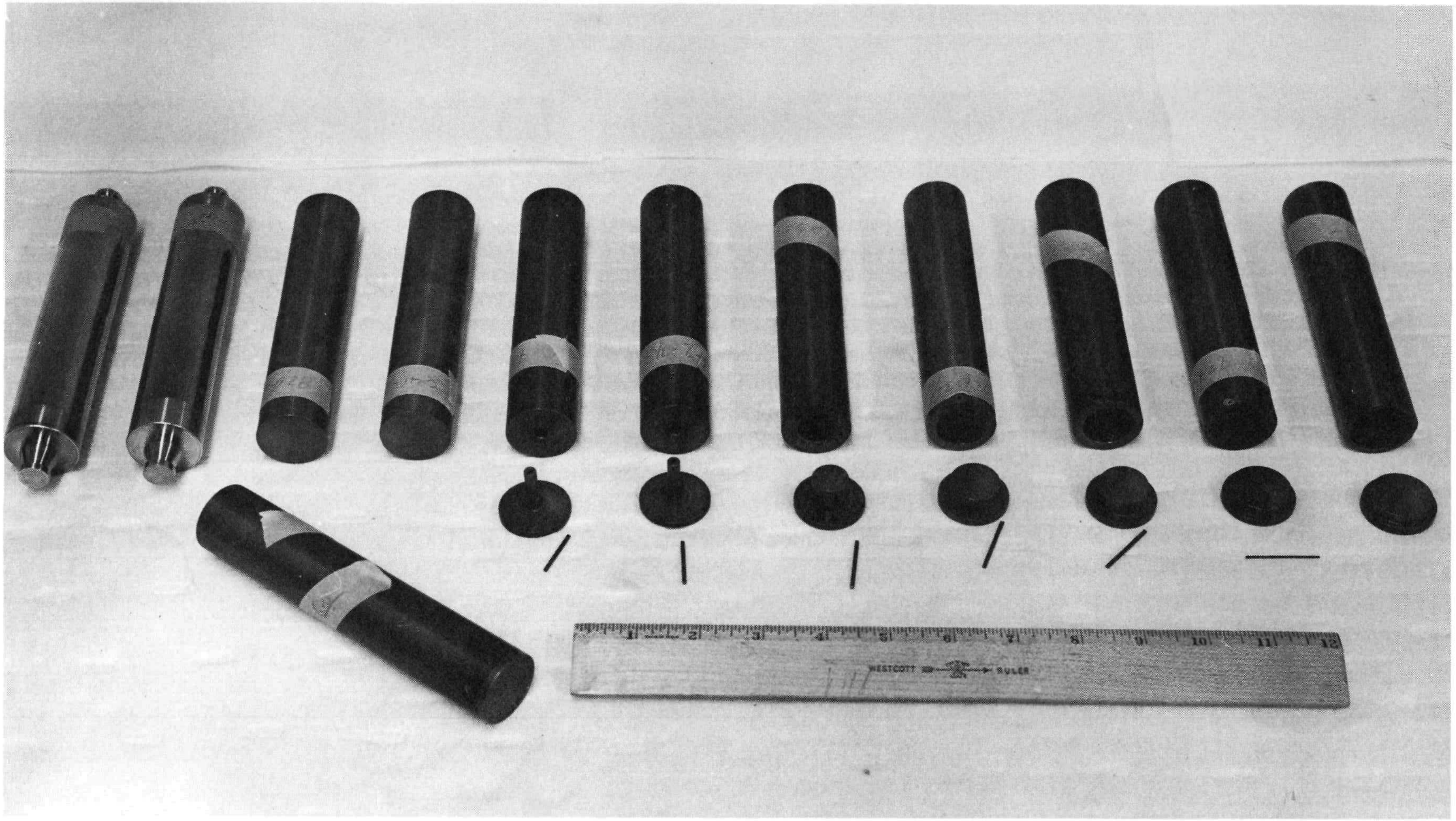

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Figure 9. Fuel Alloy Flare Specimens