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NUCLEAR ROCKET OPERATIONS

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TO

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

SUMMARY REPORT

PHASE II OF THE

COUNTERMEASURES RADIATION EFFECTS PROGRAM

JULY 1967

NERVA PROGRAM

CONTRACT SNP-1

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REPORT NO. RN-S-0384

SUMMARY REPORT
PHASE II OF THE
COUNTERMEASURES RADIATION EFFECTS PROGRAM

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ABSTRACT

This report summarizes the work accomplished on Phase II of the NERVA Countermeasures Radiation Effects Program, Sub-Subtask 1.9.1, by the Aerojet-General Corporation and Picatinny Arsenal. Phase II capsule design and qualification, explosive heat-buildup tests, propellant closed-bomb tests, test-reactor requirements, hazards, and safety procedures are discussed.

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I. INTRODUCTION

The work described is a continuation of the Countermeasures Radiation Effects Program initiated by the Aerojet-General Corporation to investigate radiation effects on high explosives and propellants.

Small-scale irradiations of 1.8-to 3.6-gram samples of candidate pseudo-stable materials, of small propellant strands, and of prototype exploding bridge wire (EBW) detonators were completed during Phase I. These small-scale tests were conducted at the General Electric Test Reactor (GETR), Vallecitos Atomic Center, Pleasanton, California. They resulted in the determination of the most radiation-stable materials for use as the main charge, booster and primary explosives, igniters, and propellants. In addition, a prototype detonator design was evaluated. The effects of radiation on the physical and chemical properties of the pseudo-stable materials were evaluated. Approximate exposure limits were established for the most radiation-stable materials. Small-scale test results are reported in Reference (1).

When NERVA flight-engine design has progressed to the point where specific countermeasures components are defined, large-scale testing of explosives, propellants, and detonators may be required. For this purpose, a containment capsule for the irradiation of high explosive in amounts to 80 grams has been developed jointly by Picatinny Arsenal and the Aerojet-General Corporation. The large capsule will allow irradiation of propellant samples sufficiently large to accurately determine burning characteristics by use of a closed-bomb or high-pressure reactor. Detonator assemblies also will be irradiated in sufficiently large quantities for statistical analysis to be applied to post-irradiation tests.

The first part of the large-scale test program was designated Phase II. Its purpose was to determine the combined effects of heat and nuclear radiation on bulk samples of explosives and propellants large enough to permit scaling up to component configurations.

Later phases were to evaluate the effects of cooling during irradiation and may have included tests on complete components and/or mock-ups of critical parts.

Engineering effort on the Countermeasures Radiation Effects Program stopped 31 March 1967. Small-scale testing and evaluation were complete at that time. Phase II and later phases were cancelled since chemical explosive-destruct is not applicable to the 4180 MW version of the NERVA engine. This report summarizes work completed in Phase II and procedures applicable to radiation effects testing of ordnance components if they are required for countermeasures systems on the NERVA flight engine.

II. SUMMARY

This report describes the hardware that was to be used in Phase II irradiations, qualification tests on Phase II capsules, preliminary pre-irradiation tests conducted to date, and experimental procedures contemplated for Phase II experiments. The primary purpose of the Phase II program was to:

- (1) Determine the combined effect of thermal and radiolytic decomposition on bulk quantities of main-charge explosives and propellants, and set exposure limits for the selected materials related to their intended functions;
- (2) Irradiate prototype radiation-stable detonators and igniters in large quantities to accurately determine the effects of radiation on their performance; and
- (3) Determine the effect of radiation exposure on propellant performance, as determined by closed-bomb tests.

Phase II experiments were to have included the obtaining of data on weight loss, dimensional stability, gas release, temperature buildup, closed-bomb tests on propellants and detonator firing: all as a function of integrated radiation-energy deposition.

A continuous monitoring of gas release from, and temperature distribution within the respective samples was to have provided data for more refined evaluation of material heat- and radiation-stability.

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III. DESCRIPTION OF IRRADIATION CAPSULE ASSEMBLY

The Phase II capsule, designed and developed by Picatinny Arsenal with technical assistance from the Aerojet-General Corporation, is approximately 10.5 inches in diameter and 36.5 inches in length (see Figure 1), as compared to the Phase I capsule assembly which was 2-1/8 inches in diameter and 9 inches in length (see Figure 2). The larger capsule is capable of containing 80 grams of high explosive for irradiation, whereas the smaller capsule assembly could contain but 1.8 grams of explosives.

The large capsule assembly was designed to these criteria:

- (1) The capsule will retain its overall integrity when twice the amount of explosives to be irradiated is detonated inside the capsule.
- (2) The gases produced by detonating this amount of explosives must be contained after detonation or released in a non-destructive manner.
- (3) The shock wave produced by detonation of the explosive sample within the capsule must be attenuated sufficiently so the test reactor will not be damaged.

An assembly drawing and a cutaway view are provided in Figures 3 and 4, respectively, to illustrate the main features of the large capsule. Some of the principal features include:

- (1) A center support-assembly (see Figure 5) to serve as a holder for the explosive sample. It is designed so minimum shock will be transmitted to the capsule walls or ends should an accidental detonation of the sample material occur.

Figure 1 - Phase II Capsule Assembly

Figure 2 - Phase I Capsule Assemblies

Figure 4 - Capsule Cutaway View

Figure 5 - Center Support-Assembly

- (2) A main chamber (serving as an expansion chamber) to reduce gas-pressure buildup produced by an accidental detonation of the sample material.
- (3) Reinforcing rings shrunk-fit at the ends of the inner cylinder (serving as support rings) to prevent expansion of the inner cylinder in these areas, and thus preventing the inner end-plugs from blowing out.
- (4) A double wall (providing an annulus between the inner and outer tubes) filled with helium to attenuate the shock wave to the outer tube and, consequently, to the surrounding area.
- (5) A double end-cap arrangement to minimize the shock-wave effect at the extreme ends of the capsule assembly.

In addition, the capsule is fitted with:

- (1) A Conax connection (of multiple-lead type) on one of the inner end-plugs to provide a shock-and leak-proof lead-through for the thermocouple wires.
- (2) A tapered plug at the normally open gas-passage between the inner chamber and the end chamber to seal off the gas passage should an accidental detonation occur.
- (3) A glass-to-metal seal for an absolute gas-tight lead-through of thermocouple wires through the outer end-cap. A second Conax connector backs up this seal to prevent leakage through the thermocouple wire lead-through in the case of a detonation where glass-seal might possibly fail from hot-gas leakage through the end plug.
- (4) A pressure port in the outer end-cap with fitting adapter and flexible stainless-steel tubing leading to the pressure supply and monitoring panel.

- (5) A flexible stainless-steel tube fitted to the helium-filled annulus and leading to a helium-supply pressure controller, and flow alarm. Alternately, a separate pressure-monitoring line could be used.

The individual explosive samples were to be instrumented to the extent that several thermocouple junctions would be imbedded in, or affixed to, the samples to obtain a temperature profile of heat buildup during irradiation (see Figure 6).

Flux wires were also to be positioned within the sample to provide data concerning absorbed neutron fluence. Figure 7 is an assembly drawing of the flux monitors.

Three versions of the basic capsule assembly were contemplated:

- (1) A capsule assembly loaded with a spherical explosive-sample (shown in Figure 6) and loaded in the capsule as shown in Figure 8. The weight of the explosive sphere was to be 80 ± 5 grams.
- (2) A capsule assembly loaded with propellant samples that was to be housed within a cylindrical can as shown in Figure 9. The weight of the explosives in the propellant (not including binders and other inert materials) was to be 80 ± 5 grams.
- (3) A capsule assembly loaded with detonators (or igniters) that was to be housed in a flat rectangular can as shown in Figure 10. This can was designed to hold 150 detonators of the configurations shown in Figures 11 and 12.

NOTES:

- 1) MATERIAL HIGH EXPLOSIVES AS SPECIFIED
- 2) SIZE BASED ON MAX. DENSITY OF 1.8 = 80 GMS.
- 3) TOLERANCE ON DEC. DIM $\pm .010$

(ISO FLUX PLANE)

Figure 6 - Explosive Sphere

Figure 7 - Neutron Flux Indicator Assembly

Figure 8 - Version 1 Capsule

Figure 10 - Version 3 Capsule

Figure 11 - Prototype Radiation-Stable Detonator,
Adhesive Assembly

Figure 12 - Prototype Radiation-Stable Detonator
Crimped Assembly

The propellant and the detonator-loaded capsule assemblies would also have had a gas cooling-line entering the capsule end-caps, passing through the end plugs, and into the sample holder. Helium would have been introduced through this line to serve as a coolant for the samples. The return of the helium gas would have been through the line used for pressure measurement in the noncooled capsules.

IV. SUMMARY OF CAPSULE QUALIFICATIONS

The requirement for irradiation of large samples of pseudo-stable materials was established at the inception of the Countermeasures Radiation Effects Program. At that time, Picatinny Arsenal was given the responsibility for the design and development of a container that would safely contain the detonation of an 80-gram explosive sample, should it accidentally detonate during irradiation (i.e., any internal impulse resulting from an explosion or burning of the sample would not damage the test reactor, adjacent experiments, or instrumentation). Extensive development tests were performed by Picatinny Arsenal to establish basic materials versus maximum amount of explosives contained, as well as size and configuration of a suitable test capsule. The report of the Arsenal was published in May, 1963^{(2)*}. Additional testing^(3,4, and 5) further defined containment parameters. This work subsequently led to the final design and qualification testing of the Phase II irradiation capsules.

Preliminary test firings with 80-gram charges established the minimum clearance between the explosive sample and the inner tube. The actual capsule qualification tests consisted of detonating a 160-gram charge in both single- and double-wall capsules.**

Picatinny Arsenal's Phase II capsule qualification effort was reported in April 1966⁽⁶⁾. Brewer Engineering Laboratories, Inc., Marion, Massachusetts had been engaged by Picatinny Arsenal to obtain pressure and strain measurements in conjunction with the qualification tests. These data were published in Reference (7).

Final capsule qualification tests were conducted at Aerojet-General Corporation's Downey, California plant in May and July 1966. These tests were witnessed by representatives from the General Electric Company and Picatinny Arsenal. The results of these tests are reported in References (8) and (9).

*Superscripts indicate reference numbers.

**The single-wall capsule actually was a standard capsule less the external tube and outer end-caps.

A. TEST CONDITIONS

All qualification tests were conducted by firing 160 grams (twice the weight to be irradiated) of C-4, an explosive with a higher energy release than any of the materials to be irradiated. The explosive was detonated across the sphere, producing a greater shock wave than would occur should the detonation initiate near the center of the sphere, the most likely location. Detonating 160 grams of explosive (in addition to releasing more energy than 80 grams) causes the detonation to occur closer to the capsule wall.

To measure the pressure pulse emanating from the stress/strain in the inner-tube-assembly of the capsule, the first test-series (conducted at Picatinny Arsenal) consisted of single-wall capsules tested in air with eight strain gages and six pressure transducers placed at the locations shown in Figure 13.

To simulate the actual conditions that might develop should a detonation occur while in the reactor (and to obtain strain data on external surfaces of the capsule and pressure measurements adjacent thereto), a capsule qualification test was conducted at Picatinny Arsenal with a double-wall capsule submerged in a glass tank filled with water. Instrumentation for this test consisted of eight strain gages and six pressure transducers as shown in Figure 14. In the last series of tests at Aerojet-General, an aluminum plate and a glass plate were mounted within 0.25 inch of the capsule to simulate the reactor pressure vessel and beryllium reflector, respectively (see Figure 15). Instrumentation for these tests consisted of seven pressure transducers at locations adjacent to the capsule surfaces and three strain gages attached to the bottom side of the glass plate.

Figure 13 - Strain Gage and Pressure Transducer Locations, Single-Wall Capsule

Figure 14 - Strain Gage and Pressure Transducer Locations,
Double-Wall Capsule, Picatinny Arsenal Tests

- PRESSURE TRANSDUCER (6 EA.) 1/4" FROM SURFACE
- STRAIN GAUGE (3 EA.)
- ▲ STRAIN GAUGE PRESSURE TRANSDUCER (1 EA.)

Figure 15 - Strain Gage and Pressure Transducer Locations,
Double-Wall Capsule, Aerojet-General Tests

A series of drop tests were performed to demonstrate that the capsule could be safely handled. In these tests, a single-wall capsule was dropped from ten feet in three different attitudes: (perpendicular to the cylindrical axis; 45° to the axis; and parallel to the axis) to determine deflection of the charge holder and the effect of such deflection on capsule integrity. Preliminary drop-tests with 160 grams of high explosive showed that the explosive did not detonate; however, the explosive charge holder did hit the side of the capsule. Consequently, a support collar and tie-rods were added to eliminate this condition and to aid in centering the charge (see Figure 5). Subsequent tests using 160 grams of inert material proved that this configuration would withstand the required drop of ten feet without excessive deflection or permanent distortion of the charge holder.*

B. TEST RESULTS

A summary of the various conditions and the data obtained is tabulated in Table I.

The conclusions reached after the initial series of tests conducted at Picatinny Arsenal were substantially confirmed by final qualification testing at Aerojet-General. They were:

1. Stress levels on the outer surfaces of both the single- and double-wall capsules (excluding the inner vessel for ± 5 in. from the centerline) do not exceed 23,000 psi, safely below the published minimum material tensile-yield value of 35,000 psi.

*It should be noted that the charge holder deflection resulting from a drop with 160 grams of material is significantly greater than that with 80 grams of material.

TABLE I
SUMMARY OF PHASE II CAPSULE
QUALIFICATION TEST RESULTS

Test No.	Date Test Fired	Basic Type of Capsule	Media Tested in	Media & Pressure in Capsule Annulus	Media & Pressure in Capsule Interior	Type of Sealing (Vee) Plug	Gasket & Plug Installation	Type of Sample Support	Types of Outer Thermocouple Wire Lead thru Seal	Average Gasket Compression	Number of Gauges		Test Configuration	Peak Pressures & Time After Detonation	Stress/Strain Levels	Maximum Inner Tube Expansion	Remarks	Gas Leakage
											Strain	Pressure						
PA #1	3/14/66	Single Wall #1-1791	Air	N/A	Air @ Atmospheric	Frustum of Cone	Dry	4-rod Cantilever	N/A	N/A	3	1		#1 center radially 12.5 psi @ 55 μsec	Strain gauges suffered bond failures	~.20" (~2.5% elong)	Capsule used for drop tests. No adverse effects.	N/A
PA #2	3/16/66	Single Wall #1-1792	Air	N/A	Air @ Atmospheric	Frustum of Cone	Dry	4-rod Cantilever	N/A	N/A	8	6	Figure 13	#1 & 2 center radially ~17.8 psi #4 end radially ± 5 psi	#2 16,900 psi #3 11,500 psi #4 16,200 psi #5 25,600 psi } @ 190 μsec ~800 in/in/sec	~.20"	Capsule ruptured; probably due to off-centered charge.	N/A
PA #3	3/17/66	Single Wall #1-1793	Air	N/A	Air @ Atmospheric	Frustum of Cone	Dry	4-rod Cantilever	N/A	N/A	8	6	Figure 13	#1 center radially 11 psi (Initial pulse 15.5 psi @ 2-3 μsec)	#1, 3 & 8 failed #2 23,300 psi #3 -15,600 psi } @ 195 μsec	~.20"	No cracking of tube.	N/A
PA #4	3/18/66	Double Wall P-155371	Water	Helium @ 25 psig	Helium @ 25 psig	Frustum of Cone	Dry	4-rod Cantilever	Glass-to-Metal	Not Measured	8	6	Figure 14	#1 center radially + 5 psi @ 530 μsec 				

NOTES:
(1) Outer tube of steel in lieu of aluminum
(2) Followed by a pulse of 90 psi of 20 μ sec duration
(3) Measured with Calipers
(4) Measured from X-ray

2. Pressures transmitted by a 160-gram charge of C-4 explosive through the helium annulus to the outer tube of the capsule at the center (in the direction of firing) will not exceed 25 psi.

3. In the double-wall capsule (with 25 psig helium in the annular space) the initial pressure-pulse transmitted by a concentrically placed 160 gram charge of C-4 at the center (in the direction of firing) will not exceed 5 psi 0.25 inch away in a water medium. Subsequent pressure pulses are produced by the propagation of elastic stress-waves from the ends of the capsule. At the center of the capsule, a pulse of 90 psi amplitude and 20 μ sec duration followed the initial pressure pulse by about 150 μ sec.

4. The radially transmitted initial pressure-wave at the ends of the double-wall capsule will not exceed 50 psi. The axially transmitted initial pressure-wave from the ends will not exceed 500 psi. The higher pressures detected at the ends are caused by a continuous aluminum path from the end of the inner chamber to the outer wall.

5. The pressure transient experienced in water beneath the beryllium reflector mock-up was less than 3 psi and maximum strain-levels at the gage location did not exceed ± 70 μ in./in.

C. ANALYTICAL CALCULATIONS

Analytical calculations were made: (1) to predict the peak shock-pressure pulse emanating from an 80-gram detonation in a double-wall capsule, should the annulus fill with water; and (2) to obtain a comparison with experimental data gathered during qualification testing, thereby determining the accuracy of the methods of calculation.

Due to the complex nature of this problem, several approaches were investigated by Picatinny Arsenal, Aerojet-General, and the Lawrence Radiation Laboratory to increase confidence in the resulting conclusions. The results of these investigations are discussed in References 9 and 10. Table II summarizes the results. The Picatinny Arsenal one-dimensional approach to the problem came closest to agreeing with test measurements.

Although peak shock-pressures as high as 100,000 psi were calculated by Aerojet-General for the water-filled case, these were not expected to cause any permanent deformation or damage to the reactor components because of the absence of permanent strain reported in the Lawrence calculations. This was confirmed by Phase I capsule-qualification tests where a peak pressure 74,000 psi produced no permanent deformation of the simulated Z-trail cable tube.*

*It should be noted that if 25-psig pressure in the helium-filled annulus cannot be maintained, or should the temperature of the sample rise above a specified point, the capsule either would be withdrawn immediately to a lower flux-region or the reactor would be scrammed. These precautions would make a detonation with the annulus filled with water very unlikely.

TABLE II
PEAK SHOCK PRESSURES IN WATER OUTSIDE OF
PHASE II CAPSULE

CASE I			CASE II	
80 gm Charge Helium in Gap			80 gm Charge Water in Gap	
	<u>Picatinny Calculations</u>	<u>Extrapolated From Tests</u>	<u>Picatinny Calculations</u>	<u>AGC Calculations</u>
Direction	psi	psi	psi	psi
Radial	0	2.1 - 3.0	3000	100,000
Axial	<370	5 - 27	<370	-
Diagonal	296	70 - 285	296	-

CASE III					CASE IV	
160 gm Charge Helium in Gap					160 gm Charge Water in Gap	
	<u>Picatinny</u>	<u>AGC</u>	<u>LRL</u>	<u>Test</u>	<u>LRL</u>	
Direction	psi	psi	psi	psi	psi	
Radial	0	140	14.7	3.5 - 5.0	3.8	
Axial	<600	-	-	8 - 45	-	
Diagonal	500	-	-	116 - 475	-	

Basis: Picatinny - Plane wave, starting with correlation of experimental shock pressure data at inner capsule walls, pressure transmitted through gas assumed zero.

AGC - Cylindrical, assumption of no end losses produced high pressures.

LRL - Spherical, reflected pressure waves from ends of capsule ignored.

V. HEAT-BUILDUP TESTING

A series of heat-buildup tests were to be conducted on representative Phase II explosive samples before irradiation began. Heat-buildup tests were thought to be necessary because safe upper temperature-limits for samples subjected to gamma heating during irradiation had to be established. The spherical explosive-samples and propellant powders were to be heated in the same bulk shape that they would have in reactor tests. Combined oven and dielectric heating was to be used to simulate the uniform heat-generation caused by gamma heating. The data obtained would have been valuable in determining reactivity control curves due to heat alone so the incremental effect of radiation damage, in turn, could have been determined.*

Some preliminary data have been obtained on explosive spheres heated in a dielectric oven. The test set-up is shown in Figure 16. The heater consists of a Thermall EO-1 500-watt dielectric heater operating in a radio frequency-range of 70 to 80 megacycles. The heater was modified to provide an extension of the electrodes on the top. This permitted a protective box to be built around the basic heater to protect it in case the sample burned. A movable thermocouple-head was mounted on top of the protection box. Figure 17 shows (1) the arrangement of the heater with the hemispherical electrodes; and (2) the movable thermocouple-head with the array of 13 thermocouples. The operation of this heater required that the thermocouples be withdrawn at time of heating and then re-inserted for temperature measurement. The heater was equipped with a timer (to 150 sec) for adjusting the heating time. The high-voltage electrode was moved vertically to adjust the heater output, by rotating a shaft. While in operation, an RF shield was placed over the electrodes and the sample (see Figure 18). The heater was turned on and the high-voltage coupling adjusted remotely. The configuration of the explosive samples used

*Detonator and igniter explosives were to be housed in small containers; therefore, bulk effects are not as critical as in the charge explosives and propellants. These were to have been heated in an inexpensive expendable oven.

Figure 16 - Heat-Buildup Test Set-Up

Figure 17 - Dielectric Heater Open

Figure 18 - Dielectric Heater Closed

in these tests is shown in Figure 19. Figure 20 shows the location of the thermocouples in the sample sphere.

The temperature indications of 12 of the thermocouples were read on a Minneapolis-Honeywell 1508 12-channel Visicorder with the 13th thermocouple read directly on a millivolt meter. An icebath served as a standard reference-junction (see Figure 21).

The operating procedure for the heat-buildup apparatus was:

1. Clamp explosive sample in plastic holder centered between metal hemispherical electrodes and turned so thermocouples slide easily into holes in the side of the sphere.
2. Check operation of mechanism which inserts and withdraws thermocouples.
3. Put RF shield over sample and set heater time to desired heating time.
4. Check to see that RF coupling control works, that upper plate is halfway between electrodes, and that plastic insulating sheets are on both sides of the plate.
5. All personnel retire behind safety wall.
6. Check icebath and operation of Visicorder.
7. Insert thermocouples and record initial temperature of sample.
8. Remove thermocouples and start RF heater.

NOTES:

- 1) MAT'L: HIGH EXPLOSIVE AS SPECIFIED ON ORDER
- 2) SIZE BASED ON MAX. DENSITY OF 1.8 = 80 GMS.
- 3) TOLERANCE ON DEC DIM. $\pm .010$

Figure 19 - Explosive Sphere For Heat-Buildup Tests

THERMOCOUPLES 1 THRU 12 READ ON VISICORDER
THERMOCOUPLE 13 READS ON MILLIVOLTMETER

Figure 20 - Thermocouple Location in Heat-Buildup Sphere

Figure 21 - Temperature Recording Equipment

9. Adjust RF heater-coupling to limit current to not more than 400 ma.

10. After heater shuts off, insert thermocouples and measure sample temperatures.

11. Check heating rate and adjust coupling or heating time as necessary to get desired rate.

12. Remove thermocouples and start RF heater.

13. Repeat Steps 9 through 12 until desired maximum temperature is reached. Use auxiliary space heater to reduce heat losses at higher temperatures. Do not exceed Differential Thermal Analysis (DTA) exotherm temperature.

14. After sample starts to cool, remove sample and allow to cool in magazine while other samples are being tested.

15. Compare heating profiles with DTA curve at the similar heating rate, and set upper temperature-limits for irradiation.

Heat buildup tests were conducted on AGA and AGH, the two main-charge explosives selected for Phase II irradiations, (code designations are given in Reference 1). These samples were manufactured and supplied by Picatinny Arsenal. A total of four AGA samples were supplied, of which two had cracked during manufacturing and were therefore supplied for use only in preliminary equipment set-up and check-out. Of the three AGH samples supplied, one was cracked and also used for preliminary set-up and testing.

The tests were started on the cracked AGH sample (Serial No. 126-2). The results of this test are shown in Table III and Figure 22. The outer surface of the sample was the coolest (thermocouples No. 5, No. 7 and No. 10). Data from thermocouple No. 7 were probably the most accurate because of poor contact between the other thermocouples and the sphere surface. The hottest spots were No. 2, No. 6, No. 9, and No. 11 (point No. 6 is at the center of the sphere). The off-center heat buildup at No. 2, No. 9 and No. 11 could be due to variations in the RF field or density of the explosive sample. An exotherm started at 160°C: therefore, this temperature appears to be the safe upper-limit of AGH explosive samples. However, additional tests should be made using external heaters to supplement the dielectric heating so samples could be heated to destruction.

The second test was conducted on AGH sample Serial No. 125-2. The results are shown in Figure 23. An exotherm begins at 160°C: although the buildup is not as rapid as in the previous test, the start of the exotherm agrees with the previous test.

The third test was conducted on AGA sample Serial No. PAE 54774. In this test, it was discovered that the dielectric constant of this material apparently is such that no heat can be introduced into the sample. Several methods were attempted to increase the heat input, but without success. This test therefore, should be done in an oven with most of the heat-flow from the outside, unless a larger or more efficient dielectric heating system is provided.

The fourth test was conducted on the second perfect sphere of AGH explosive (Serial No. 26-1). To increase the heat input (or decrease the surface-temperature loss) a circular resistance-type heater was mounted in the top portion of the RF shield. To introduce as much energy as possible, an aluminum block (approximately 3/4 inch x 3-1/2 inches x 4 inches) was placed on top of the movable high-voltage electrode to permit closer coupling to the load electrode. This arrangement produced a heating-rate more rapid than in

TABLE III

HEAT TEST ON AGH #126-2 SAMPLE (82,925 GM) CONDUCTED OCT. 6, 1966

Run No.	Time	Ma	Heat Time	Total Heating Time ET (min)	Temperature °C		Remarks
					Maximum #11	Surface #7	
1	1242	11	10	0.17	29	21	Electrode 1/2 way up
2	1244	11	20	0.50	32	27	Electrode 1/2 way up
3	1247	12	20	0.83	32	27	Electrode near top
4	1251	13.2	30	1.33	38	27	
5	1257	13.2	40	2.00	43	32	
6	1302	13.2	50	2.83	54	38	
7	1307	13.7/14.1	60	3.83	74	49	Electrode in max. top position
8	1312	13.8/14.1	60	4.83	93	60	
9	1316	13.8/14.0	80	6.17	107	66	
10	1321	13.2/13.8	80	7.50	116	71	
11	1327	13.2/13.3	80	8.83	118	74	
12	1331	12.8/13.0	90	10.33	127	79	
13	1336	12.8/13.0	90	11.83	132	80	
14	1341	12.8/13.0	100	13.50	132	85	
15	1345	12.8/12.8	120	15.50	138	88	
16	1349	12.8	120	17.50	141	93	
17	1353	12.8	120	19.50	143	96	
18	1358	12.6/12.8	140	21.83	146	99	
19	1402	12.8	140	24.33	154	104	
20	1407	12.8	150	26.83	154	107	
21	1412	12.8	150	29.33	163	110	
22	1417	13.0/13.2	150	31.83	188	121	

- 1) Sample originally cracked during fabrication.
- 2) After run #22 test was stopped and sample allowed to cool. Sphere cracked badly across equator after test.

Figure 22 - AGH Explosive Heat Buildup Data, Test 1

Figure 23 - AGH Explosive Heat Buildup Data, Test 2

previous tests; however, a power failure caused interruption of the heating cycle. The results of this test are shown in Figure 24.

Because of the power interruption at the critical stage of the heating cycle, these results are of less interest than the first two. Additional testing is desirable (when a heating oven is available) to permit heating samples to destruction.

Figure 24 - AGH Explosive Heat Buildup Data, Test 4

VI. CLOSED-BOMB APPARATUS AND OPERATION

The only post-irradiation test not to be performed within the confines of the RML hot-cell is the closed-bomb test on propellant samples. This is a test which has not been performed previously.

The closed-bomb test was incorporated into Phase II to accurately measure the effect on radiation on propellant burning-characteristics. In this test, a propellant sample is burned within a container (the closed-bomb or high-pressure reactor) of a specific internal volume (50 cc). The closed-bomb is shown in Figure 25: the recording circuit is shown in Figure 26. The closed-bomb has a rated working-pressure of 60,000 psig. The reactor would be located within a secondary confinement chamber to eliminate contamination and gas-release hazard.

Propellant samples of 10 to 20 grams are placed in the bomb and ignited with a standard electric igniter. A piezoelectric pressure transducer is used to measure pressure buildup within the container. This pressure output versus time is presented on the lower beam of a dual-beam oscilloscope while the ratio-of-charge of pressure versus pressure is presented on the upper beam.

Figure 25 - Closed Bomb

Figure 26 - Closed Bomb Recording Circuit

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VII. PRESSURE- AND TEMPERATURE-MEASUREMENT APPARATUS

A gas-pressure measurement apparatus was to be used in conjunction with the irradiation capsule to permit continuous measurement of main chamber-pressure during Phase II irradiation. The apparatus itself consists primarily of a panel, the design of which includes a capsule connection, needle valves, safety rupture-disc, vacuum gage and tanks, pressure gage, and exhaust filter (see Figure 27). Figure 28 shows the panel piping. Radioactive particles are prevented from entering the apparatus by a filter in the capsule pressure-monitoring line. A potentiometer on the pressure gage provides indication of pressure on a millivolt recorder, using the circuit shown in Figure 29.

A panel, housing a psi pressure gage and a vacuum gage, would control the evacuation of the outer capsule annulus and monitor the helium pressure in the annulus during irradiation. Pressure recording would have been accomplished in a manner similar to that described for the main chamber. An alarm, incorporated into the annulus pressure-measurement circuit, would indicate any drop in pressure.

Prior to irradiation, the capsule assembly pressure-line would have been connected to the gas pressure-measurement apparatus and the capsule assembly pressure-checked for leakage at 50 psig helium. Thereafter, the system would have been vented to atmospheric pressure by opening and closing the capsule vent-valve (Valve B in Figure 28). Similarly, the helium supply-line of the annulus would be connected to the helium control-panel and the outer jacket evacuated and then pressure-checked for leakage at 50 psig helium. Then pressure would be reduced and maintained at 25 psig. After completion of the leak check, the capsule would be lowered into the reactor pool on the I-beam trail-cable assembly and irradiated. During irradiation, joints in the pressure-line system connected to the capsule would be monitored for leaks. After radiation and retrieval, the interior and annulus of the capsule would be evacuated through needle valves into the vent tanks and the valve at the capsule closed. The helium supply-line, pressure line, and thermocouple plug would then be disconnected from the panels.

Figure 27 - Pressure Measurement Panel

Quantity		Description
1	1	Pressure Gauge, Heise 0-100 psi, 8-1/2" dial, .2 psi per division, 1/5 subdivided, with remote 5K potentiometer, 316 s.s. tube.
2	1	Vacuum Gauge, Marshalltown No. 22B, 2' dial size.
3	2	Vacuum Tanks, 60 Liters, 12" x 24", s.s.
4	5	Needle Valve, Whitey No. OKS 2-316, 1/8" size, s.s. w/swagelok fittings.
5	1	Safety Head, screw type, Black, Sivalis & Bryson Assy No. SA-9; s.s. - 100 psia bursting pressure
6	1	Filter, Nupro "F" Series Inlet Filler, Cat. No. SS-2F-7, 5-10 microns, s.s.

Figure 28 - Pressure Measurement Panel Piping

Figure 29 - Pressure Measurement Circuit

In the event of a detonation during radiation, a tapered plug would seal the inner-capsule plug. Should it fail to seal completely, the rupture-disc at the vent tanks would open, relieving the pressure. The capsule and tubing, it should be noted, would contain the released pressure without venting. The filter in the line would keep contamination out of the panel system and permit both the tubing to be removed and new capsules attached without releasing any contamination. The vent tanks are large enough (60 liters total) to contain all gases produced (when 80 grams of explosive burns within the capsule) and still remain near one atmosphere. Unless a sample burns, or a leak occurs, it would not be necessary to evacuate the vent tanks. The activity of the vent tank would be monitored periodically, and pumped out if necessary to keep the activity to an acceptable level.

The temperature of the samples would have been monitored by the welded copper-constantan thermocouples imbedded in or affixed to the samples, using the circuitry shown in Figure 30. The small-diameter (30 gage) thermocouple wire permits all lead wires to fit inside the aluminum tubing, assures rapid response to temperature changes, minimizes error because of gamma heating of the thermocouple wires, and minimizes radioactivity due to neutron activation.

The values of the measured thermocouple resistance and insulation resistance would be checked just before irradiation to verify that the thermocouples were not damaged in transit. Copper-constantan thermocouple wire was chosen to produce a high-voltage output, and allow use of a copper-wire and millivolt recorder for both temperature and pressure.

The use of an oven set at $150 \pm 0.2^{\circ}\text{F}$ for the cold-junction compensation would permit increased sensitivity in the range of interest. This type of thermocouple was used successfully in irradiation tests in Phases IA and IB.

Figure 30 - Temperature Measurement Circuit

VIII. TEST REQUIREMENTS

A. CAPSULE REQUIREMENT

As indicated earlier, the Phase I capsule assemblies were irradiated in the General Electric Test Reactor (GETR) at the Vallecitos-Nuclear Center. Figure 31 is a sketch of a possible GETR facility modification utilizing an I-beam rail and cable to place the Phase II capsule on the reactor-core center line and to retract it following radiation.

It is estimated that Phase II would have required one year to complete. Irradiation of the samples could have been accomplished in the GETR during one reactor-cycle consisting of approximately 28 days of full-power operation. A total of eight capsules were to have been manufactured for irradiation testing and reloaded for additional irradiation tests, if desired, by replacing only the sample holder and end plugs.

The eight capsules were to have been loaded and irradiated as described in Table IV.

B. EXPLOSIVE IRRADIATIONS

The two most radiation-stable explosives tested in prior phases were to have been irradiated in Phase II. Their radiation stability was high enough so that it was expected they would reach their maximum temperature-limit before a significant amount of radiation damage occurred. To obtain more information, a series of irradiations would have been made on each sample at different flux levels while monitoring temperature build-up and gas release. The samples then would be allowed to cool in the reactor pool between radiation tests. Testing the two best explosives was desirable since they both would have had about the same radiation stability (one with higher temperature-stability, the other with higher explosive-power).

Figure 31 - GETR Facility Modification

TABLE IV

PHASE II CAPSULE REQUIREMENTS

<u>Capsule</u>	<u>Contents</u>	<u>Remarks</u>
1	Simulated Explosive and Gamma Detector	Determine temperature and gamma flux at several flux levels.
2 & 3	50 EBW Detonators 50 Hot Wire Detonators 50 Igniters	Irradiate to different dosages.
4	80-gram Sphere of Best Explosive	Measure heat build-up at several different rates.
5	80-gram Sphere of Contingency Explosive	Measure heat build-up at several different rates.
6 & 7	100-gram Best Propellant	Irradiate to different dosages.
8	100-gram Contingency Propellant	

C. DETONATOR AND IGNITER IRRADIATIONS

The amount of explosive in detonators and igniters is small enough (about 0.2 gm) so 150 units could have been irradiated in each capsule. At least fifty of each type were to have been fired to accurately evaluate the effects of radiation on their performance; therefore, 50 each of three designs were to have been irradiated in each capsule. For NERVA applications, the detonators and igniters could have been located so the case and main-charge material provide shielding, thereby subjecting them to both a lower temperature and radiation flux-rate than the main-charge explosive and thus allowing the use of less stable materials. This is necessary since the high-stability explosives cannot be ignited rapidly by a reasonable amount of electrical energy.

Two detonator designs were to have been tested, one having maximum temperature and radiation stability (but requiring a high-voltage firing unit), the other allowing use of a standard 2000 volt EBW firing-unit. The lower-voltage unit is desirable, since it possibly would have been difficult to make a high-voltage firing unit which would have been radiation-stable.

The igniter design would have probably made use of the lower firing-voltage EBW detonator, combined with a mild detonating fuse (MDF) and an ignition mixture.

It was planned to cool the detonators and igniters with a flow of helium gas to prevent them from exceeding their temperature limit during continuous irradiation. This would have been accomplished by adding a helium inlet-line to the capsule and allowing hot gas to vent-off through the existing vent line. Pressure-buildup data could not have been taken on these materials.

Prior work by the Naval Ordnance Laboratory, Lockheed, Sandia, and Picatinny has established the feasibility of using earlier evaluated radiation-stable booster explosives to make EBW detonators. Development of an optimum

design for a specific application, however, was not justified; therefore, a typical test-housing adapted to the unique requirements of reactor irradiation-testing was to have been used. These include: glass or ceramic seals instead of plastic, minimum-size external components, and an aluminum body to reduce radiation absorption and neutron activation. This design would have been used to evaluate the effects of radiation on the functioning of the explosive trains. Data obtained then would have been used in the design of the detonator and igniter prototypes to be proof-tested in Phase III.

Tests of detonators and igniters before and after irradiation exposure included:

1. Bridgewire resistance
2. Insulation resistance
3. Weight loss
4. Current and voltage during firing
5. Firing time
6. Bruceton 50% firing-energy
7. Bruceton 50% barrier-thickness for booster initiation
8. Plate dent

D. PROPELLANT IRRADIATIONS

Propellant performance can be measured accurately by a high-pressure, closed-bomb burning test. Not enough propellant could be irradiated in the small capsules to make this test earlier. Therefore, previous data were used only to select the best propellants. Phase II closed-bomb tests would have been necessary to establish radiation tolerance-limits for propellants. If the best propellant was chosen on the basis of Phase IC test-data and non-irradiation tests made at Picatinny Arsenal, two or three capsule irradiations should have been sufficient to bracket the threshold exposure. Helium-gas cooling of propellant samples was planned.

E. FLUX MONITORS

1. Neutrons

Total neutron fluence would have been determined by employing flux wires approximately 0.50-inch in length, sealed in quartz tubing (2mm outside diameter, 1mm interior diameter). Aerojet Drawing No. 515265, illustrating the design of these flux wires, is shown in Figure 7. Aluminum cobalt wires were to have been used for thermal-flux measurements, while nickel wires were to have been used for fast-flux measurements. These wires will be supplied by the test reactor.

Each capsule for Phase IC was to have contained one of each type of flux wire. The exact position of these wires would have depended upon whether the capsule contained granular explosive or propellant strands.

The flux wires were to have been forwarded to the Test Reactor Chemistry Laboratory for counting after removal from the irradiation capsule. Counting may have required as long as two weeks for completion, depending upon the induced activity of the wires.

2. Gamma

Test-reactor personnel were to have assisted in making a gamma-traverse to designate the position of maximum dose-rate. An ionization chamber identical to that used in Phase I traverses was to have been installed in a mock explosive in a Phase II capsule for the traverse.

IX. REACTOR PROCEDURES

A. PRE-IRRADIATION

Prior to the irradiation of Phase II samples, an instrumented Phase II capsule-assembly loaded with charcoal (mock explosive) and a gamma monitor was to have been irradiated to check the temperature- and pressure-measurement apparatus. Irradiation procedures for this capsule are listed below:

B. IRRADIATION PROCEDURES

1. Attach the steel-cable yoke to the capsule lifting-lugs. Check to make certain that the cable is firmly attached.
2. Position and strap the capsule onto the I-beam dolly making certain the "MAX FLUX" mark on the capsule is lined up with the centerline of the dolly.
3. Locate the pressure-measurement panel, helium control-panel and the vacuum pump close to the I-beam opening and connect the helium supply and vacuum pump to the panels. (First capsule only)
4. Carefully unroll the bundle of aluminum and stainless steel tubes leading from the capsule.
5. Check the resistance of all thermocouples and compare the readings with those reported at time of assembly.
6. Connect the helium supply-line to the helium control-panel and evacuate the capsule annulus.

7. Pressurize the capsule annulus with helium to 50 psi, close supply valve and observe for leaks for five minutes. Correct leaks as required.

8. Reduce pressure in the annulus to 25 psig.

9. Connect the pressure line with the valve and filter to the pressure-measurement panel. (On propellant- and detonator-loaded capsules also attach the helium coolant-line to the helium control-panel.)

10. Connect the T/C plug to the thermocouple receptacle on the pressure-measurement panel.

11. Turn on the pressure and temperature recorder.

*12. Check to see that Valves B, D, and E are closed, as well as the capsule valve. Make sure Valve C is open. Slowly open Valve A until the gage reads 50 psi, then close. Check capsule connection and other panel connections for leaks using a liquid leak-detector. Gross leaks will be shown by a drop in pressure. Correct leaking connections as necessary by tightening them in small increments and then rechecking.

*13. After correction of leaks, pressurize to 50 psig. Then close Valve A and verify that pressure does not decrease over a five minute period.

*14. Slowly bleed pressure down to atmospheric through Valve B, stopping at even increments of 10 psi and recording these positions on the pressure strip-chart recorder. Close Valve B.

*15. Open the capsule valve and slowly bleed helium into the capsule cavity at a rate not greater than 10 psi/minute until 50 psig is reached. Observe for leaks for five minutes and correct if necessary.

*These steps apply to both the capsule main-chamber and the annulus pressure-apparatus.

16* Slowly bleed the pressure down to 25 psig with Valve B (maximum 10 psi/minute). Close Valve B.

17. Carefully lower the capsule into the position of maximum flux in the I-beam trail facility. This position will be supplied by General Electric personnel prior to irradiation of each capsule.

18. As soon as the capsule reaches the maximum-flux position, the reactor technician will record the following information on the capsule data-sheet:

- a. Time that capsule reaches irradiation depth
- b. Irradiation depth
- c. Power level of reactor
- d. Average rod bank
- e. Pool water-temperature, inlet and outlet
- f. Date of reactor startup
- g. Barometric pressure
- h. Temperature in facility

19. Throughout the irradiation, the helium control-panel and the temperature and pressure recorders will be reviewed at least every 30 minutes. The reactor technician will record both the time and the actual pressure reading of the pressure gage.

20. The length of irradiation will be predetermined and shown on the individual capsule data-sheets. The irradiation will be stopped in the event of excessive pressure and/or temperature readings, or at the end of the desired irradiation time.

21. When the irradiation requirements (either time, pressure, or temperature) have been met, remove the capsule from the maximum flux position

*These steps apply to both the capsule main-chamber and the annulus pressure-apparatus.

and allow it to remain below water until the radiation level permits it to be pulled to the surface.

22. The reactor technician then will record the following information:

- a. Time that capsule leaves irradiation depth
- b. Total irradiation time
- c. Capsule pressure after cooling to pool temperature
- d. Any unexpected events
- e. Maximum pressure recorded on the helium control-panel and the pressure monitoring-gages and maximum pressure and temperature shown on the recorder.

23. Open the valve to vent the tank and reduce pressure to below atmospheric. Close the valve and disconnect pressure line as well as T/C plug from the panel. Disconnect helium supply-line.

24. Transfer the capsule assembly to the reactor canal.

25. After the capsule has cooled sufficiently, it may be transferred to a cask for transportation to the RML Laboratory.

C. POST-IRRADIATION PROCEDURES

1. Transfer of Irradiated Capsules from the GTR to the RML (Hot Cell)

Remove the irradiated capsule from the storage position in the reactor canal-zone and place into one of the GEVAL Series 300 casks. Lower the GEVAL cask from the reactor third-floor level to the first floor. Transfer the GEVAL cask to the RML building. Handling operations before, during, and after cask transfer should be such that excessive impact or vibratory movements are

not applied to the capsules or their containers. Remove the capsule assembly from the transfer cask in the hot cell. Check capsule identification and record.

2. RML (Hot-Cell) Operation

The principal operation in the hot cell consists of: (1) capsule disassembly; (2) sample-weight and size determinations; (3) detonator firing; (4) dividing samples into smaller lots which can safely be handled outside the hot cell; and (5) observations (e.g., photography) as might be necessary.

a. Capsule Disassembly

(1) Place the capsule assembly into the capsule holder and strap down.

(2) Apply strap-type pipe wrench or special spanner wrench to end-cap with tube connections.

(3) Unscrew end-cap and pull out sample holder-assembly

(4) Cut off bundle of T/C wires with wire cutters

(5) Disassemble sample holder from support rods

(6) Weigh sample-holder assembly

(7) Carefully open sample-holder housing explosive sphere, detonator (igniter), or propellant assemblies. Remove flux indicators. Place flux indicators in vials properly marked and send to chemistry laboratory for counting. Discard T/C wire remnants.

(8) Place explosive sphere and detonators in well-padded containers. Transfer propellants to suitable containers

b. Sample Weight and Dimension

Weigh and measure explosive spheres (obtain diameter at two axes). Weigh each detonator (igniter) assembly. Weigh propellant samples.

c. Breakdown of Sample Size

Divide samples of explosives and propellants into as small lots as required for samples to be easily handled outside of the hot cell. Additional post-irradiation tests on explosives may be established later.

d. Detonator Firing

The detonators will be test fired in the hot cell using an improved version of the detonator firing-fixture used in Phase I-A (see Figure 32). The instrumentation to be located outside the hot cell will consist of a high-voltage firing unit, a dual-beam oscilloscope (Tektronix 555), and a rasterscope (Moran 101) (see Figure 33). The schematic of the high-voltage firing unit is shown in Figure 34.

Data to be recorded when firing the detonators consists of:

- (1) Bridgewire resistance
- (2) Firing voltage and current
- (3) Function time
- (4) Plate dent

Figure 32 - Detonator Firing-Fixture

Figure 33 - Detonator Firing Apparatus

S_1 = AC POWER SWITCH
 S_2 = SAFETY PLUG
 S_3 = HIGH VOLTAGE SWITCH
 S_4 = SHORTING SWITCH
 L_1 = NEON AC LIGHT
 L_2 = RED HIGH VOLTAGE SWITCH
 L_3 = GREEN GROUND SWITCH
 T_1 = VARIAC
 T_2 = PLASTIC CAPACITOR, INC.
 HIGH VOLTAGE POWER SUPPLY
 HV 150-152 M 1.5 ma 15KV DC

C_1 = PLASTIC CAPACITOR, INC.
 DE 200 - 105 1 μ fd 20 KV CAPACITOR
 R_1 = JENNINGS RADIO MFG. CO.
 VACUUM RELAY NO. 403014
 50 KV, 100 K AMPS, NORMALLY OPEN
 M_1 = 20 μ a METER (HIGH VOLTAGE)
 M_2 = 3 ma METER (CHARGE CURRENT)
 M_3 = KELVIN BRIDGE

Figure 34 - High-Voltage Firing Unit Circuit

The loading and firing procedure for detonators will be as follows:

(1) Measure bridge-wire resistance by inserting detonator in bridge-wire test fixture connected to Kelvin bridge.

(2) Remove cover from firing fixture and remove debris from previous test as required. Save witness block from previous test and discard rest of residue.

(3) Check resistance of firing cable. If it is below 10,000 ohms, clean insulator at bottom of firing fixture.

(4) Ascertain that firing cable is shortened at firing panel.

(5) Assemble detonator into firing fixture and install witness block.

(6) Check witness-block connections.

(7) Replace cover on firing fixture.

(8) Check resistance of cable to detonator. If resistance differs by more than 0.02 ohm from that found in Item 1, disassemble, determine cause of trouble and correct as required. When resistance is approximately equal to the preassembled value, the unit is ready for firing.

(9) Set scope voltage-gain (2 v/cm if below 10 kV, 5 v/cm if above 10 kV).

(10) Check Tektronix scope:

- (a) Trigger level
- (b) Intensity
- (c) Film in camera
- (d) Reset trigger

(11) Check Rasterscope:

- (a) High voltage ON
- (b) Raster appearance (switch in INT)
- (c) Close viewing ports on windows
- (d) Check film in cameras
- (e) Battery connected
- (f) Turn Raster switch to FIRE
- (g) Trigger reset light ON

(12) Connect detonator firing-cable to high-voltage connector on panel.

(13) Turn on high voltage and charge high-voltage capacitor to desired voltage.

(14) Disconnect high voltage.

(15) Open camera shutters, push firing button and close shutters.

(16) Develop film and identify.

(17) Disconnect battery.

e. Closed Bomb Propellant Tests

To be provided later.

3. Transfer of Samples from RML Hot Cell to Explosive Test Facility

a. Place the transfer cylinders, or cans containing respective samples, on the floor of the interlock.

b. Remove one unit at a time from the lock.

c. Debag each transfer cylinder, or can, and transfer by dolly to the explosive testing-laboratory.

X. HAZARDS AND SAFETY

Radiological safety monitoring will be performed in accordance with test-reactor standard procedures. Test reactor personnel will have the responsibility for providing film badges, dosimeters, radiation monitoring gages, etc., to all personnel in connection with this program. In addition, test reactor personnel will provide complete radioactive-safety monitoring of all testing procedures (including ventilation) and assigned personnel. All nontest reactor personnel will follow test-reactor personnel instructions regarding safety.

Assembly and loading instructions for Phase II capsules are detailed in Appendix A. The ability of the capsule to contain the detonation of an explosive depends upon proper assembly; therefore, all critical assembly steps will be witnessed by a quality-control inspector. Typical inspection certification sheets are presented in Appendix B. As a double check, X-rays showing the internal assembly, will be taken of all loaded capsules at the test reactor immediately prior to irradiation. The X-rays will be examined for acceptable location of the sample holder and for verification of proper assembly. Capsules damaged in shipment from AGC to the test reactor will not be irradiated.

Hazards associated with the handling and testing of the explosive-loaded capsules are negligible since the capsules have been extensively tested to prove their ability to contain detonation of twice the weight of explosive to be used. Three capsules withstood drop tests from 10 feet without allowing 160-gram samples (twice the weight to be irradiated) of the explosive charge to come closer than 7/8 inch from the inner wall of the capsule⁽¹³⁾. The same distance of travel that would locate a 160 gram sphere in a position 7/8-inch from the wall would only bring the 80-gram sphere to 1-1/16 inch from the wall due to its smaller diameter. Since the capsule safely contained the detonation of 80 grams of explosive 3/4 inch from the wall, no hazard exists in accidental drops of at least 10 feet. The low impact-sensitivity of the main-charge

explosives being tested is such that the chance of their detonating if impacted during a drop is very remote. The propellants are even less susceptible to detonation. Although the detonator explosives are more impact-sensitive, they will be protected from impact by the detonator bodies. The total weight of explosive material in a capsule containing 150 detonators is approximately 30 grams.

A possible hazard exists after the capsules have been opened, and the explosive, propellant, or detonators are exposed in the hot cell. Although the possibility of any reaction is remote (evidenced by the work done on the same materials in previous phases) the worst case would be if the explosive-sphere detonated. In the GETR RML hot cell, this would produce a peak shock-pressure of 25 psig on the nearest inner wall of the cell, 3-1/4 feet away. However, a plastic shield would be desirable to protect the window and surrounding equipment from flying fragments. The static-pressure increase would be 0.5 mm Hg in the cell due to the 3 cubic feet of gas released⁽¹⁴⁾.

A minimum amount of work will be done on the explosive in the RML hot cell. It will be weighed, measured, flux-wires removed, and photographed. The propellant powder will be weighed, divided into smaller amounts, flux-wires removed, and sent to the RML basement laboratory for closed bomb testing.

The capsules of detonators are loaded with the same explosives already tested in Phase IA and IC. They require a pulse of very-high voltage and current to explode the bridgewire before they will detonate; therefore, no unusual electrostatic sensitivity problems will be encountered. The radio-activity induced in aluminum and in the ceramic insulator will make it necessary to fire them remotely in the hot cell. A steel firing-chamber will be used to confine the blast and fragments during firing. The gas generated when the explosion occurs will be released into the cell. This is a very small quantity (about 300 cu cm of gas at STP from the 0.4 g of explosive in each detonator) and is easily handled by the hot-cell exhaust system.

Although it is very unlikely that a detonator would detonate while testing bridgewire resistance, the cover of the firing chamber will be set over it while this is being accomplished. The firing unit is provided with a separate, grounded plug. The detonator firing-line will be plugged into this and grounded (green light ON) at all times when the firing chamber is open to prevent premature firing of a detonator. In addition, a safety plug on the high-voltage power supply will be removed except when the firing line is connected to the firing plug. This will protect personnel from being shocked by the open plug, although no current is applied to this plug until the firing button is pushed.

The back of the firing unit should be kept closed except for repairs. If it is necessary to open the back, all high-voltage terminals should be grounded with a grounding strap before repairs are attempted.

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APPENDIX A

PRELIMINARY ASSEMBLY AND TESTING INSTRUCTIONS
FOR PHASE II CAPSULES

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APPENDIX A

PRELIMINARY ASSEMBLY AND TESTING INSTRUCTIONS FOR PHASE II CAPSULES

A. PRE-ASSEMBLY INSTRUCTIONS

1. Insure that all capsule components and hardware required for the complete assembly are available.
2. Insure that proper tools and equipment for assembly are available and in good working order.
3. Mark body assembly $\textcircled{1/3}$ on two sides (180° apart) and end rings $\textcircled{3/4}$ with applicable serial numbers. Numbers and figures will be at least 1-inch high and will be scribed in the metal and then "filled-in" with felt pen.
4. Similarly mark one half of the sample holder using at least $3/8$ -inch high numerals.

B. NOMENCLATURE

"Blue goop"	Shop name for Leak Lock Sealant produced by Highside Chemicals Inc., Clifton, New Jersey
"Graph-oil"	A mixture of graphite in a suitable carrier, or Molykote "G" lubricant.
"Live end"	Denotes the end of the capsule or the end plate through which the thermocouple and pressure-monitoring lines enter.
"Dead end"	Denotes the end of the capsule opposite the live end.

C. ASSEMBLY OF END PLATE ASSEMBLY

1. Cut and flare aluminum tube (6/1); cut T/C wires and insert through tube.
2. Solder glass seal (5/1) to preheated adapter (21/6) and screw in Conax base (30/7) .
3. Insert copper and constantan wires (0.040 inch diameter) into glass seal and thread through Conax insulators.
4. Pull wires back into Conax connector and solder wires to glass seal.
5. Torque Conax connector to 160 ft/lb and screw adapter into end plate (5/4) .
6. Slip bell reducer (11/1) and tubing adapter (2/1) over end of T/C lead wire and tubing.
7. Connect T/C lead wires to respective 0.040-inch diameter wires.
8. Connect bell reducer and tubing adapter to Conax connector and connect tubing.
9. Attach multipin plug to other end of T/C wires.

D. ASSEMBLY OF SUPPORT PLUG AND EXPLOSIVE HOLDER

1. Thread Conax base (1/1) into support plug (11/5) and tighten.
2. Install Conax insulator assembly with 9 T/C assemblies installed. Tighten Conax gland nut.

3. Install and line up the four support rods (13/6) into plug.
4. Install the three 3/16-inch diameter tie rods (28/7) into the plug.
5. Position collar (27/7) to its approximate position and screw on three No. 10-24 hex head nuts (29/7) .
6. Fit together the two halves of the sample holder (24/6) and secure lightly with four No. 6-32NF 5/16" 1'g self-tapping screws (17/6) .
7. Align cup and clamp to support rods.
8. Drill holes through rods and flanges of cups with No. 11 drill, as required.
9. Secure with four No. 10-32 NF 1/2" 1'g round-head screws (14/6) with nuts (15/6) . Check alignment.
10. Mark cups and rods to assure correct reassembly and remove.
11. Assemble V-plug (20/6) to strap (22/6) using one No. 5-40 NC x 1/4" 1'g round head machine screw (23/6) and attach to support plug using back-up strap (19/6) and two No. 10-24 NC x 1/2" 1'g round head machine screws (34/6) .
12. Verify free air-passage through gas relief-port.
13. Install T/C wires in respective holes in explosive sphere (25/7) and on surface of sphere.

14. Clamp hemispherical holder around explosive sphere and secure with four self-tapping screws.

15. Position explosive holder and secure to support rods.

16. Fasten T/C wires to support rods using soft aluminum-wire.

E. ASSEMBLY OF CAPSULE

1. Coat inside threads of live end of capsule with graph-oil and thread in support plug assembly.

2. Verify centering tolerances of sample holder from opposite end of capsule and remove.

3. Apply blue-goop to bottom 1-1/2 inch of buttress threads on live end of capsule and thread in support plug-assembly until tight.

4. Mark direction of explosive holder (MAX FLUX position) on outside of capsule wall using three punch marks and felt-pen line.

5. Verify centering of sample holder again.

6. Apply blue-goop to threads on dead end and seat plug (6/5) .

7. Apply blue-goop to gasket-well of dead end. Seat gasket (7/1) and cover with additional blue goop.

8. Position end plate (2/4) . Apply graph-oil to outside threads of capsule and thread on end-ring (3/4) until hand tight.

9. Verify air passage through V-plug.

10. Apply blue-goop to gasket-well of live end. Seat gasket (7/1) and cover with additional blue goop.
11. Connect T/C wires to respective pins on glass seal.
12. Check and record resistance in all T/C couples and double-check identities versus location of all T/C couples.
13. Set end-plate assembly in place and verify that glass seal is not opposite V-plug hole.
14. Apply graph-oil to outside buttress threads and thread on end-ring until hand tight.
15. Measure and record gap distance at keyed locations.
16. Tighten end caps 1/4 turn (90°).
17. Re-measure gap distances to verify that end caps have been properly tightened.
18. Apply blue-goop to fitting on pressure monitoring line (31/5) and screw into end cap.
19. Apply blue-goop to fitting on helium supply line (32/5) and screw into external jacket.
20. Pressure test internal and external chambers for leaks.

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APPENDIX B

INSPECTION INSTRUCTIONS FOR CAPSULES

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APPENDIX B
INSPECTION INSTRUCTIONS FOR CAPSULES

A. PRE-ASSEMBLY CHECK

1. Insure that all capsule components and hardware required for the complete assembly are available.
2. Insure that the proper tools and equipment necessary for assembly are available and in good working order.
3. Pressure test external jacket of capsule with 50 psi of helium.
4. Inspect capsule and all component parts as required (X-ray, visual, dimensions, etc.).
5. Record pre-assembly measurements and key their locations with metal punch if posttest measurements are to be taken.
6. Clean thoroughly the threaded areas of capsule and corresponding threaded members, coat with graph-oil, and test that plugs and caps thread together smoothly and completely.

B. END PLATE ASSEMBLY

1. Pre-heat adapter (21/6) and solder on glass-to-metal seal (5/1) .
2. Seal any pins which are not to be used.
3. Thread Conax connector base to adapter (21/6) using blue-goop and tighten.

4. Seal unused holes of Conax insulators and sealant with 3 inch lengths of 0.040 inch diameter straight wire with rounded ends.
5. Cut length of 5/16 inch O.D. tubing (6/1) to suit, flare end, and feed through desired length of 0.040 inch firing leads. Strip off 6 inches of insulation.
6. Apply blue goop to base of fitting (2/1) and tighten into modified Conax connector cap (30/7) .
7. Feed firing leads through two open holes in Conax connector, insert 1-1/2 inch length of insulation on wire and feed through pins of glass-to-metal seal.
8. Tighten Conax connector cap.
9. Tighten (5/16) fitting cap (2/1) .
10. Solder glass-to-metal seal pins to firing leads.
11. Place insulation over protruding wire.
12. Test for continuity and shorts.
13. Apply shorting wire.

C. ASSEMBLY OF SUPPORT PLUG AND EXPLOSIVE HOLDER

1. Thread Conax base (1/1) into plug and tighten.
2. Install Conax connector assembly (with I/C wires attached).

3. Install the four cantilever rods (13/6) into plug.
4. Install the three 10-24 rods (28/7) into plug.
5. Position collar (27/7) to its desired location.
6. Fit together the two halves of cup (16/6) or (24/6) and secure lightly with four 4-40 bolts.
7. Align cup.
8. Drill holes through rods and flange with No. 11 drill.
9. Secure with four 10-32 bolts and recheck alignment.
10. Mark cups and rods to assure reassembly and remove.
11. Assemble V-plug (19/23/6) and affix to support plug. Verify free air-passage.
12. Install T/C wires in respective holes in explosive sphere and on surface of sphere.
13. Clamp hemispherical holder around explosive sphere and secure with four self-tapping screws.
14. Position explosive holder and secure to support rods.
15. Fasten T/C wires to support rods using soft aluminum-wire.

D. CAPSULE ASSEMBLY

1. Coat inside threads of live end of capsule with graph-oil and thread in support plug assembly.
2. Verify centering tolerances of cup from opposite end, and remove.
3. Apply blue-goop to bottom 1-1/2 inch of thread and thread in support plug-assembly until tight.
4. Mark direction of explosive holder on outside of capsule wall.
5. Apply blue-goop to threads on dead end and seat plug (6/5) .
6. Apply blue-goop to gasket well of dead end; seat gasket and cover with more blue-goop.
7. Position plate (4/2) , graph-oil outside threads of capsule and thread on end-cap (3/4) until hand tight.
8. Verify air passage through V-plug.
9. Apply blue-goop to gasket well of live end and seat gasket.
Connect T/C wires to plug on glass-to-metal seal and set plate assembly in place so glass-to-metal seal is not opposite V-plug hole.
10. Apply graph-oil to threads and thread on cap until hand tight.
11. Measure and record gap distance at keyed locations.
12. Tighten end-caps 1/4 turn (90°).
13. Re-measure gap distance.

14. Apply blue-goop and thread in the two pressure lines (31/5) and (32/5) .

15. Pressure test internal and external chambers for leaks.