GENERAL ATOMIC

DIVISION OF **GENERAL DYNAMICS**

AEC RESEARCH AND
DEVELOPMENT REPORT

GA-4554 (Rev.)
Vols. I, II & III

FINAL SAFETY AND HAZARDS REPORT FOR THE SNAP-15A GENERATOR

Prepared under
Contract AT(04-3)-167
Project Agreement No. 21
for the
San Francisco Operations Office
U.S. Atomic Energy Commission

October 30, 1964

DISCLAIMER

GENERAL ATOMIC
DIVISION OF
GENERAL DYNAMICS

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FINAL SAFETY AND HAZARDS REPORT FOR THE SNAP-15A GENERATOR

by

R. J. Campana, F. Bold, R. W. Dexter,
W. G. Homeyer, W. E. Sargent,
and W. P. Wallace

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SUMMARY

The basic criteria for the use of Pu^{238} were established and the maximum credible accident to the SNAP-15A generator was defined. The most serious of possible accidents were found to be fire, impact, and loss. A safety test program was devised based on the generator and capsule design and hazard analysis.

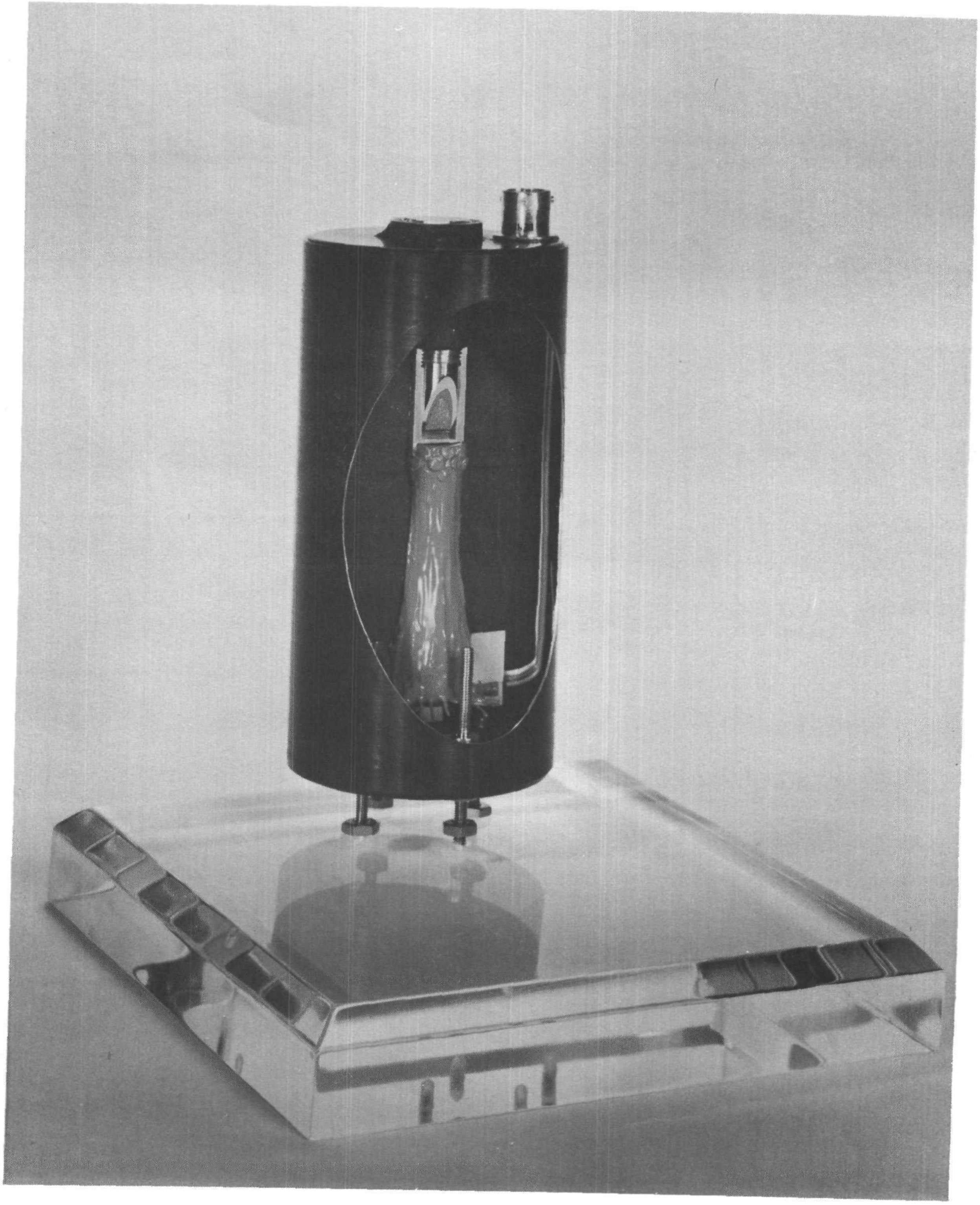
Ten types of tests were conducted to prove the adequacy of the design and the safety aspects of the capsule and generator in the event of the maximum credible accident. The tests were: (1) fire, (2) thermal shock, (3) pressure burst, (4) impact, (5) vibration, (6) hammer drop, (7) salt water corrosion, (8) fresh water corrosion, (9) air corrosion, and (10) dose-rate measurement. The test results demonstrate that the capsules and generators are safe in all respects except for impact under very special conditions with an extremely low probability of occurrence.

Volume I

SNAP-15A SAFETY PROGRAM

by

R. J. Campana, W. G. Homeyer, and W. P. Wallace



Cutaway view of the SNAP-15A generator

FOREWORD

The safety program for the SNAP-15A generator is summarized in this report. Volume I describes the program conducted and contains analyses of the effects of accidents as well as test program results. Volume II outlines the procedures used in handling fuel capsules and fueled generators at General Atomic. Volume III is a handling manual for users of the SNAP-15A generator.

CONTENTS

I. INTRODUCTION

The SNAP-15A thermoelectric generator developed by General Atomic for the U. S. Atomic Energy Commission is designed to supply a power of about 1 mw at a minimum of 4. 5 v for a period of 5 yr. Power is generated in metal thermocouples contained within an aluminum can 2. 5 in. in diameter and 5. 0 in. long, which is filled with thermal insulation. The generator is powered by heat generated from the decay of Pu^{238}. A cutaway model is shown in the frontispiece.

To assure the safe use of Pu^{238}, a comprehensive program of analyses and experiments was conducted. This report describes the safety program and presents test results. The basic criteria established for the safe use of Pu^{238} are discussed, and the handling procedures adopted are described. Accidents that might create radiation hazards have been considered, and their effects on the fuel are analyzed in detail. Safety tests are defined and test results are presented.

The use of Pu^{238} as a fuel for a thermoelectric generator has been previously studied under the SNAP-9A program, and methods of safe handling have been developed and demonstrated.(1-4) The extensive analyses and experiments performed for the SNAP-9A program have been very useful in the formulation of the safety program for the SNAP-15A generator.

The experience with Pu^{238} acquired by Mound Laboratory during the SNAP-9A program has also been very valuable to the present program. Mound Laboratory was responsible for the loading and sealing of SNAP-15A fuel capsules and has given advice on the design and testing of these capsules.

II. SAFETY CRITERIA

The use of Pu^{238} poses a serious safety problem because of the extreme toxicity of this isotope. The maximum permissible concentrations of Pu^{238} in air and in water are 1×10^{-12} and 3×10^{-6} μC/ml respectively.(5) The chemical reactivity of plutonium, which burns readily in air, greatly increases the danger of dispersion of the fuel, followed by inhalation or ingestion. To ensure the safe use of this material, it is necessary to prevent its dispersion unless adequate dilution can be assured.

The General Atomic safety program for the use of Pu^{238} can be summarized in two words: encapsulation and control. Capsules are designed to prevent release of the isotope during normal use and during any unavoidable accidents that may occur during use. The handling, transportation, and distribution of these capsules and of fueled generators are carefully controlled to prevent accidents, to minimize external radiation hazards, and to keep the capsules out of irresponsible hands.

ENCAPSULATION

The encapsulation material for Pu^{238} must have high strength and resistance to oxidation and corrosion, so that it can survive any of the accidents that might befall it. The accidents which can be hypothesized fall into three categories: fire, impact, and loss. Transportation accidents are by far the most important, both with regard to probability of occurrence and severity.

Fire

The worst credible fire is that which could follow the crash of a fully fueled aircraft in an inaccessible location. The high concentration of combustible fuel would lead to extremely high fire temperatures, much above those experienced in building fires or in fires following crashes of other transportation media.

Impact

The worst impact would be the free impact of a capsule falling at its terminal velocity in air against a rigid surface. This is a very improbable accident, which could result only from a catastrophic aircraft explosion that could destroy the shipping container and generator. It would be much more severe than any compressive impact that could be suffered in transportation accidents, since the generator and shipping container would provide three thicknesses of aluminum, three thicknesses of insulation, and two thicknesses of steel to protect against and cushion any external blows.

Loss

All practical precautions must be taken to prevent any loss of the Pu^{238} fuel. There is a possibility, however, that fuel capsules or fueled generators could be lost as a result of a transportation accident. Loss of a capsule creates two potential hazards: the capsule walls may be penetrated as a result of mechanical damage or slow corrosive attack, or the capsule may eventually burst as a result of the accumulation of helium pressure from the α-decay of Pu^{238}. While the latter hazard has been eliminated by proper capsule design, the danger of eventual corrosive penetration cannot be entirely removed. Thus, if a capsule is lost, it is necessary that concerted efforts be made to recover it unless it can be shown that (1) the probability of anyone ever finding the capsule is extremely small, (2) the probability of corrosion is very small, or (3) if corrosion occurs, the dilution of the Pu^{238} will be to within safe concentration levels.

CONTROLS

All phases of the handling, transportation, distribution, and return of capsules and fueled generators must be carefully controlled. Controls are required to protect the capsules from tampering by irresponsible or unknowing persons, to reduce the hazard caused by a poorly sealed and leaking capsule, and to protect personnel from the effects of penetrating neutron and gamma radiation. These safeguards are provided through adherence to shipping and handling manuals, special equipment and handling procedures, and monitoring and supervision by a competent health physicist. Only careful control can eliminate the danger of deliberate damage to the capsule by humans and limit accidents to the unavoidable ones described above.

Documents

Manuals have been prepared to outline in clear, simple form the procedures that must be followed and the precautions that must be taken in shipping and handling capsules and generators. One manual, intended for users of the SNAP-15A generator, describes the shipping and handling of fueled generators. A second manual, for use within General Atomic, outlines the handling of the Pu^{238} capsules between the time they are received at General Atomic and the time the fueled, sealed generators are placed in their shipping containers. These manuals present detailed handling procedures and emphasize restriction of the capsules to areas accessible only to qualified, responsible personnel.

Special Handling

All handling of a fuel capsule outside of a shipping container or generator is performed in a dry box under the supervision of a safety officer and a member of the General Atomic Health Physics Group. As the shipping container is opened, each surface exposed is wiped and monitored for α-activity. The capsule is placed in a generator only if wipes of its surface indicate α-activity of less than a specified maximum. The dry box is opened only after the generator within is completely sealed.

Fueled generators are also subjected to special handling. Periodic surface wipes are made to check for α-activity. Spent generators will be placed in the insulated generator shipping containers for return to the fuel fabricator.

Radiation Protection

The external radiation hazard, while not a serious one, must be recognized and guarded against. The calculated dose rates at the surfaces of the capsule and generator are summarized in Table 1. The assumptions made and the detailed calculations are outlined in Appendix A. Measured dose rates from fuel capsules are presented in Section IV under "Test Results."

Table 1

EXTERNAL DOSE RATE FROM FUEL

Photon Energy (Mev)	Yield per Disintegration (%)	Dose Rate (mrem/hr)				
		Capsule Surface		Generator Surface		One Foot from Fuel
		Side	End	Side	End	
0.0438	0.038	<0.13	Neg.	Neg.	Neg.	Neg.
0.099	$8(10)^{-3}$	5	<4	Neg.	Neg.	Neg.
0.150	$1(10)^{-3}$	12	<17	Neg.	Neg.	Neg.
0.203	$4(10)^{-6}$	Neg.	Neg.	Neg.	Neg.	Neg.
0.760	$5(10)^{-5}$	435	120-863	3	3	0.05
0.810	e/γ large	---	---	---	---	----
0.875	$2(10)^{-5}$	179	67-408	1.5	1.3-1.6	0.02
Total γ		631	187-1292	4.5	4.3-4.6	0.07
Neutrons		163	241	2.6	2.8	0.04
TOTAL		794	428-1533	7.1	7.1-7.4	0.11

III. ANALYSES OF ACCIDENTS

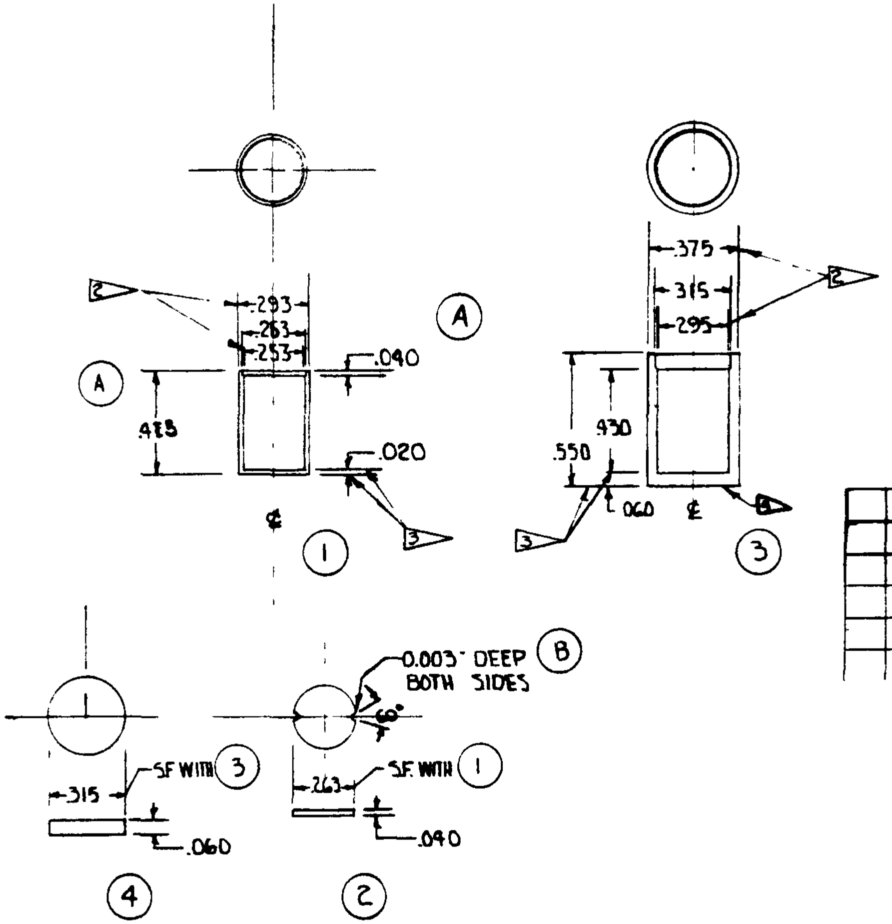
The analyses of accidents and their effects on SNAP-15A fuel capsules are presented below. Figure 1 shows the capsule configuration upon which the analyses are based. The purpose of the inner capsule, made of pure tantalum, is to resist metallurgical attack by the plutonium. The outer capsule, made of Haynes-25 alloy, reinforces the inner capsule and protects against oxidation in air at high temperatures and corrosion in sea water and other liquids. Plutonium fuel is inserted into the tantalum capsule, which is then heliarc-welded shut. The tantalum capsule is then inserted into the Haynes-25 capsule, which is sealed by fusion welding (electron beam).

Since the welds are critical to the capsule integrity, a detailed weld-qualification procedure has been established to assure uniform high quality. This procedure is outlined in Appendix B. The composition of any material used must be certified by its producer, and rigid purity requirements have been specified for the tantalum. The dimensions and the quality of machining of the capsules are also strictly controlled. All finished parts must pass a rigid inspection which includes Zyglo tests to search for cracks or holes in the capsule surfaces. Complete records are kept on each of the serially numbered capsules. These quality controls ensure that all capsules tested or fueled are as nearly identical as is practical to one another and to the capsule considered in the analyses.

FIRE

The most serious effect of fire on the fuel capsule is to increase the internal helium pressure while reducing the tensile strength of the Haynes-25 alloy. In the worst case, a poorly designed capsule might burst and disperse the radioisotope over a large area. This problem becomes more serious at longer times after the capsule is sealed, since the accumulation of helium varies nearly linearly with time for the first 5 or 10 yr.

The design lifetime of the generator is 5 yr. A conservative assumption would be, then, that the maximum time after closure at which a serious fire could occur is 10 yr. This allows for overuse of the generator by 5 yr, or, alternatively, provides a safety factor of almost two on the pressure at the end of the design life of the generator.



GENERAL NOTES

1. REMOVE ALL BURRS & SHARP CORNERS
▷2 DIA TO BE CONCENTRIC WITHIN .0005 TIR
▷3 TO BE ⊥ WITH ℄ .001
▷4 AFFIX SERIAL NUMBER PER GA SPEC 354-1
Ⓒ 5 KEEP PARTS SEPARATED BY MATCHED SETS. SET TO CONSIST OF 1 EACH OF ITEMS 1 THRU 4
6 ZYGLO - NO CRACKS OR PORES PERMISSIBLE

	4		.315 DIA. × .060	HAYNES 25
	3		.375 DIA × .550	HAYNES 25
	2		.263 DIA × .090	TANTALUM
	1		.293 DIA × .415	TANTALUM

Fig. 1--SNAP-15A fuel capsule

Transportation accidents may result in fires with extremely high flame temperatures if large quantities of highly combustible fuel are present. The proposed Interstate Commerce Commission regulations (Section 73391, (a) (3)) recommend that radioisotope capsules be resistant to a temperature of 1700°F. This temperature is higher than those reached in all but a very small fraction of fires and, as discussed below, provides a good starting point for protection against the few exceptional fires. The capsule in Fig. 1 was designed to withstand the pressure produced at 1700°F by the helium accumulated in 10 yr of decay of the fuel. The pressure and stress calculations upon which the design was based are outlined in Appendix C. The internal pressure is shown to be 6710 psi.

Uncontrolled aircraft fires may reach temperatures well above 1700°F for short periods of time if there are no explosions or other events to disperse the fuel. Under these conditions, a well-designed shipping container can be expected to remain intact and, if properly insulated, to protect the capsule from temperature extremes. The shipping container for the SNAP-15A generator is designed to withstand exposure to 1100°C (2012°F) for 30 min and also to keep the temperature of the fuel capsule below 1700°F. This choice of time and temperature is based upon the specification of the Civil Aeronautics Administration (now the Federal Aviation Agency) on the fire resistance of the record of an aircraft flight recorder. In the CAA Technical Standard Order, Part 514, TSO-C51, exposure to 1100°C on 50% of the surface of the recorder for 30 min was specified as the qualification test for flight recorders whose location in the aircraft is not restricted. According to workers in the field of aircraft safety, there has been no instance of fire damage to the record of a recorder which qualified under this specification.(6)

The design of the shipping container is described in Appendix D.

The other possible effect of fire, oxidation of the capsule, is not expected to be serious. Haynes-25 alloy has been successfully used in many jet-engine parts, including turbine blades, combustion chambers, afterburner parts, and turbine rings.

IMPACT

The terminal velocity of the capsule in the air will be less than 225 ft/sec when 2.86 g of fuel are used. The calculations of this velocity and the resulting impact pressure are outlined in Appendix E. The impact pressure (6740 psi) is less than the internal pressures for which the capsule was designed, indicating that the capsule should survive impact at terminal velocity.

The closure weld is clearly the most critical impact region, as previous experience with isotope capsules has shown.(4) A shoulder has been provided on the SNAP-15A capsule to allow a part of the impact load to be transferred from the cap directly to the walls of the capsule.

LOSS

An estimate of the detectable range of a lost capsule has been made using standard scintillation counters for gamma and bremsstrahlung radiation and infrared detectors of the type used by infantrymen for night maneuvering and detection of enemy personnel. SNAP-15A capsules have a detectable radius of 3.3 yards with only air attenuation of nuclear radiations and 35 yards when the capsule is lying or standing free of the generator with only air attenuation of infrared radiation.

The capsules have been designed to withstand the maximum helium pressure that will be produced as the Pu^{238} decays. The calculations of this maximum pressure (23,000 psi) and of the stress levels within the capsule are outlined in Appendix F. Burst tests have indicated the burst strength of the Haynes-25 outer capsule to be in excess of 40,000 psi at room temperature.

Haynes-25 alloy has been demonstrated to be resistant to most acids at room temperature. The resistance of the capsule to corrosion by salt water has been evaluated on previous programs by other contractors.

IV. TEST OF CAPSULES

The SNAP-15A fuel capsules were subjected to a series of tests to verify the design analyses and ensure the safety of the capsule against all credible accidents. The tests were based on the recommendations of Mound Laboratory, the Interstate Commerce Commission, Sandia Corporation, and the Atomic Energy Commission, in addition to General Atomic. The tests conducted are defined below, followed by test results.

Capsule components were fabricated at General Atomic as shown in Fig. 1. Fuel capsule components were machined from materials of certified composition, which were inspected by dye penetrant techniques for holes, cracks, pits, etc., before and after fabrication of components. Components were selected on the basis of best fit and packaged in sets. Assembly and sealing of capsules was performed at Mound Laboratory according to specifications written by General Atomic and Mound Laboratory personnel. The tantalum inner capsule was sealed by heliarc welding while the Haynes outer capsule was sealed by electron beam welding. Radiographic examinations and helium mass spectrometer leak detection tests were performed at Mound Laboratory and at General Atomic.

DEFINITION OF TESTS

Safety tests related to fire, impact, and loss of capsules have been defined and will be performed in order to ensure safe capsule design and generator operation. These tests include (1) fire tests, (2) thermal shock tests, (3) burst tests, (4) impact tests, (5) vibration tests, (6) hammer tests, (7) salt water corrosion tests, (8) fresh water corrosion tests, and (9) air corrosion tests.

Fire Test

The dummy capsules will be exposed to the CAA fire tests, Part 514, Technical Standard Order, C-51, Regulations of the Administrator, "Aircraft Flight Records," which stipulates a temperature of 2000°F enveloping 50% of the capsule surface for a 30-min interval. The procedures for conducting this test are contained in "Standard Fire Test Apparatus and Procedures for Flexible Hose Assemblies," March 1961, FAA, System Research and Development Service, National Aviation Facilities Experimental Center, Atlantic City, New Jersey. Following the heating period, the capsule will be removed from the high-temperature environment and immediately doused with room-temperature (20°C) water until the capsule attains room temperature. This thermal shock test will be repeated once in order to simulate a condition that might occur in a fire-fighting situation.

Thermal Shock Test

The fuel capsules will undergo thermal shock from operating temperature (500°F) to about -100°F (solvent, dry ice). This test will be conducted for four cycles. A cycle consists of heating the capsule for 20 min at operating temperature and transferring it immediately to the low-temperature bath for a 20-min soak. After the soak, the capsule will be transferred within 10 sec or less to the operating-temperature environment, and the test will be repeated.

Burst Test

The fuel capsule, with a simulated void volume, will be exposed to the following environment: The temperature of the capsule will be raised to the test temperature and held for the duration of the test. Test temperatures of 500°, 1200°, 1500°, 1750°, and 2000°F will be employed. At each temperature the capsule will initially be pressurized to the following internal pressure: at 500°F, 20,000 psi; at 1200°F, 3000 psi; at 1750°F, 3000 psi; at 2000°F, 1500 psi. The internal pressure of the capsule will be increased slowly in increments of 2500 psi in the 500° test and 1000 psi in the remaining tests. After each increment of pressure rise, the pressure will be held constant for 15 min. This procedure will be continued until the capsule bursts or leaks.

Impact Test

Fuel capsules with a simulated fuel loading and maintained at terminal temperature (that is, the temperature corresponding to the terminal velocity at impact) will be impacted against granite or a comparable hard surface at a velocity in excess of the calculated free-fall terminal velocity when released from 10,000 ft above mean sea level with impact at 3000 ft above sea level. The capsules will be impacted in each of five attitudes: head on, side on, end on, and at 45° to the principal axes from both the head-on and end-on impacts. Before and after impact the capsule will be pressurized and subsequently immersed in an acetone bath to detect the presence of any leaks or ruptures.

Vibration Test

Fuel capsules with a simulated fuel loading will be subjected to a 15-*g* sine wave from 10 to 2000 to 10 cps for 3 hr along the vertical and horizontal planes. If resonant frequencies are detected, additional testing for 5 hr at these frequencies will be made.

Hammer Test

Capsules will be placed on a soft pine board with the welded end facing up and will be struck a blow of 10 ft-lb with a steel hammer.

Salt Water Corrosion Test

Fuel capsules will be subjected to the corrosion effects of sea water. One capsule will be placed below the ocean level at low tide, and one will be placed slightly above this level so that it will be exposed to air twice a day. The capsules will be weighed and inspected under a microscope for pits and surface roughening before immersion and after 1, 3, and 6 months. In the microscopic inspection, particular attention will be given to the weld zone of the capsule.

Fresh Water Corrosion Test

Capsules will be immersed in water at a pH of 7.0 at 70°F for one week. The capsules will be weighed and examined under a microscope before and after immersion. The weld zone, in particular, will be closely examined.

Air Corrosion Test

Capsules will be heated to 90°F in air and held at this temperature for one week. They will be weighed and examined under a microscope both before and after the test, with the weld zone being given special attention.

Dose Rate Test

The gamma and neutron dose rates at the surface of the generator will be measured and compared with the standard established for AEC laboratory workers.

TEST RESULTS

Fire Test

A capsule welded at General Atomic from components fabricated at General Atomic was raised to 1700°F and was pressurized at 4000 psi in an early initial test. After 1 hr at the test temperature, the capsule was subjected to water jets until it reached room temperature. There were no observable effects other than discoloration of the capsule. All dimensions remained the same except for the center diameter, which increased from 0.375 to 0.379 in.

Three capsules were tested according to the test definition with the following results:

Capsule 42. This capsule was helium leak-checked, dye-penetration checked, and inspected under a microscope. No detectable leaks or cracks were observed prior to the test. The leak detector was calibrated to a standard leak of 4.7×10^{-11} atm-cm^3/sec. The same checks were made after the test and a leak rate of 8.4×10^{-10} atm-cm^3/sec was measured. The capsule showed signs of pits or porosity at one end of the capsule when subjected to dye. Careful examination showed the pits to be $\leq 1/2$ mil deep.

Capsule 46. This capsule was also leak-checked, dye-penetration checked, and inspected under a microscope prior to the test. It had a leak rate of 3.7×10^{-8} atm-cm^3/sec. The permissible leak rate is 1×10^{-7} atm-cm^3/sec. No cracks were observed during the dye-penetration test. After the test, the same checks were again performed on this capsule, and a leak rate of 2.3×10^{-10} atm-cm^3/sec was recorded. No other physical defects were noted as a result of the fire test.

Capsule 50. This dummy capsule was leak-checked, dye-penetration checked, and inspected under a microscope. No detectable leaks or cracks were observed. After the test, the capsule was again checked and no leaks could be measured. No other physical defects were noted as a result of the fire test.

Thermal Shock Test

Two sets of thermal shock tests were conducted. In the first test, 22 capsules were placed in an oven at 500°F; then, after being soaked for 20 min, they were dropped, one at a time, into a mixture of acetone and dry ice at about -100°F. X-ray, liquid penetrant, and helium leak tests showed no effects on any of the capsules. The second set of tests consisted of subjecting six dummy fuel capsules to the same test. Examination was conducted as in the first set of tests. The results showed no damage to the capsules.

Burst Test

Burst tests were conducted using capsules attached to a pressurization tube. Capsule components were fabricated at General Atomic; assemblying and welding were conducted at Mound Laboratory and pressure testing was done at World Research, Inc. An attempt was made to assemble the capsule nipple to the connecting cross by silver soldering. The massive cross required considerably more heat than did the flange. The 40-mil thermocouple was unable to withstand the soaking heat of the cross and was destroyed. Thus, it was necessary to modify the test assembly. One arm of the cross was machined and threaded, and the other face of the arm was then lap-faced. A connecting nut was fabricated with a center hole to accommodate the nipple and thermocouple. The nut was made to match closely the threading of the cross arm. The capsule flanges were turned down on the diameter, and the inner face of the flange was lap-faced to match the face of the cross arm. With the capsule inserted in place in the chamber, a leak-tight metal seal was achieved which worked well, and no further problem was encountered. The details of the tests are given below, and the results are summarized in Table 2.

Capsule 9. The first capsule was tested at 1500°F. At 1345°F, pressurization of the capsule was begun. The pressure was to be brought to an initial test pressure of 8000 psi, but during the rise from 4000 to 5000 psi a leak occurred, and the test was discontinued. Since the leak could occur at points other than the capsule itself, it was decided to proceed with the same test using another capsule.

A subsequent leak test indicated that the tantalum inner capsule was leaking, not the connected tube or test apparatus. Careful machining of the Haynes-25 capsule to extract the tantalum capsule for testing was performed. The end of the tantalum capsule through which the pressurization tube was connected fell off where the weld was found to be faulty.

Capsule 7. This capsule was tested at 1500°F. At 1507°F, pressurization was commenced in 1000-psi increments. The initial test pressure of 8000 psi was achieved at a furnace temperature of 1495°F. In bringing the capsule from 10,000 to 11,000 psi, the high-pressure pump check valve froze and 30 min was required to free the valve and achieve the pressure of 11,200 psi. The capsule burst after 4 min at this pressure and at 1520°F.

Capsule 2. An attempt was made to test at 2000°F. At about 1500°F, it was observed that the temperature difference was increasing between the oven temperature and the capsule. This was because the oven input power was limited by the circuit at World Research. As the temperature increased, the losses from the oven became quite large. At about 1700°F, the capsule temperature rise was about 2° to 3° per minute. It was decided, therefore, that the test would be made at 1750°F rather than 2000°F. At 1750°F the oven temperature was 2550°F. The capsule was brought to 3000 psi in 1000-psi increments at approximately 3 min per increment. The initial test pressure was 3000 psi. The capsule burst after 3 min at 7000 psi and at a capsule temperature of 1750°F.

Capsule 6. The capsule was tested at 500°F. The initial test pressure was to be 25,000 psi, attained in 1000-psi increments of 2 to 3 min each. At the 4000- to 5000-psi increment, the high-pressure check valve began to leak and the pressure could no longer be increased by increments. Since the test could not be stopped at this point without losing pressure, it was decided to throttle back as far as possible on the high-pressure inlet valve. This would then increase capsule pressure continuously but at a time rate comparable to that of the incremental increases. The capsule burst at slightly over 30,000 psi. Since the pressure was being increased continuously, a precise determination of the capsule pressure was not possible.

Capsule 14. This capsule was tested at 500°F. The capsule was brought to an initial test pressure of 30,000 psi in 1000-psi increments at about 3-min intervals. The capsule burst after about 5 sec at 30,000 psi. The 30,000-psi initial test pressure was established from earlier tests conducted at room temperature. However, from the tests of Capsules 6 and 14, which indicated 30,000-psi burst pressure at 500°F, it was decided to attempt a third burst using a lower initial test pressure.

Capsule 8. A new oven was installed in order to achieve the 2000°F temperature required. The initial test pressure of 1500 psi was applied. The pressure was increased at 15-min intervals to 2500, 3050, and 3500 psi. The capsule burst after 6 min at 3500 psi at 2000°F.

Capsule 3. Capsule 3 was installed and pressurized to an initial test pressure of 1500 psi, when capsule temperature was 2000°F. The pressure was increased to 2500 psi and then to 3000 psi. The capsule burst after 5.5 min at this pressure.

Capsule 10. A third test was conducted at 500°F. The capsule was pressurized to 25,000 psi in 1000-psi increments at about 2-min intervals. The initial test pressure of 25,000 psi was achieved at a temperature of 510°F. Pressure was increased in 1000-psi increments every 15 min. The capsule burst instantly at 31,000 psi and 500°F.

The following equipment was used in the burst tests:

Gauge: Heise 0-100 kpsi, Serial No. H-34137, Heise Company

Pump (gas booster): 0-20,000 psi, Haskel Model AG-152

Intensifier: 0-150 kpsi, World Research, Inc., driven by Denison hydraulic pump

Helium gas source: 240-ft^3 cylinder

All fittings and valves: World Research, Inc.

Oven: Blue M Model M-15A-1A, Serial No. 1404, Blue M Company

Duo-Seal pump: Serial No. 53177-0, Welch Scientific Company

Potentiometer: Rubicon Portable, Serial No. 120281, Minneapolis-Honeywell Regulator Company

NRC thermocouple gauge control: General Atomic No. 10963

Thermocouple: Chromel-Alumel

Table 2

BURST TEST DATA SUMMARY

Capsule	Temperature ($^{\circ}$F)	Initial Pressure[a] (psi)	Burst Pressure (psi)	Time[b]
2	1,750	3,000	7,000	3 min
3	2,000	1,500	3,000	5.5 min
6	500	Continuous	30,000	0
7	1,520	8,000	11,200	4 min
8	2,000	2,500	3,500	6 min
9	1,500	3,000	12,000	9 min
10	500	25,000	31,000	1.0 sec
11	1,500	(c)		
14	500	30,000	30,000	5 sec

[a] First pressure, at which capsule remained for 15 min.

[b] Time at which capsule remained at burst pressure before rupture.

[c] Leaked at 4000 to 5000 psi.

In addition to the tests conducted by General Atomic and World Research, two burst tests were conducted by Mound Laboratory. In one test the capsule was pressurized at room temperature after being fabricated as previously indicated. The capsule pressure was raised in steps, and the capsule eventually burst at about 40,000 psi. A second capsule was pressurized at elevated temperature. However, because a system for pressurization was not available with a capacity greater than about 3000 psi, it was decided to go to higher temperature. Thus, the second capsule was tested at approximately 1275°C (2325°F) and was reported to have burst at about 2300 psi.

The results of all the tests are shown in Fig. 2, where the burst pressure is plotted as a function of capsule temperature. Also shown on

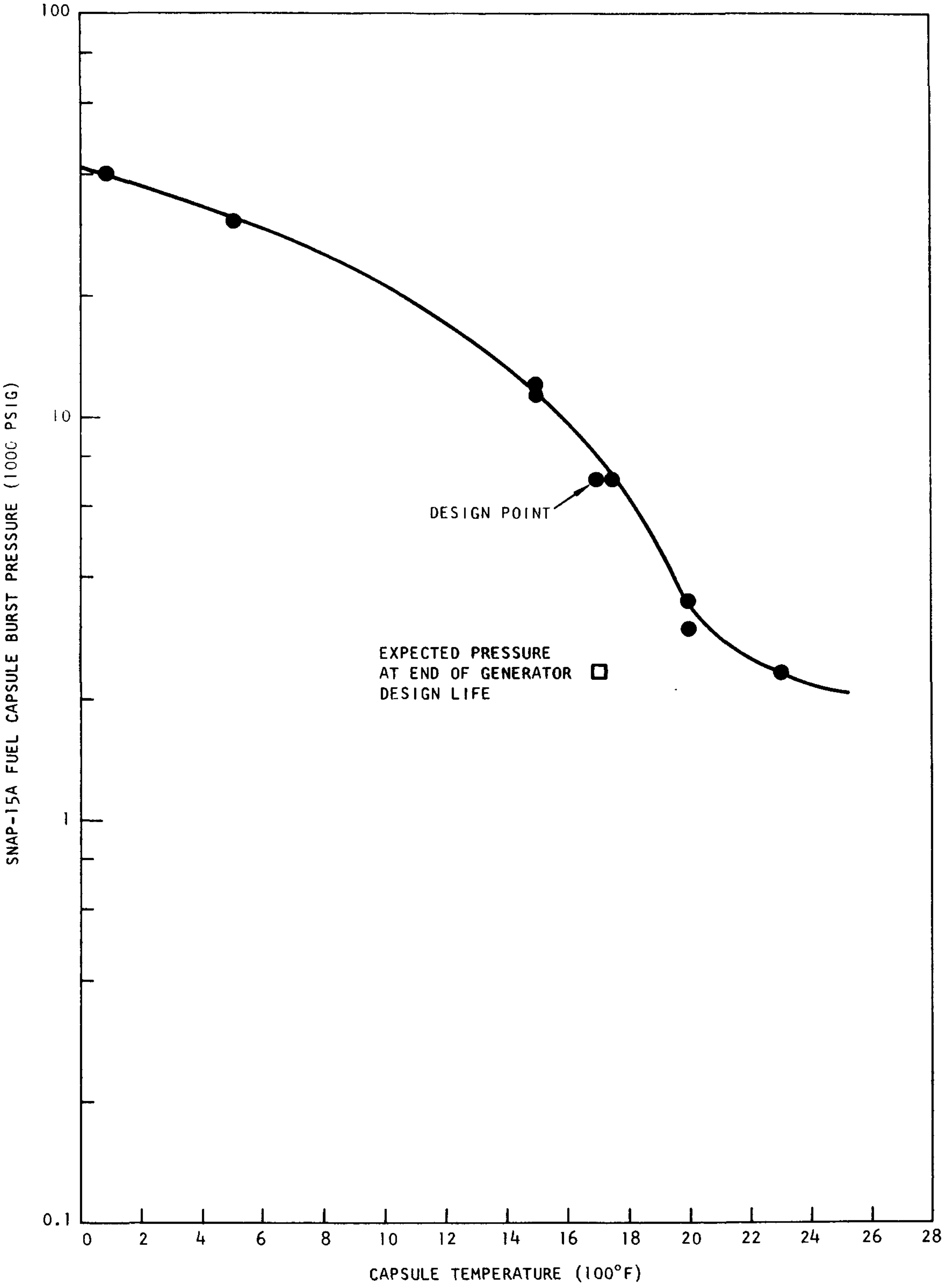


Fig. 2--Variation of fuel capsule burst pressure with capsule temperature

this plot are the capsule design point and the pressure expected at the end of the 5-yr generator life. The difference between the expected pressure at end of life and the design point, or the curve through the experimental burst test points, indicates that the margin of safety available in the SNAP-15A fuel capsules is almost a factor of three. The life of the capsule was calculated based on the experimentally determined curve of pressure versus time of buildup and was found to be approximately 12 yr when the capsule was subjected to a 1700°F fire and 4.75 yr when subjected to a 2000°F fire. In the figure, it may be noted that the curve tails off at the higher temperatures. This is believed to be the result of the two-material construction; that is, at the lower temperatures the basic strength of the capsule is determined by the Haynes-25 material, but at elevated temperatures, the Haynes-25 material loses strength more rapidly than tantalum. At the higher temperatures (2000°F and higher), the tantalum determines the basic strength of the capsule. Figure 3 shows the capsule in its pretest condition and the results of several burst tests at 500°F, while in Fig 4 the results of elevated temperature tests are shown.

Impact Test

Capsules to be used for impact testing were constructed as operational capsules except that different materials were used to simulate the plutonium fuel. Three different sets of impact tests were conducted and three sets of capsules were used. In the first and third sets the capsule components were fabricated at General Atomic and assembled and welded at Mound Laboratory. The second set of capsules, made of stainless steel, was fabricated by a subcontractor for Sandia Corporation. In the first set of capsules, the plutonium fuel was simulated by tantalum by permitting the tantalum liner to be only partially counterbored so that the volume and mass of tantalum remaining simulated the plutonium fuel mass and volume. Stainless steel model capsules are described in Appendix G, which reproduces the Sandia Corporation reports. Briefly, the stainless steel model consisted of a stainless steel shell of the size of a Haynes-25 capsule. It contained a compacted tungsten powder and lead to simulate the plutonium fuel in mass and volume. The third set of fuel capsules contained a plutonium fuel simulant composed of compacted tungsten powder. Tables 3 and 4 give the basic information on the compacted tungsten material.

Table 3

SPECIFICATION FOR COLD-PRESSED TUNGSTEN POWDER COMPACTS

Press from	Wah Chang Corp.* powder, 325 mesh
Compaction pressure	155,000 psi
Weight of powder per compact	3.810 ±0.005 g
Compacted diameter	0.251 ±0.001 in.
Minimum compacted density	13.2 g/cc

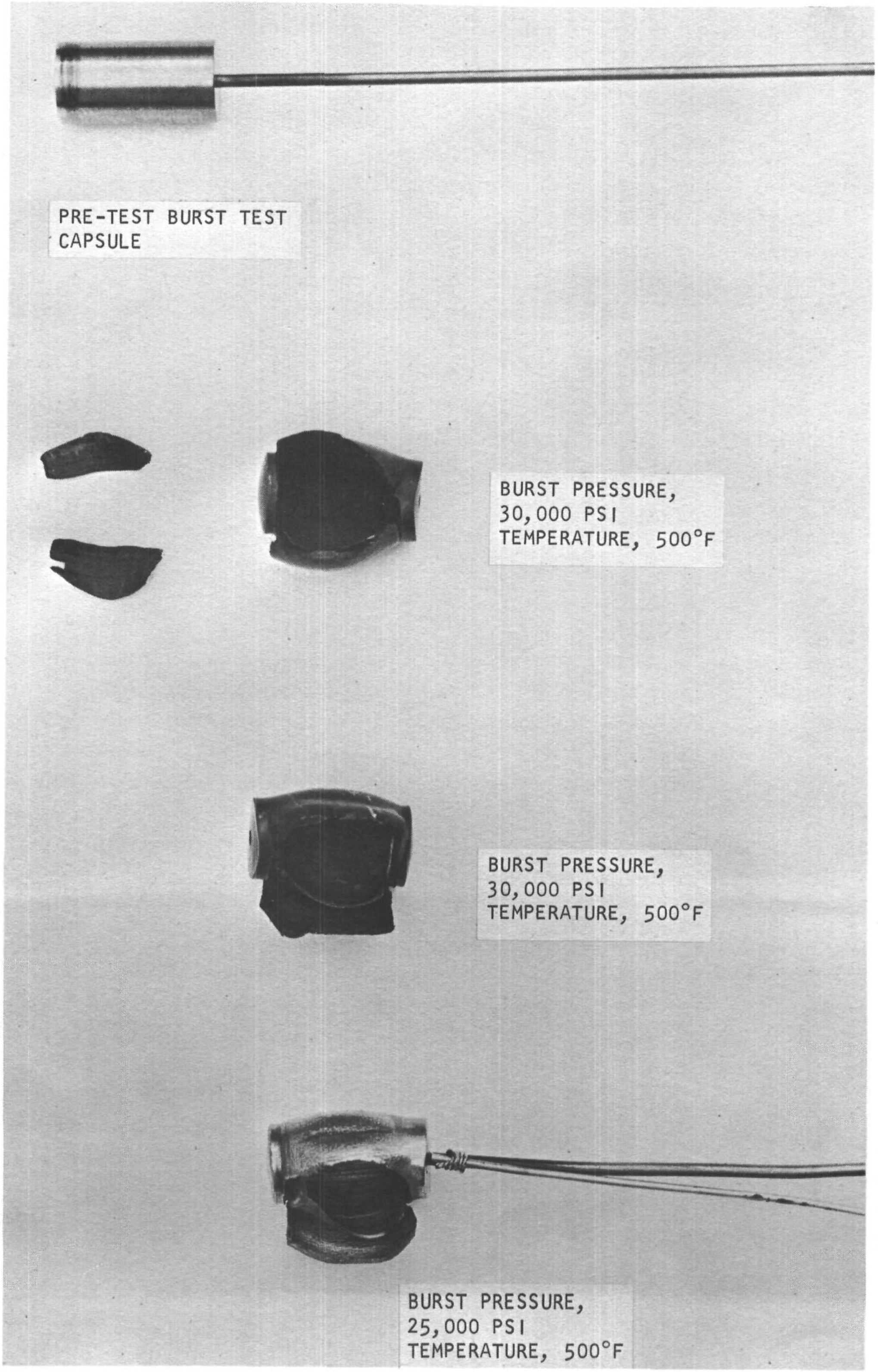


Fig. 3--Capsule pre-test condition and appearance after burst tests at 500°F

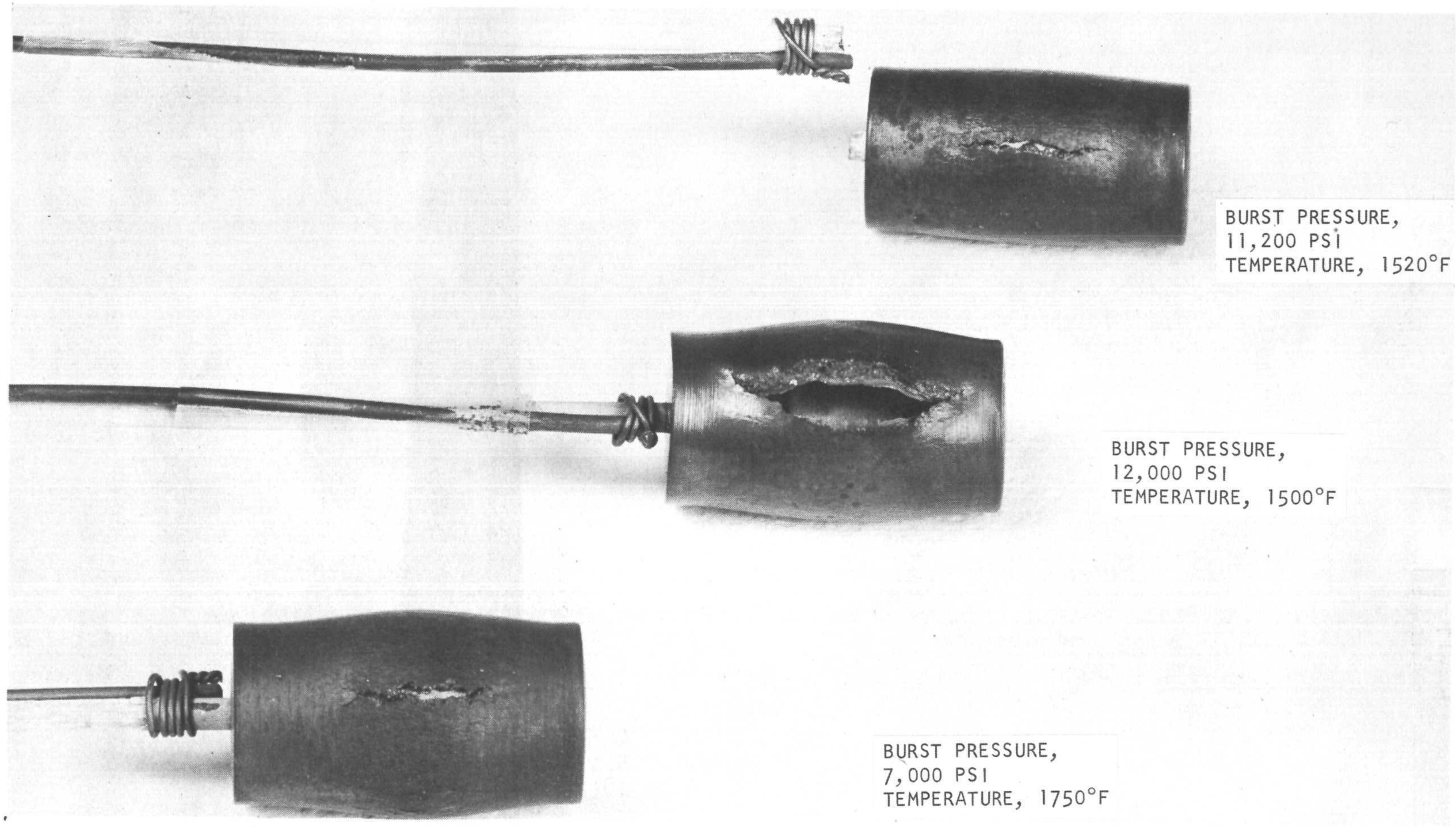


Fig. 4--Capsule appearance after burst tests at elevated temperature

Table 4

MEASURED ULTIMATE COMPRESSIVE STRENGTH OF TUNGSTEN POWDER COMPACTS

(Samples Taken from Production Run)

Sample No.	Ultimate Compressive Strength (psi)
21	15,760
22	13,740
23	14,540
24	16,460
25	14,140

In the impact test, capsules were heated by infrared radiation to 255°F, the temperature computed to be attained at the moment of impact. The capsules were hung by fine wires and impacted by a piece of granite carried by a bazooka rocket. The preliminary testing of six capsules using the tantalum metal as fuel simulant was conducted with inconclusive results as shown in Table 5. The second series of impacts using the stainless steel capsule model was conducted to determine the range of failure velocity and the most critical attitude. Results of these tests are shown in Table 6, where it is clear that the attitude of 45° is the most severe as indicated by the highest number of ruptures at the lowest velocity range. In the third series of impacts, thirty capsules were tested, with the results shown in Table 7. Since rupture occurred in three of ten trials at approximately 110% of the computed free fall terminal velocity when impacted at an attitude of 45°, it was concluded that either (1) the capsule would require modification to survive such impacts or (2) the probability of such impact will have to be demonstrated analytically to be sufficiently small to be an acceptable risk. Details of the tests and results are contained in the four Sandia Corporation progress reports comprising Appendix G.

Vibration Test

Dummy fuel capsules for vibration testing were fabricated in the same manner as operating capsules would be fabricated. The components were fabricated at General Atomic, and assembly and sealing was performed at Mound Laboratory. Vibration tests were carried out at Ryan Electronics under the supervision of General Atomic personnel. The details of the test and the test results are contained in Appendix H, the Ryan report of this test series. In summary, 22 capsules were vibrated along three mutually perpendicular axes with 1/2-in. double amplitude from 10 to 34 cps; from 34 to 2000 psi, a 30-*g* maximum acceleration was maintained.

Table 5

SERIES 1 IMPACT TEST RESULTS
(Tantalum Simulated Fuel Load)

Attitude, θ (degrees)	Impact Velocity (fps)	Results
3	302	Survived
23	298	Ruptured
39	242	Ruptured
39	349	Ruptured
43	399	Ruptured
47	197	Ruptured

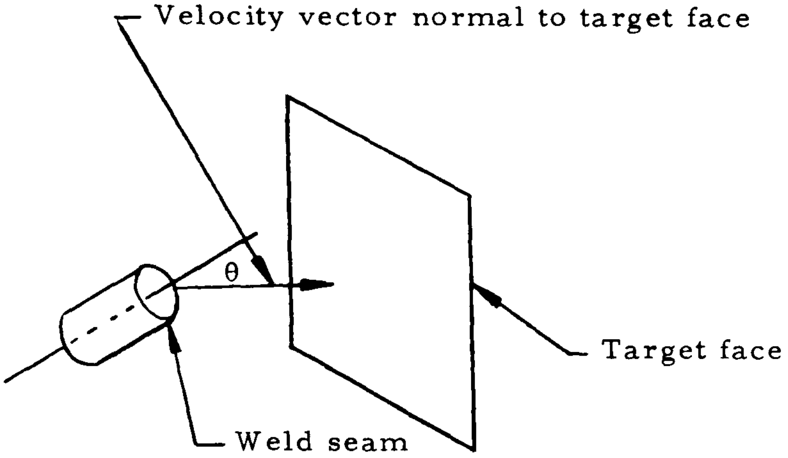


Table 6

SERIES 2 IMPACT TEST RESULTS
(Stainless Steel Capsule Models)

Attitude, θ (degrees)	Range of Velocity (fps)	Results [a]
0	292-449	6-S, 2-R
45	146-276	6-S, 5-R
90	294-415	3-S
135	250-352	5-S
180	258-399	5-S

[a] S = survived, R = ruptured.

Table 7

SERIES 3 IMPACT TEST RESULTS
(Tungsten-compact Simulated Fuel Load)

Attitude, θ (degrees)	Number of Tests and Failures[a]		
	225 fps[b]	250 fps	300 fps
0	---	2	1
45	10(3F)	6(3F)	1(1F)
50	---	1(1F)	---
90	---	2	1
135	---	2	1
180	---	2	1

[a] (XF) = number of failures by rupture of outer capsule.

[b] Impact velocity.

The frequency scan proceeded from 10 cps to 2000 cps in 1/2 hr to 10 cps in another 1/2 hr. There were no resident points found. There was a considerable amount of noise, which resembled the sound of a swarm of angry bees. This is believed to be caused by the tantalum capsules being loosened in the Haynes-25 outer capsule. The motion within the outer capsule was somewhat rotational as evidenced by the large "cross-talk" output. In the range of 700 to 1100 cps, the acceleration in a direction 90° from the basic 30-*g* input reached 18 *g*. The capsules were leak-checked and no failures were found.

Hammer Test

A guillotine-type rig was made with a 5.7-lb flat-bottomed steel hammer held 1.75 ft above the end of the capsule, which was set on a pine board in the base of the rig. When released, the weight struck the capsule with a 10-ft-lb impact. This drove the capsule 0.1 to 0.13 in. into the board. A new position on the board was used for each capsule. Twenty-two capsules were tested in this manner. Radiographs, leak penetrant tests, and helium mass-spectrometer leak checks before and after the hammer blow showed no failures.

Salt Water Corrosion Test

Two dummy fuel capsules were tested according to the test definition. Examination of the capsules after one month showed no corrosive effects. After three months, the continuously immersed capsule had been lost by unknown means. The other capsule showed no corrosive effects upon examination and the test was terminated.

Fresh Water Corrosion Test

Eleven capsules were immersed in 70°F tap water with pH of 7.0 for one week. Some discoloration was noted that appeared in streaks resembling machine tool marks. It has been suggested that iron abraided from the machine tool may have been corroded, but no definite evidence is available. Photomicrographs revealed nothing except that the affected surface was very shallow.

Air Corrosion Test

Eleven capsules were placed in an oven at 90°F for one week. Discoloration was noted with the same results as in the fresh water test.

Dose Rate Test

The dose rate from gamma plus neutrons from the SNAP-15A capsule was measured at Mound Laboratory and at General Atomic with the following results:

At General Atomic dose rates were measured by attaching a film to the surface of a generator and exposing it for 93.5 hr. Capsule 76 containing Pu^{238} equivalent to 1.56 watts output was inserted into the generator. Results of these measurements are shown in Table 8. The film measurement report indicates no thermal neutron dose at top or bottom positions and that 5.26% and 4.88% of the dose from the sides is from thermal neutrons, while the remainder is from fast neutrons. Attenuation of gamma or neutron radiation by the materials of the generator is completely negligible except in the direction of the thermal capacitor (bottom) where the metal of the thermopile and particularly the rather thick stainless steel block are effective absorbers. It is seen from the table that the relative importance of gamma and neutron dose as compared with that predicted in the section on Safety Criteria is reasonable. Also, the measurement verifies the predicted total dose within about 30%.

Table 8

DOSE RATE MEASUREMENT OF SNAP-15A GENERATOR
(Fuel Capsule 76)

Position	Distance from Fuel Center (cm)	Dose Rate		
		Gamma (mr/hr)	Neutron (mrem/hr)	Total (mrem/hr)
Top	4.1	3.3	3.2	6.5
Side (0°)	3.3	6.4	3.9	10.3
Side (180°)	3.3	6.3	4.2	10.5
Bottom	8.6	0.37	0.21	0.58

Measurements of radiation from the capsules made by Mound Laboratory are shown in Table 9. The neutron dose measurements were made with portable neutron counter PNC-1, No. 110. The gamma dose readings were taken with a Jordan Electronic Company instrument, Model No. AGB-50 FB, Serial No. 230.

The results of the measurements made at Mound Laboratory and those made at General Atomic on Capsule 76 are seen to be significantly different even when the difference in source to detector is accounted for. The reason for this difference has not yet been determined. However, the higher of the two values is close to the predicted radiation dose and well within the limits the generator is capable of accepting over its design life. From a radiation hazards standpoint, it may be seen that it would be difficult for a worker to exceed the maximum permissible exposure for AEC laboratory workers during the normal course of his activities. Nevertheless, a minor potential radiation hazard exists and should be taken into account in the handling of these generators.

Table 9

RADIATION DOSE RATE FROM SNAP-15A FUEL CAPSULES
(Measured at Mound Laboratory)

Capsule No.	Neutron Dose Rate (mrem/hr)			Gamma Dose Rate (mr/hr)			Total Dose Rate (mrem/hr)		
	Contact	5 cm	1 m	Contact	5 cm	1 m	Contact	5 cm	1 m
63	1.15	0.675	0.195	1.20	0.45	0.15	2.35	1.13	0.35
66	0.99	0.615	0.195	1.30	0.56	0.16	2.29	1.18	0.36
67	1.14	0.720	0.165	1.30	0.55	0.15	2.24	1.27	0.32
71	2.58	0.795	0.150	1.30	0.51	0.16	3.88	1.31	0.31
74	1.02	0.675	0.150	1.20	0.44	0.18	2.22	1.12	0.33
76	1.02	0.615	0.195	1.70	0.61	0.18	2.72	1.23	0.38
75	1.26	0.765	0.015	1.0	1.3	0.1	7.26	2.07	0.12

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Appendix A

DOSE-RATE CALCULATIONS

The radiation dose from the SNAP-15A fuel capsule is caused by neutrons and gamma rays. Since the dose rates from the two types of radiation are of the same magnitude, both must be calculated accurately. The results of the calculations outlined below are summarized in Table 1 on page 1-4.

GAMMA RAYS

The gamma dose rate was calculated with the help of a first collision approximation in which the photon energy-absorption coefficient(1) is used as an attenuation coefficient. This corresponds to using a build-up factor

$$B = e^{-\sigma_s x} , \qquad (1)$$

where σ_s is the scattering portion of the Compton cross section and x is the distance through the scattering and absorbing medium from the source point to the detection point. For the case of photons of low energy and absorbers of high atomic number, this is a good approximation, particularly near the photon source. It has the important advantage that it implicitly integrates the build-up factor over the source distribution.

The energies of the several gamma rays and their yields per disintegration were taken from Ref. 2. Photon energy-absorption cross sections, which are summarized in Table A. 1, were obtained from Ref. 3. The fuel was assumed to be in the shape of a right circular cylinder 0.253 in. in diameter and 0.123 in. high. Dose rates were calculated at the four points shown in Fig. A. 1 with the help of the formulas and graphs of Ref. 4. Attenuation by the Min-K insulation was neglected since the effect will be small.

NEUTRONS

Neutrons produced in the fuel by spontaneous fission will be almost unattenuated by the fuel capsule and probably only slightly attenuated by the generator. An upper limit on the neutron dose rate can be obtained by assuming that there is no attenuation. In this case, the neutron flux per

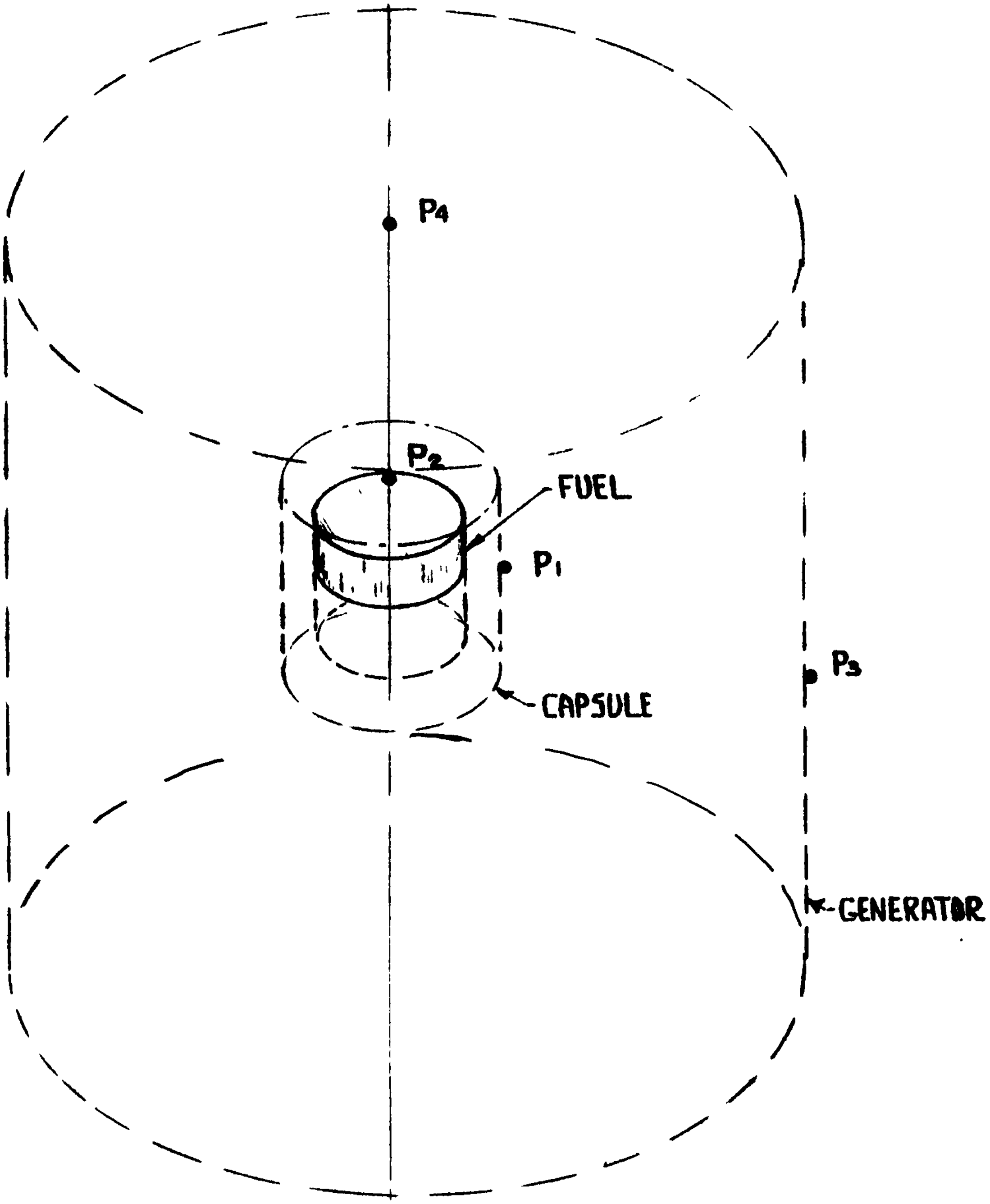

Fig. A.1--Source and detection points

Table A. 1

PHOTON ENERGY-ABSORPTION CROSS SECTIONS FOR CAPSULE AND FUEL MATERIALS

Material	Cross Section (cm^2/g)				
	0.043 Mev	0.099 Mev	0.15 Mev	0.76 Mev	0.875 Mev
Ta	5.67	4.08	1.31	0.0442	0.0386
Co (≅Fe≅Ni)	2.95	0.255	0.0881	0.0274	0.0267
W	5.95	4.22	1.36	0.0450	0.0392
Cr	2.07	0.180	0.0654	0.0273	0.0267
Pu	11.6	1.07	2.46	0.0721	0.0600
Al				0.0281	0.0276

unit neutron energy is

$$\phi(E) = S_v(E) \int_V \frac{dV}{4\pi\rho^2} = S_v(E)I \quad , \qquad (2)$$

where $S_v(E)$ is the volume source strength per unit energy, V is the source volume, and ρ is the distance between an element of source volume dV and the point at which the flux is to be calculated. The volume source strength is

$$S_v(E) = F_v \nu N(E) \quad , \qquad (3)$$

where F_v is the volume fission rate, ν is the average number of neutrons per fission, and N(E) is the number distribution of the neutrons over energy.

The integrated dose rate is

$$R_D = \int_o^\infty \phi(E)R_{DS}(E)dE \quad , \qquad (4)$$

where $R_{DS}(E)$ is the dose rate produced by a unit flux of neutrons of energy E. Combining Eqs. (2), (3), and (4) gives

$$R_D = F_v \nu I \int_o^\infty N(E)R_{DS}(E)dE \quad . \qquad (5)$$

In the absence of data for Pu^{238}, the values of ν and N(E) were assumed to be equal to those for the thermal fission of U^{235}. This probably overestimates the source strength, since the neutron excess of U^{236} is greater than that of Pu^{238}.

The integration over energy was performed graphically using the data on pages 22 and 33 of Ref. 4. The value of F_V was taken from Ref. 2, and ν was assumed to be 2.5. The calculations of the integral I for the dose rates at the end and side of the source are discussed below.

At End of Capsule

For the configuration shown in Fig. A.2,

$$I = \frac{1}{2} \int_o^t \int_o^r \frac{rdr}{r^2 + (a + z)^2} dz \ , \qquad (6)$$

which may be integrated to obtain

$$I = \frac{1}{4} \left\{ (a + t) \ln\left[1 + \left(\frac{R}{a + t}\right)^2\right] - a \ln\left[1 + \left(\frac{R}{a}\right)^2\right] + 2R\left[\tan^{-1}\left(\frac{a + t}{R}\right) - \tan^{-1} \frac{a}{R}\right]\right\}. \qquad (7)$$

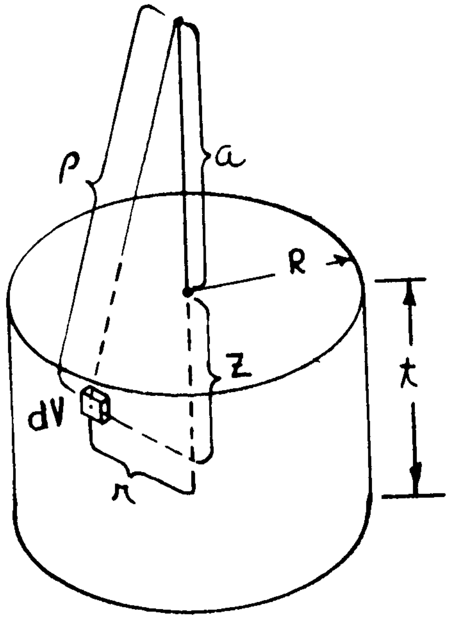

Fig. A.2--Detection point on axis of cylindrical source

At End of Generator

In this case, R << a and Eq. (7) is not accurate. If use is made of the expansions

$$\ln(1 + x) = \sum_{n=1}^{\infty} (-1)^{n+1} \frac{x^n}{n} \quad (|x| < 1) \tag{8}$$

and

$$\tan^{-1} x = \frac{\pi}{2} + \sum_{n=1}^{\infty} \frac{(-1)^n}{(2n - 1) x^{2n-1}} \quad (|x| > 1) \ , \tag{9}$$

Eq. (7) can be written as

$$\begin{aligned} I &= \frac{R}{4}\left\{\left[\frac{R}{a} - \frac{R}{a + t}\right] - \frac{1}{6}\left[\left(\frac{R}{a}\right)^3 - \left(\frac{R}{a + t}\right)^3\right] + --- \right\} , \\ &= \frac{R}{4} \sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{n(2n - 1)} \left[\left(\frac{R}{a}\right)^{2n-1} - \left(\frac{R}{a + t}\right)^{2n-1}\right] . \end{aligned} \tag{10}$$

The first two terms of this expansion were found to be sufficient for the calculation of the dose rate at the end of the generator.

At Side

Since the source provides no significant self-absorption, it may be replaced by a line source at its centerline(4) to obtain

$$I = \frac{R^2}{2(a' + R)} \tan^{-1}\left[\frac{t}{2(a' + R)}\right] , \tag{11}$$

where a' is the distance from the side of the source to the point at which the dose is to be calculated.

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Appendix B

WELDING PROCEDURES AND QUALIFICATIONS OF WELDED FUEL CAPSULES FOR SNAP-15A GENERATORS

The following procedures shall be adhered to in the preparation of fuel capsules for the SNAP-15A generators:

1. The X-ray standards, leak rate, and metallographic criteria by which the welded containers and/or assemblies will be accepted or rejected will be mutually agreed upon by Mound Laboratory and General Atomic after sample welds are evaluated.

2. Tantalum will be used for the inner container and Haynes-25 alloy will be used for the outer container. Each of these may be produced from seamless tubing or machined from bar stock. Tantalum will be heliarc-welded and Haynes-25 may be welded in a vacuum chamber by the electron-beam welding method, or fusion welded.

3. The container parts will be cleaned in an ultrasonic cleaner with suitable solvents and will be free of foreign substances before they are welded.

4. Welding of each batch of capsules and its control samples will be accomplished by the same team, consisting of a welder and an observer. (The welder will be qualified either as an AWS welder or as a staff metallurgist who has been adequately checked on procedures and techniques of fusion welding.)

5. Five empty tantalum inner containers will be welded at the same voltage and current settings and rotation of the holding fixture. These five ~~samples will be X-rayed and~~ leak-tested with a helium leak detector. Two containers will then be sectioned for metallographic examination.

6. If the above tests reveal pin holes or internal voids, the remaining three capsules will also be sectioned for metallographic examination. The results of these tests will be used to determine new settings for voltage, current, and rotation, and step 5 will be repeated.

7. Once satisfactory welds of the inner containers are obtained, three inner containers will be inserted into Haynes-25 alloy outer containers and the latter will be welded shut.

8. The three assemblies will be tested for leaks and X-rayed. Two of the assemblies will be sectioned for metallographic examination and one will be subjected to a pressure test, to destruction, by General Atomic.

9. If the results reveal unsatisfactory welds, steps 7 and 8 will be repeated. If the welds are satisfactory, fueled and unfueled tantalum containers will be welded as described below.

10. Two empty containers will be welded first, and then five fueled tantalum containers will be welded; following this operation the two remaining empty containers of tantalum will be welded.

11. The four control units will be decontaminated, leak-tested, sectioned, and examined metallographically.

12. If the results of the tests on the control units prove that the welding of the containers was satisfactory, the fueled containers will be decontaminated and leak-tested. If they pass the leak test, the fueled containers will be calorimetered and assembled into Haynes-25 outer containers. The tantalum containers will be inserted lid first into the Haynes-25 containers.

13. Two empty assemblies will be welded, followed by five fueled assemblies, followed by two empty assemblies. The sectioned tantalum containers may be used for assembly of these four controls; to permit this, quarter sections should be used in inspecting the welds metallographically. The four empty assemblies will be leak-tested and X-rayed. One assembly from the first two and one assembly from the last two controls will be sectioned for metallographic examination; the remaining assemblies will be shipped to General Atomic for further evaluation.

14. If the results of step 13 reveal satisfactory welds, the five fueled containers will be removed from the welding chamber, monitored for α-activity, leak-tested,and X-rayed. They will then be stored for 1 week and monitored again for α-activity. If these results reveal that the containers are tight, they will be packaged for shipment to General Atomic.

15. If the fuel assemblies fail to pass the required tests, other assemblies will be prepared as outlined above.

16. It is expected that the fueled capsules will be prepared in three five-capsule batches. If a smaller number are to be welded, then test capsules shall be prepared before and after each batch as designated in steps 10 through 15.

Appendix C

CALCULATION OF INTERNAL PRESSURE AND STRESS DURING A FIRE

When a fuel capsule is heated during a fire, the plutonium expands, compressing the helium gas which has accumulated within the capsule. The pressure of the helium is also increased by the rise in temperature, while the tensile strength of the capsule walls is decreased.

From the ideal gas law, which is a very good approximation for helium, the internal pressure is

$$p = \frac{nRT}{V} \quad , \tag{1}$$

where n is the number of gram-atoms of helium present, R is the gas constant, T is the absolute temperature, and V is the gas volume within the tantalum inner capsule. The number of gram-atoms of helium present at time t after the capsule is sealed is

$$n = \frac{m}{238} (1 - e^{-\lambda t}) \quad , \tag{2}$$

where m is the mass of Pu^{238} with which the capsule was fueled and λ is the decay constant of this nuclide. The volume occupied by helium gas will be at least

$$V = \frac{\pi}{4} d_i^2 L - \frac{M}{\rho_m} \quad , \tag{3}$$

where d_i and L are the inside diameter and inside length of the tantalum capsule, and M and ρ_m are the mass and density of the fuel material. The implicit assumptions here are that the inside capsule will not deform under pressure, and that the fuel is incompressible. These assumptions tend to underestimate the gas volume, and thus serve as an additional safety factor on the capsule design.

Combining Eqs. (1), (2), and (3) yields

$$p = \frac{(m/238)\, RT\, (1 - e^{-\lambda t})}{\pi\, d_i^2 (L/4) - (M/\rho_m)} \quad . \tag{4}$$

If the capsule shown in Section III (Fig. 1) is loaded with 3.82 g of fuel (2.865 g Pu^{238}), and is heated to 1700°F 10 yr after it is sealed, the pressure produced in the capsule will be

$$\frac{(2.865/238)(82.1)(1200)[1 - e^{-8.157\times10^{-3}(10)}]}{\pi(0.253)^2(0.533)(16.4)/4 - 3.819/16.2} = 456 \text{ atm} \quad ,$$

$$= 6710 \text{ psi} \quad , \qquad (5)$$

where the decay constant of Pu^{238} is obtained from Ref. 1 and the density of the molten plutonium is taken from Ref. 2.

The stresses induced in the capsule walls by this pressure can be calculated accurately only with great difficulty. An estimate can be made fairly easily, however, with the help of a few assumptions. The first assumption is that the walls of the inner capsule will be stressed up to the yield point of tantalum. This assumption is substantiated by a brief analysis of the physical processes that take place when the capsule is heated. Since tantalum has a lower thermal expansion coefficient than Haynes-25 alloy,(3, 4) the two capsules will tend to separate as they are heated. The internal pressure, however, will be great enough to deform the tantalum capsule, which will yield until it is restrained by the Haynes-25 capsule. Since the elongation of tantalum prior to failure has been shown(4) to be greater than 40%, and the ultimate strength of tantalum is substantially higher than the yield strength, it is reasonable to expect the stress level in the walls of the tantalum capsule to be at least as high as the yield strength of tantalum. The net pressure on the inside of the Haynes-25 capsule is then

$$p_n = \frac{1}{D_i}[d_i p - 2t_w \sigma_y] = \frac{1}{0.295}[0.253(6710) - 2(0.020)(12,000)] = 4130 \text{ psi} \quad , \qquad (6)$$

where t_w is the thickness of the tantalum container wall and D_i is the inside diameter of the Haynes-25 capsule. The yield strength of tantalum at 1700°F, σ_y, was obtained from Ref. 4.

Another simplifying assumption is to neglect the strengthening provided by the thick lid and base of the capsule and to treat the capsule as a long, thick-walled cylinder. The maximum shear stress in the cylinder occurs at the inside surface and is given by Ref. 5.

$$\tau = p_n\left[1 - \left(\frac{r_i}{r_o}\right)^2\right]^{-1} = 4130\left[1 - \left(\frac{0.295}{0.375}\right)^2\right]^{-1} = 10,830 \text{ psi} \quad , \qquad (7)$$

where r_i and r_o are the inner and outer radii of the Haynes-25 capsule. From the data of Ref. 3, it is estimated that Haynes-25 alloy can withstand a tensile stress of 25,000 psi for 1 hr at 1700°F. According to the maximum-stress theory of deformation,(5) the maximum shear stress will be one-half this, or 12,500 psi. Since the maximum shear stress in the capsule wall is only 10,830 psi, the capsule can be expected to withstand a 1-hr exposure to 1700°F at 10 yr after it is sealed.

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Appendix D

SHIPPING CONTAINERS FOR THE SNAP-15A GENERATOR

The design of the shipping container for the SNAP-15A generator presents an unusual problem. The shipping container must protect the Pu^{238} fuel capsule from fires and the resulting thermal transients, but must not provide so much thermal insulation that it overheats the generator and damages sensitive components. The shipping container designed for this purpose (see Fig. D.1) consists of a heavy steel outer container which is separated from a massive inner container by a layer of thermal insulation. It meets the conflicting thermal requirements by providing a large thermal mass inside the relatively thin layer of insulation. The thermal analyses on which the design is based are presented below.

The outer container is sealed air-tight with a rubber O-ring. A second air-tight seal will be provided by the generator housing, which, with the fuel capsule, makes a total of four independently sealed containers for the Pu^{238}.

TEMPERATURE OF THE GENERATOR DURING SHIPMENT

The generator is designed to have a maximum surface temperature of 165°F. Ambient temperatures during shipment may, under normal circumstances, be as high as 120°F. The shipping container must therefore produce a temperature rise due to heat transfer from the fuel of less than 45°F.

The capsule will produce a maximum of 1.65 watts of thermal power. The chief barriers to the escape of this heat from the shipping container will be the Min-K-2000 insulation and the air film at the outside surface of the shipping container.

Temperature Difference Across Min-K

The temperature drop across the Min-K insulation is given by

$$\Delta T_1 = \frac{q}{k\pi[(DL/t_s) + (D^2/2t_e)]} , \tag{1}$$

Fig. D. 1--Shipping container for the SNAP-15A generator where q is the rate of heat generation, k is the thermal conductivity of the insulation, L and D are the average length and diameter of the shell of insulation, respectively, and t_s and t_e are the thicknesses of the sides and ends, respectively, of this shell. Using the thermal conductivity of 0.20 Btu-in. /hr-ft^2-$^{\circ}$F reported by the manufacturer(1) and the dimensions of the container, we find that the temperature difference across the Min-K insulation will be 2.7°F.

Temperature Difference Across Air Film

The heat transferred from a surface to air is given by

$$q = h_c A_s \Delta T_2 , \tag{2}$$

where h_c is the film heat transfer coefficient, A_s is the surface area for heat transfer, and ΔT_2 is the temperature difference between the surface and the bulk of the surrounding air. The film coefficient for the transfer of heat from a vertical surface to air is(2)

$$h_c = 0.29(\Delta T_2/H)^{0.25} , \tag{3}$$

where H is the vertical dimension of the surface. For the transfer of heat upward from a horizontal surface, (3)

$$h_c = 0.27(\Delta T_2/d)^{0.25} , \tag{4}$$

where d is a characteristic horizontal dimension (in this case the diameter) of the surface. We can obtain a very conservative upper limit on ΔT_2 for the shipping container by assuming that heat is lost only from the sides and top of the container and that the handle of the container will not increase the rate of heat loss. With these assumptions, Eqs. (2), (3), and (4) can be combined to obtain

$$\begin{aligned} \Delta T_2 &= \left[\frac{q}{0.29\pi d_w H^{0.75} + 0.27(\pi/4)d^{1.75}}\right]^{0.80} \\ &= \left[\frac{1.65}{0.29\pi(0.417)(0.662)^{0.75} + 0.27(\pi/4)(0.542)^{1.75}}\right]^{0.80} = 3.3^{\circ}\mathrm{F} , \end{aligned} \tag{5}$$

where d_w is the diameter of the outside wall.

Total Temperature Drop

The total temperature drop across the shipping container is obtained by adding the temperature drops across all of the materials. The drops across the two metal shells can be calculated by the same methods as were used for calculating the drop across the Min-K insulation. The results of these and the other calculations are summarized in Table D.1. We conclude that the temperature drop across the shipping container will be less than 8°F, which indicates that the generator surface temperature will be less than 128°F.

Table D.1

TEMPERATURE DROP ACROSS SHIPPING CONTAINER

Component	T(°F) From Input of 1.65 Watts
Foam insulation	<2
Inner steel	negligible
Min-K insulation	2.7
Outer steel shell	negligible
Air film at surface	3.3
Total	<8

TRANSIENT TEMPERATURE RISE

An aircraft fire could produce very high temperatures for short periods of time. The worst condition envisioned is a temperature of 1100°C (2012°F) for 1/2 hr. The generator shipping container has been designed to withstand this condition and maintain the aluminum housing of the generator below its melting point.

Accurate calculations of transient heat transfer in systems made up of several materials are very difficult and time-consuming to perform. ~~With the help of certain~~ simplifications, however, an upper limit on the rate of rise of the generator temperature can be calculated with relative ease. If we ignore the heat capacity of the generator and of the Min-K insulation and assume that the outer container provides no barrier to heat transfer, the rate of heat flow from the outer steel shell to the inner steel shell is given by

$$q = \frac{\overline{k}A}{t}(T_a - T) = mC_p \frac{dT}{d\theta} , \qquad (6)$$

where $\bar{k}$, t, and A are the average thermal conductivity, thickness, and area of the Min-K insulation, respectively; T_a is the temperature at the outside of the shipping container; T, m, and C_p are the temperature, mass, and heat capacity of the inner shell, respectively; and 0 is the time.

If we neglect the temperature dependence of the thermal conductivity and heat capacity, we can integrate Eq. (6) to obtain

$$T = T_a - (T_a - T_o)\, e^{-(kA/mC_p t)0} \quad , \qquad (7)$$

where T_o is the initial temperature of the inner metal shell. To obtain the maximum temperature rise, we take the maximum value of $\bar{k}$ (the average over the range from T_a to the melting point of aluminum) and the minimum value of C_p (at T_o). If $T_a = 2012^\circ F$ and $T_o = 165^\circ F$, Eq. (7) reduces to

$$\Delta T(^\circ F) = 2012 - 1847\, e^{-1.490(hr)} \quad . \qquad (8)$$

Table D.2 gives the temperature of the inner shell at several times after T_a is raised to 2012°F. We conclude from this table that the generator shell will remain intact for more than 30 min while the shipping container is subjected to an external temperature of 1100°C.

Table D.2

VARIATION OF INNER SHELL
TEMPERATURE WITH TIME
($T_a = 2012^\circ F$)

Time (min)	Temperature °C	Temperature °F
15	393	740
30	614	1137
34.2	660[a]	1220[a]

[a] Melting point of aluminum.

REFERENCES

1. Johns-Manville Industrial Insulation Division, "Min-K Thermophysical Properties," 1962.

2. McAdams, W. H., Heat Transmission (3rd ed.), McGraw-Hill Book Company, Inc., 1954, p. 173.

3. Ibid, p. 177.

Appendix E

CALCULATION OF TERMINAL VELOCITY AND IMPACT PRESSURE

The terminal velocity of a body falling in air is the velocity at which the drag force from air friction is equal to the force of gravity. It may be calculated from the formula

$$v = \left(\frac{2W}{SC_D \rho_a} \right)^{1/2} , \qquad (1)$$

where W is the weight of the body, S is its projected area, C_D is the coefficient of drag, and ρ_a is the density of air. The SNAP-15A fuel capsule can be expected to tumble as it falls, so the projected area and drag coefficient will vary. The minimum value of their product will occur when the capsule falls end first, and will produce the maximum terminal velocity. By taking the projected area and drag coefficient for the capsule falling end first and an air density equal to that at 10,000 feet above sea level,

$$v = \left[\frac{2(2.91)(10)^{-2}}{7.67(10)^{-4}(0.85)(1.756)(10)^{-3}} \right]^{1/2} = 225 \text{ ft/sec} \qquad (2)$$

is obtained for an upper limit on the terminal velocity of the fuel capsule.

In the worst case, the capsule might impact on a rigid material such as granite. The impact pressure on the capsule can be estimated from a fluid model$^{(1)}$ to be

$$p_i = \rho_c v^2 , \qquad (3)$$

where ρ_c is the density of the fuel capsule. If the impact velocity is 225 ft/sec, the impact pressure is

$$p_i = 0.137(225)^2 = 6940 \text{ psi}, \qquad (4)$$

which is very much less than the internal pressure that the capsule can withstand at temperatures of 450°F or lower.

REFERENCE

1. Reinhart, J. S., and J. Pearson, Behavior of Metals Under Impulsive Loads, American Society for Metals, Cleveland, 1954.

Appendix F

CALCULATION OF MAXIMUM INTERNAL PRESSURE

As the Pu^{238} in the fuel capsule decays, helium will accumulate and the temperature of the fuel and capsule will decrease. The accumulation of helium tends to increase the internal pressure, while the decrease in temperature tends to reduce the internal pressure and to increase the strength of the capsule walls.

The critical factor is the ratio of the internal pressure to the ultimate strength of the Haynes-25 alloy, which, from Eq. (1), Appendix C, is

$$J = \frac{nRT}{V\sigma_u} , \tag{1}$$

where σ_u is the ultimate strength of the Haynes-25 alloy. The absolute temperature of the fuel capsule can be expressed as

$$T = T_a + (T_i - T_a)e^{-\lambda t} , \tag{2}$$

where T_a is the ambient temperature and T_i is the initial temperature at which the capsule is maintained by the nuclear heat. The ultimate tensile strength of the Haynes-25 alloy can be approximated by a straight line over the temperature range from 70° to 450°F:(1)

$$\sigma_u(\text{psi}) = a - bT = 175,300 - 55.5T(^\circ R) . \tag{3}$$

Substituting Eqs. (2) and (3) and Eq. (2) of Appendix C into Eq. (1) gives

$$J = \frac{mR(1 - e^{-\lambda t})[T_a + (T_i - T_a)e^{-\lambda t}]}{V\{a - b[T_a + (T_i - T_a)e^{-\lambda t}]\}} . \tag{4}$$

The time at which J reaches its maximum can be calculated by setting the derivative of J with respect to t equal to zero:

$$t = \frac{1}{\lambda} \ln \left[\frac{b(T_i - T_a)}{a - bT_a - \sqrt{a(a - bT_i)}}\right] . \tag{5}$$

When the fuel capsule is in the generator, it is insulated with Min-K insulation to provide a temperature difference (T_i - T_a) of 285°F. The exceptionally low thermal conductivity of the insulation assures that this temperature difference will be the maximum that will occur during the life of the capsule. With this temperature difference of 285°F, it is found from Eq. (5) that there is no maximum in J before time infinity if the ambient temperature is greater than -143°F. The conclusion, then, is that the worst condition will occur after almost all of the fuel has decayed, and the helium pressure is

$$p = \frac{mRT_a}{238V} = \frac{2.865(82.1)(300)}{238(0.192)} = 1550 \text{ atm} \cong 23,000 \text{ psi} \quad ,$$

where Eq. (3), Appendix C, is used to compute V and the capsule is assumed to be at room temperature (300°K). The net pressure on the inside of the Haynes-25 capsule is found from Eq. (6), Appendix C, to be 18,000 psi, and the maximum shear stress, from Eq. (7), Appendix C, is 47,000 psi.

The room-temperature tensile strength of the Haynes-25 alloy is certified by the manufacturer to be in excess of 147,000 psi, indicating that the shear strength will be greater than 73,500 psi, and that the capsule will withstand at least 1.5 times the maximum pressure.

REFERENCE

1. Haynes Stellite Company, "Haynes Alloy No. 25," 1962.

Appendix G

FUEL CAPSULE IMPACT TEST REPORTS

The material in this appendix is based on four progress reports, submitted by Sandia Corporation to the USAEC, which describe the impact tests of SNAP-15A fuel capsules. The illustrations are direct reproductions of the figures from the Sandia reports. Material not related to tests of SNAP-15A capsules has been deleted.

FIRST PROGRESS REPORT

Four of the six SNAP-15A capsules (provided Sandia by General Atomic) with tantalum fuel simulation have been impact tested. The results are summarized in Table [G.1]. The test sequence and results were as follows.

1. Initial capsule integrity verified by leak testing all capsules using Radiflo.
2. Capsule #49 was impacted at 298 fps (feet per second). Radiflo check after impact indicated no rupture. The granite target broke at impact. The target failure was attributed to the use of the target for all of the firings (approximately 8) used in the development of the test setup.
3. Testing was interrupted to modify the capsule holder, because the desired 45^{o} impact angle was not attained. Additional Sandia fabricated "dummy" capsules were impacted to verify the setup.
4. Capsule #41 was impacted at 349 fps. The Radiflo again indicated no post-impact rupture. The target also broke on this impact. Additional study of the two broken targets and the films of both tests indicated that the target failures might have resulted from impacting the capsules too close to the edge of the targets.
5. The capsule holder was modified to obtain impact closer to the center of the granite target and another "dummy" capsule was impacted.
6. Capsule #58 was impacted at 399 fps. Radiflo again indicated no rupture of capsule.

7. On April 13, 1964, via telecon, Sandia recommended to General Atomic, and received their concurrence, that the remaining three capsules should be impacted at other attitudes. This was desirable because of the apparent survival of the capsules at velocities up to approximately 200% of maximum estimated sea level terminal velocity.

8. Capsule #39 was impacted fuel end on (i.e., capsule cylindrical axis normal to target face with fuel toward target) at 302 fps. The Radiflo check indicated no rupture.

9. At this time an inspection of capsule #58 under a 60 power microscope caused concern that the results of the Radiflo checks were erroneous.

10. Capsules 49, 41, 58, and 39 were tested for rupture using the following procedure:

    a. Place capsule in a "bomb" and pressurize "bomb" to 10 psig with helium.

    b. Remove capsule from "bomb" and "wash" with nitrogen.

    c. Immediately place capsule under a bell jar and check with Veeco helium detector.

    Although the results were inconclusive, capsule rupture was indicated.

11. The four capsules that had been impacted were then checked twice using the following procedure:

    a. Clean capsule with acetone, dry, and weigh capsule.

    b. **Submerge capsule in acetone.**

    c. Place submerged capsule under a bell jar.

    d. Evacuate bell jar until acetone approaches boiling.

    e. Observe capsules for emission of bubbles during d and f.

    f. Hold vacuum in bell jar until no bubbles are emitted from capsules.

    g. Vent bell jar.

h. Allow approximately 10 minute "soak" in acetone at ambient pressure.

i. Remove capsule from acetone and dry.

j. Weigh capsule.

Bubbles were emitted from capsules 49, 41, and 58 (see Fig. [G.1]). Capsule #39 emitted no bubbles in either check. Capsules 49, 41, and 58 were heated between checks to drive out the absorbed acetone. The results of this test are shown in Table [G.2]

12. General Atomic was informed via telecon on April 15, 1964, that the April 13, 1964, report was incorrect and that the three capsules impacted at angles had ruptured.

13. General Atomic concurred with the recommendation that the next capsule should be impacted at 250 fps with all test conditions identical to the first three impacts.

14. The velocity for the sixth impact will be determined from the results of the 250 fps impact.

15. The desirability of attempting to section the capsules through the ruptured area was discussed with General Atomic. Because the exact path of the leak through the capsule wall cannot be determined, the crack could be obliterated in the sectioning. Therefore, the impacted capsules are being returned unsectioned to General Atomic for their evaluation.

TABLE [G.1]
TEST SUMMARY

Capsule No.	Test No.	Impact Attitude* Desired	Impact Attitude* Actual	Temp. °F	Velocity fps	Comments
49	A-1	45°	23°	255	298	Capsule Ruptured Target Broken
41	A-2	45°	39°	255	349	Capsule Ruptured Target Broken
58	A-3	45°	43°	255	399	Capsule Ruptured
39	A-4	90°	87°	260	302	Capsule Not Ruptured

*Capsule cylindrical axis to target face.

TABLE [G.2]
ACETONE LEAK TEST

Capsule No.	Capsule Weight in Grams Before Soak	Capsule Weight in Grams After Soak	Capsule Weight in Grams Increase	Acetone Temp. °F	Volume Absorbed* in.^{3}
49	13.3734	13.4058	.0324	60-62	.002504
	13.3695	13.4070	.0375	64-65	.002290
41	13.3698	13.4040	.0342	60-62	.002643
	13.3730	13.4042	.0312	64-65	.002411
58	13.3679	13.3792	.0113	60-62	.0008733
	13.3672	13.3900	.0228	64-65	.001762
39	13.3114	13.3116	-	72-74	-
	Checked for bubbles only				-

*Acetone and capsule assumed at 68°F. Specific gravity of acetone 20°C/20°C = .791. Density of water 20°C = .036063 pounds per cubic inch.

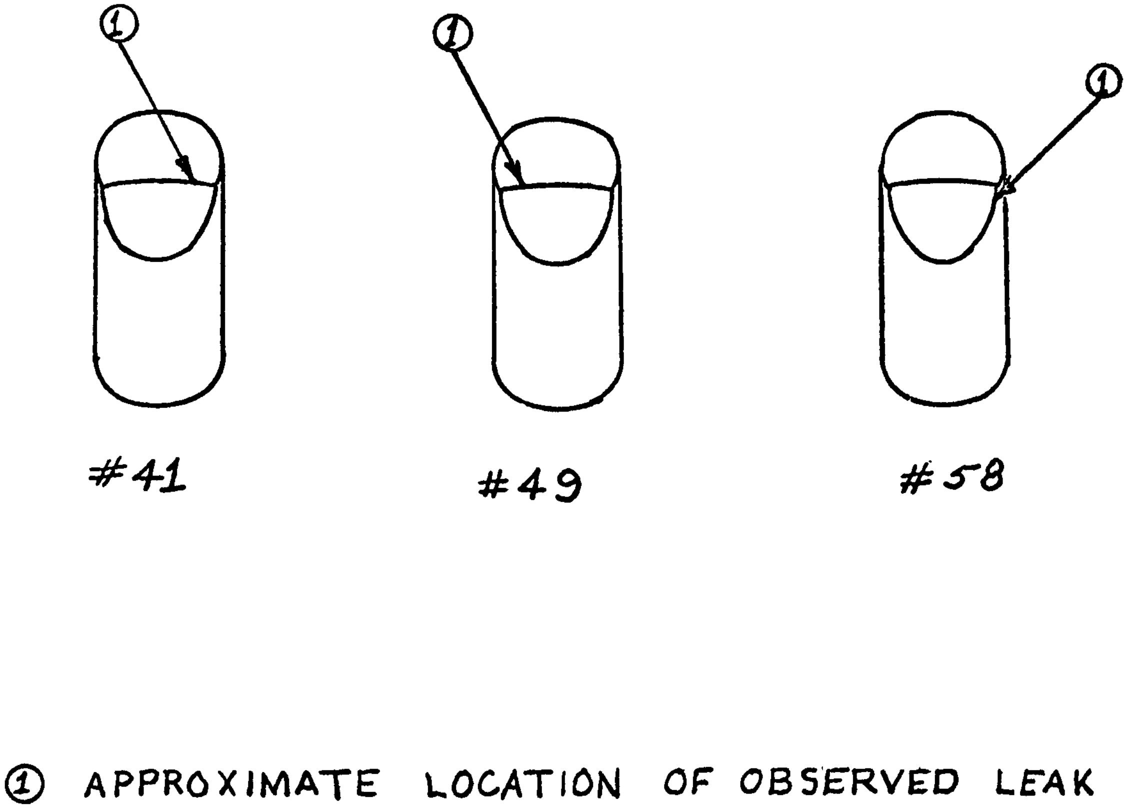


Fig. [G.1]

SECOND PROGRESS REPORT

The two remaining SNAP 15A capsules (of the six provided by General Atomic Division of General Dynamics) have been impacted. The SNAP 15A capsules contained tantalum for the fuel simulation.

The fifth SNAP 15A capsule was impacted at 242 fps (feet per second) at 250°F with the capsule cylindrical axis at 39° to the target face. This capsule ruptured. The sixth SNAP 15A capsule was impacted at 197 fps at 250°F with the capsule axis at 47° to the target face. This capsule also ruptured.

The test procedure was as follows:

1. Initial capsule integrity was verified by leak testing using Radiflo.
2. The capsules were visually inspected after impact.
3. All capsules were checked for leaks using the following procedures:
    a. Clean capsule with acetone, dry, and weigh.
    b. Submerge capsule in acetone.
    c. Place submerged capsule under bell jar.
    d. Evacuate bell jar until acetone approaches boiling.
    e. Observe capsules for emission of bubbles during d and f.
    f. Hold in bell jar until no bubbles are emitted from the capsule.
    g. Vent bell jar.
    h. Allow approximately 10 minute "soak" in acetone at ambient pressure.
    i. Remove capsule from acetone and dry.
    j. Weigh capsule.

Bubbles were emitted from the SNAP 15A capsules (see Fig. [G.2]). See Table [G.3] for test summary. The results of the acetone leak test are shown in Table [G.4].

TABLE [G.3]

TEST SUMMARY

Capsule No.	Test No.	Impact Attitude* Desired	Impact Attitude* Actual	Temp. °F	Velocity fps	Comments
34	A-5	45°	39°	250	242	Rupture
36	A-6	45°	47°	250	197	Rupture

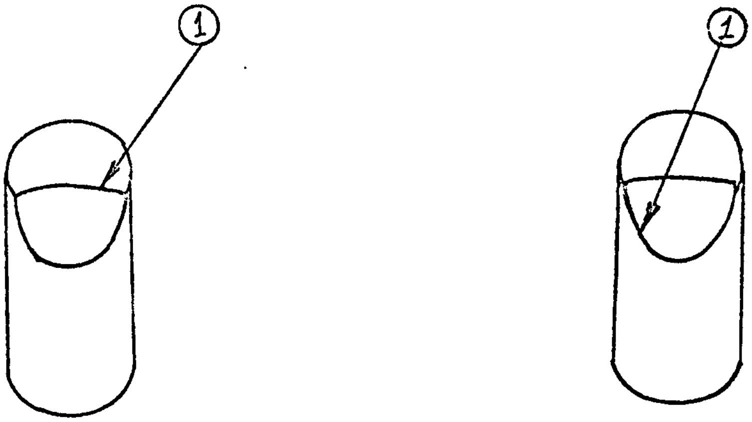
*Capsule cylindrical axis to target face.

TABLE [G.4]

ACETONE LEAK TEST

Test/ Capsule No.	Capsule Weight in Grams Before Soak	Capsule Weight in Grams After Soak	Capsule Weight in Grams Increase	Acetone Temp °F	Volume Absorbed* in.^{3}
A-5/34	13.4331	13.4625	.0294	70	.00227
A-6/36	13.4083	13.4235	.0152	68	.001175

*Acetone and capsule assumed at 68°F.
Specific gravity of acetone 20°C/20°C = .791.
Density of water 20°C = .036063 pound per cubic inch.



#34

#36

① APPROXIMATE LOCATION OF OBSERVED LEAK

Fig. [G.2]

THIRD PROGRESS REPORT

The impact testing of the SNAP 15A model capsules procured by Sandia Corporation has been completed.

For the SNAP 15A model capsule the 45° attitude with the fuel toward the target produced failures at velocities within the range of the maximum free fall velocity at sea level predicted by Sandia Corporation (V_{MSL}). The models survived at velocities $\geq 1.5\ V_{MSL}$ when impacted at the four remaining attitudes [0°, 180°, 135°, 90°].

The model capsules impacted are shown in Fig. [G.3]. The adhesive specified was deleted and the capsule was machined to provide a shoulder (approximately .001 inch) to secure the fuel simulation. This was necessary because faulty capsule closure welds were resulting from outgassing of the adhesive. Six samples of fuel simulant were checked to determine their density and ultimate compressive strength. These results are shown in Fig. [G.4]. The results of the impact tests of the SNAP 15A model capsules are tabulated in Fig. [G.5], and plotted in Fig. [G.6]. The results of Sandia Corporation's velocity and temperature calculations for an unprotected capsule released with zero velocity at 10,000 feet above sea level with the capsules as operating temperature are shown in Fig. [G.7].

Thirty SNAP 15A production quality capsules are presently available at Sandia Corporation for impact tests.

With the concurrence of DRD and General Atomic Division of General Dynamics Corporation and General Instrument Corporation, Sandia will proceed as follows:

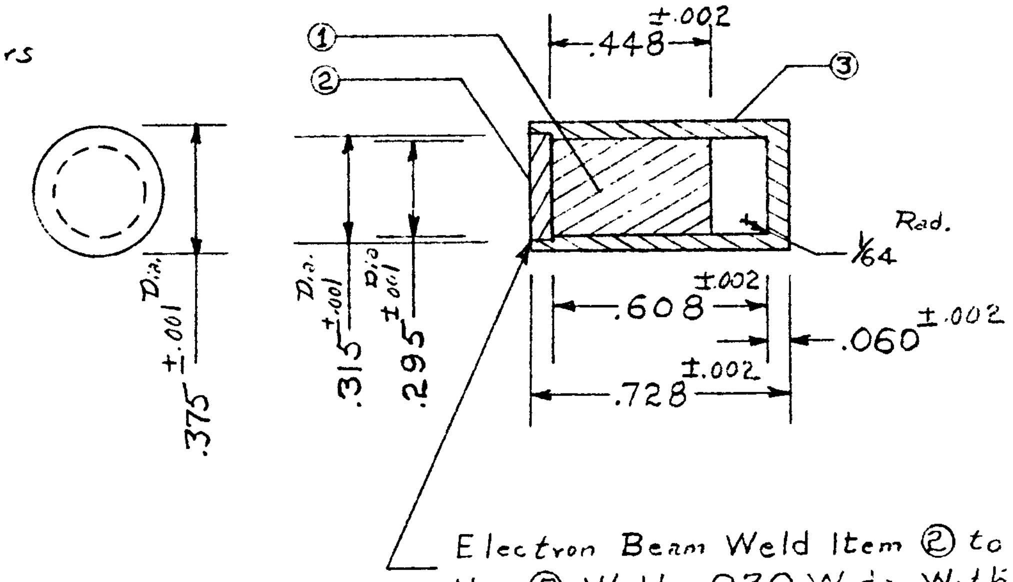
1. SNAP 15A - Impact two capsules at each of five attitudes at 250 feet per second and 230°F. The first attitude will be 45° on the welded end of the capsule (outer case). General Atomic will be informed of each failure before proceeding to the next capsule attitude. The results of previous tests [first and second reports] indicate that failures may occur at the 45° attitude.

2. SNAP 15A - Impact seven capsules at 45° on the welded end at 230 feet per second and at 230°F. If no failures occur, impact one capsule at each of the remaining four attitudes. If failures occur, repeat test except decrease velocity to 200 feet per second. If failures occur at 200 feet per second, repeat test. If failure repeats, halt test. If no failure occurs at 200 feet per second, increase velocity to 230.

▷A ①- 90% Tungsten & 10% Lead Powders
Cold Pressed at 50,525
PSI. Bond in Place With
Eastman 910 Adhesive.

② AISI Type 304L
Stainless Steel

③ AISI Type 304L
Stainless Steel



Electron Beam Weld Item ② to
Item ③. Weld .030 Wide With
.060 Penetration

▷A - Six Samples to be Furnished for
Evaluation By Sandia Corp.

Fig. [G. 3]

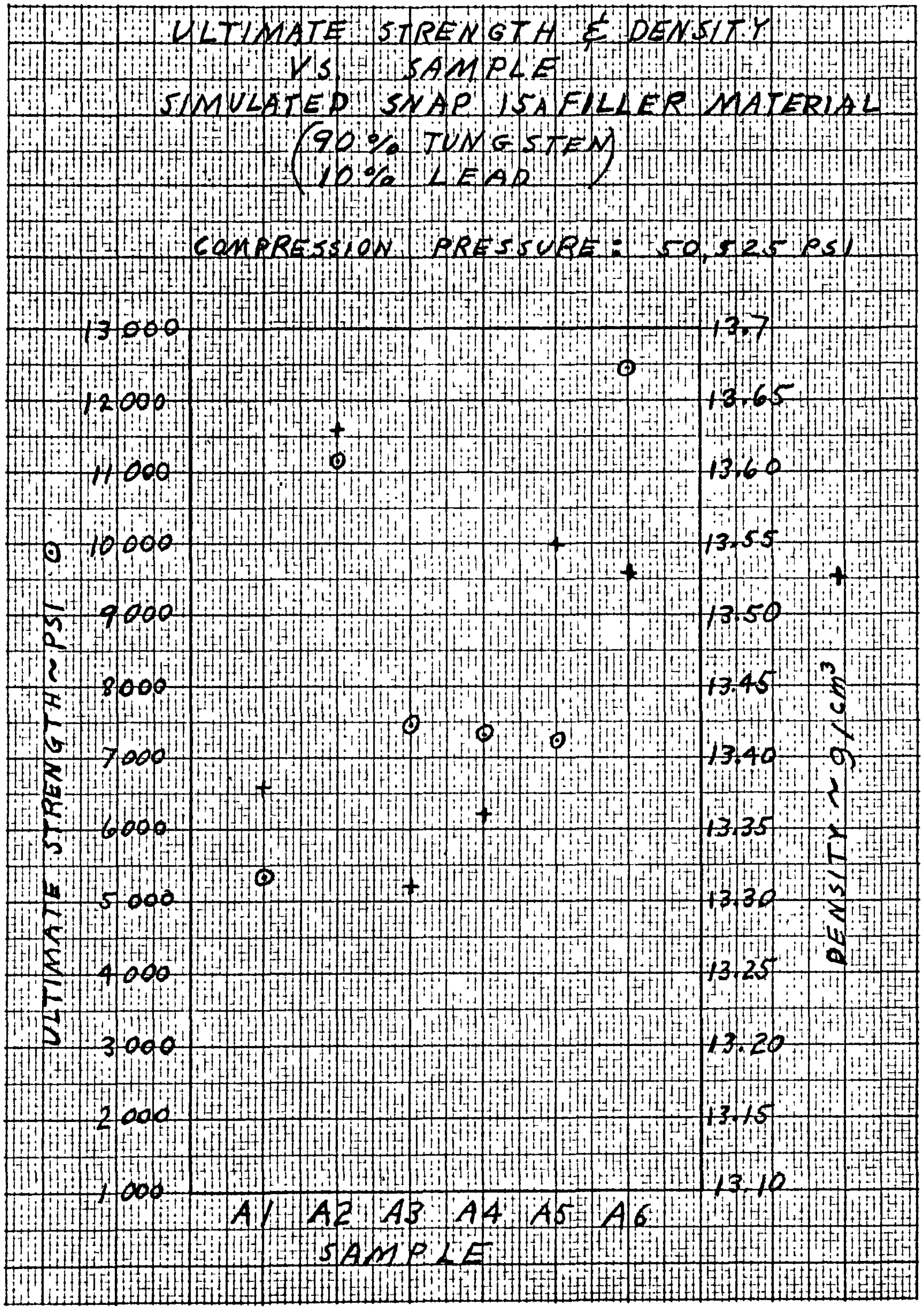

ULTIMATE STRENGTH & DENSITY
VS SAMPLE
SIMULATED SNAP 15A FILLER MATERIAL
(90% TUNGSTEN
10% LEAD)
COMPRESSION PRESSURE: 50,525 PSI
ULTIMATE STRENGTH ~ PSI ⊙
13 000
12 000
11 000
10 000
9000
8000
7000
6000
5 000
4 000
3 000
2 000
1 000
DENSITY ~ g/cm³ +
13.7
13.65
13.60
13.55
13.50
13.45
13.40
13.35
13.30
13.25
13.20
13.15
13.10
A1
A2
A3
A4
A5
A6
SAMPLE

Fig. [G.4]

SNAP 15A IMPACT TEST RESULTS
SANDIA MODELS

ATTITUDE	SAMPLE NUMBER	IMPACT VELOCITY FT/SEC	RESULTS
①	1	204	CAPSULE RUPTURED
	2	183	RUPTURED
	3	150	INTACT
	4	173	RUPTURED
	5	146	INTACT
	6	173	INTACT
	7	197	INTACT
	8	224	INTACT
	9	254	INTACT
	10	276	RUPTURED
	11	249	RUPTURED
②	1	292	INTACT
	2	344	INTACT
	3	415	RUPTURED
	4	378	INTACT
	5	401	INTACT
	6	430	INTACT
	7	449	RUPTURED
	8	425	INTACT
③	1	258	INTACT
	2	271	INTACT
	3	307	INTACT
	4	349	INTACT
	5	399	INTACT
④	1	250	INTACT
	2	272	INTACT
	3	297	INTACT
	4	328	INTACT
	5	352	INTACT
⑤	1	294	INTACT
	2	342	INTACT
	3	415	INTACT

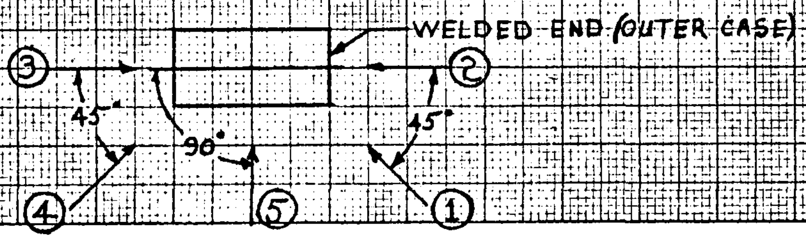


Fig. [G.5]

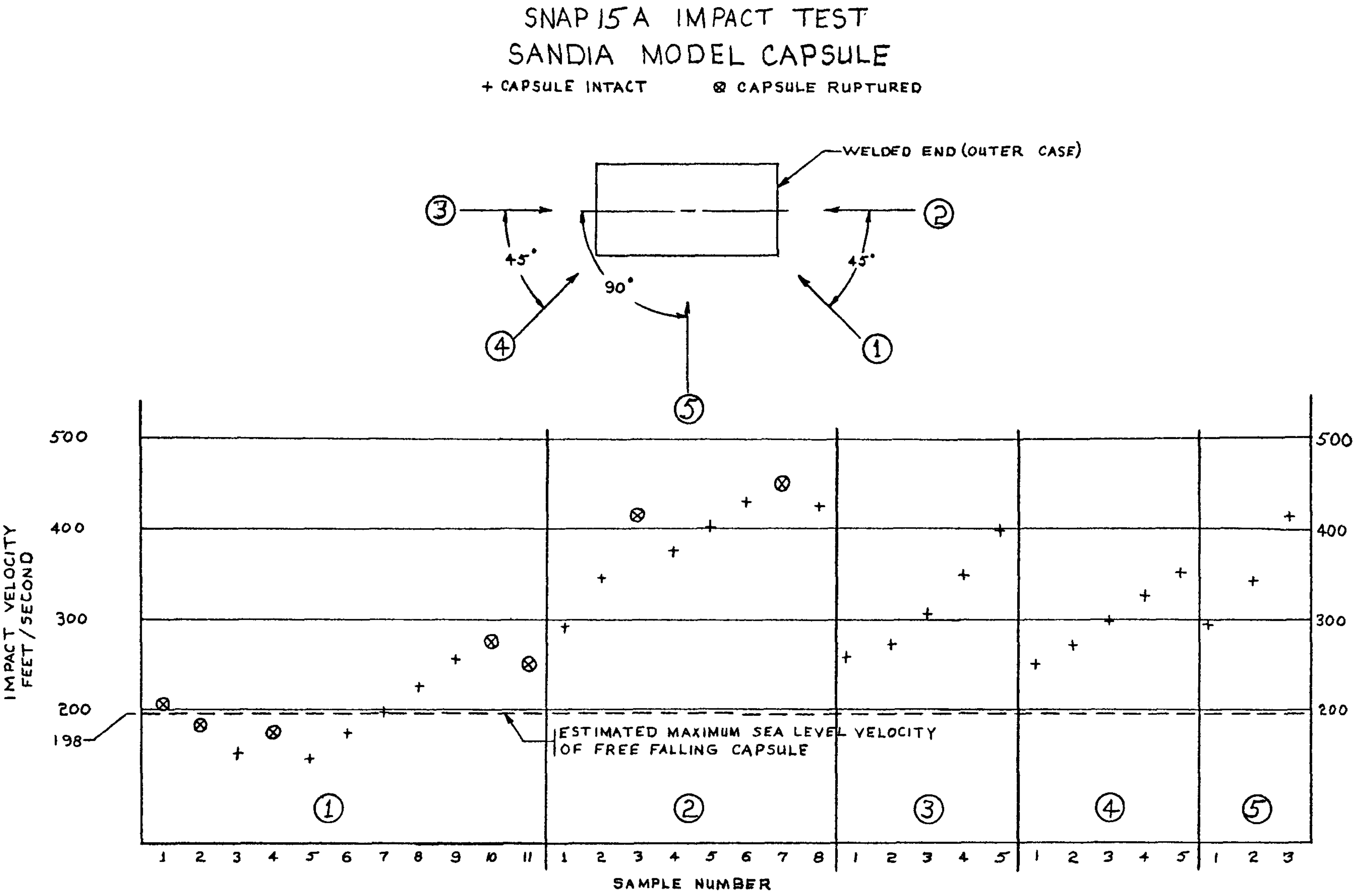

SNAP 15A IMPACT TEST
SANDIA MODEL CAPSULE
+ CAPSULE INTACT
⊗ CAPSULE RUPTURED
WELDED END (OUTER CASE)
③
②
45°
45°
90°
④
①
⑤
500
400
300
200
198
IMPACT VELOCITY FEET / SECOND
ESTIMATED MAXIMUM SEA LEVEL VELOCITY OF FREE FALLING CAPSULE
①
②
③
④
⑤
1 2 3 4 5 6 7 8 9 10 11
1 2 3 4 5 6 7 8
1 2 3 4 5
1 2 3 4 5
1 2 3
SAMPLE NUMBER

Fig. [G. 6]

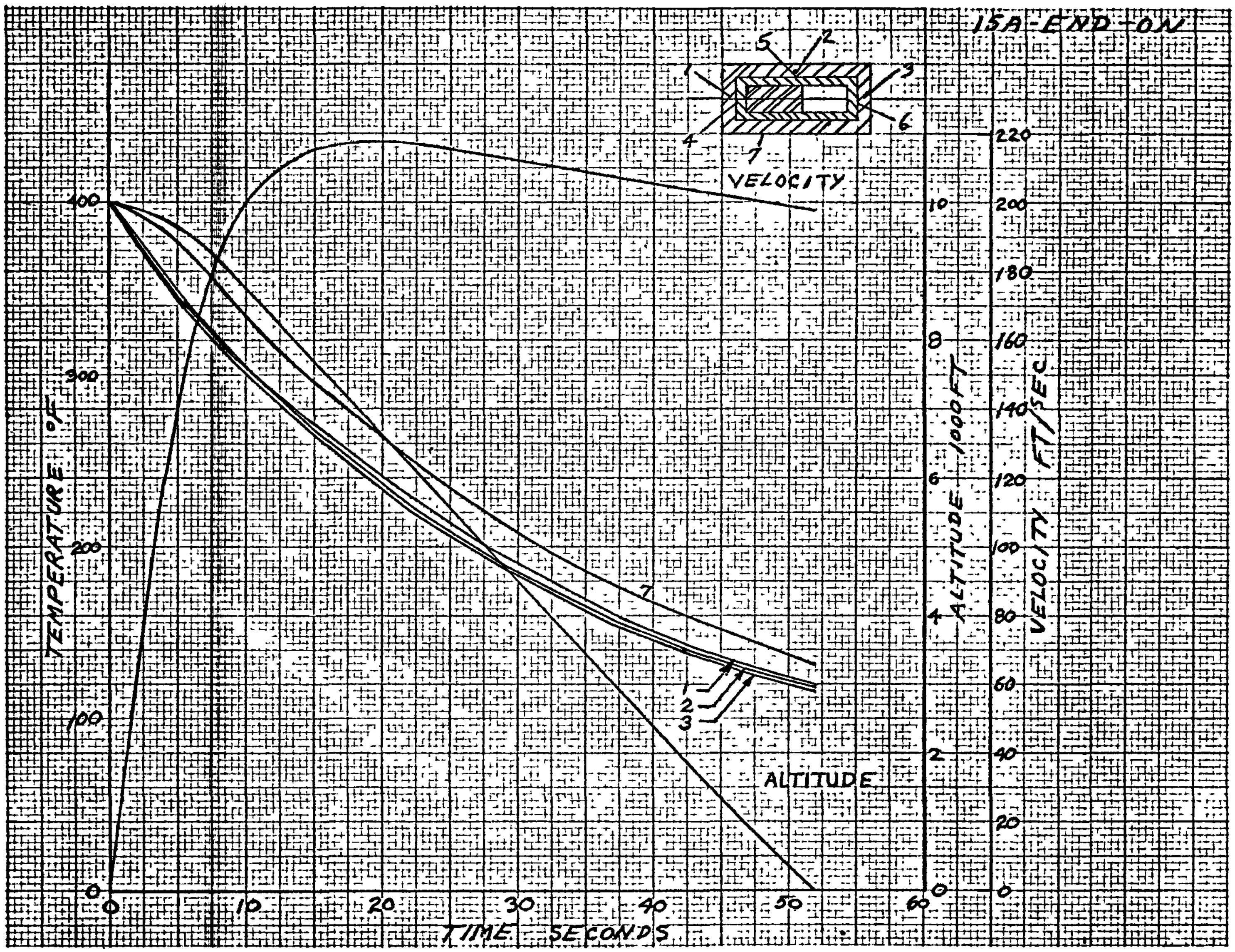

15A-END-ON
1
2
3
4
5
6
7
VELOCITY
ALTITUDE
TEMPERATURE °F
0
100
200
300
400
ALTITUDE 1000 FT
0
2
4
6
8
10
VELOCITY FT/SEC
0
20
40
60
80
100
120
140
160
180
200
220
TIME SECONDS
0
10
20
30
40
50
60

Fig. [G.7]

FINAL PROGRESS REPORT

Sandia Corporation has completed the impact testing of 30 SNAP 15A production quality capsules provided by General Atomic, a division of General Dynamics. The critical impact attitude was found to be 45° on the fuel end of the capsule. Of 18 capsules impacted at this attitude at velocities ranging from 220 fps to 300 fps, eight ruptured. A total of 12 capsules were impacted at the other four attitudes at velocities ranging from 247 to 300 fps with no ruptures. The results are shown graphically in Fig. [G.8] and are tabulated in Fig. [G.9].

The Sandia Corporation estimate of the temperature and velocity of an unprotected SNAP 15A capsule released with zero velocity from 10,000 feet altitude is shown in Fig. [G.7]. The numbers associated with three of the curves denote the locations within the capsule at which the temperatures are calculated. The initial impact velocity was chosen to be 250 fps, which is approximately 125 per cent of the maximum estimated sea level velocity of a free falling capsule, and the temperature was 230°F taken from curve number 7, Fig. [G.7].

The general test plan as outlined was followed on the first 10 impact tests. For the remaining tests, it was determined that more information could be obtained by deviating from the proposed test plan. Each deviation from the proposed test plan was coordinated by telephone with Robert Campana, General Atomic.

Prior to testing, each capsule was leak checked by Radiflo, weighed, and leak checked by the acetone bubble test. None of the capsules leaked. After impact, each capsule was cleaned, weighed, and acetone leak checked. The results are given in Fig. [G.10]. The void volume between the tantalum liner and the outer capsule cylinder was calculated to be between .0087 and .0023 cubic inches. The void volume inside the inner liner is approximately .009 cubic inches. During impact the void volume will change, but the volume of acetone absorbed (Fig. [G.10]) seems to indicate that only the outer cylinder has ruptured. However, it is possible that during impact a crack in the inner liner could be sealed. It is therefore recommended that the inner liner be removed and given an additional leak check and that each capsule be sectioned and examined. Capsule number 123 was not considered ruptured due to the small weight change. Special care should be given in the inspection of this capsule to determine if in fact the capsule did rupture.

After the capsules were leak checked and weighed, they were heated under an infrared heat lamp to force out the absorbed acetone. As the acetone boiled out of the cracks, a red dye-type material was emitted with the acetone. This dye-type material is visible around the crack in every ruptured capsule except number 99 which had absorbed only a small volume of acetone.

The capsules were returned to General Atomic.

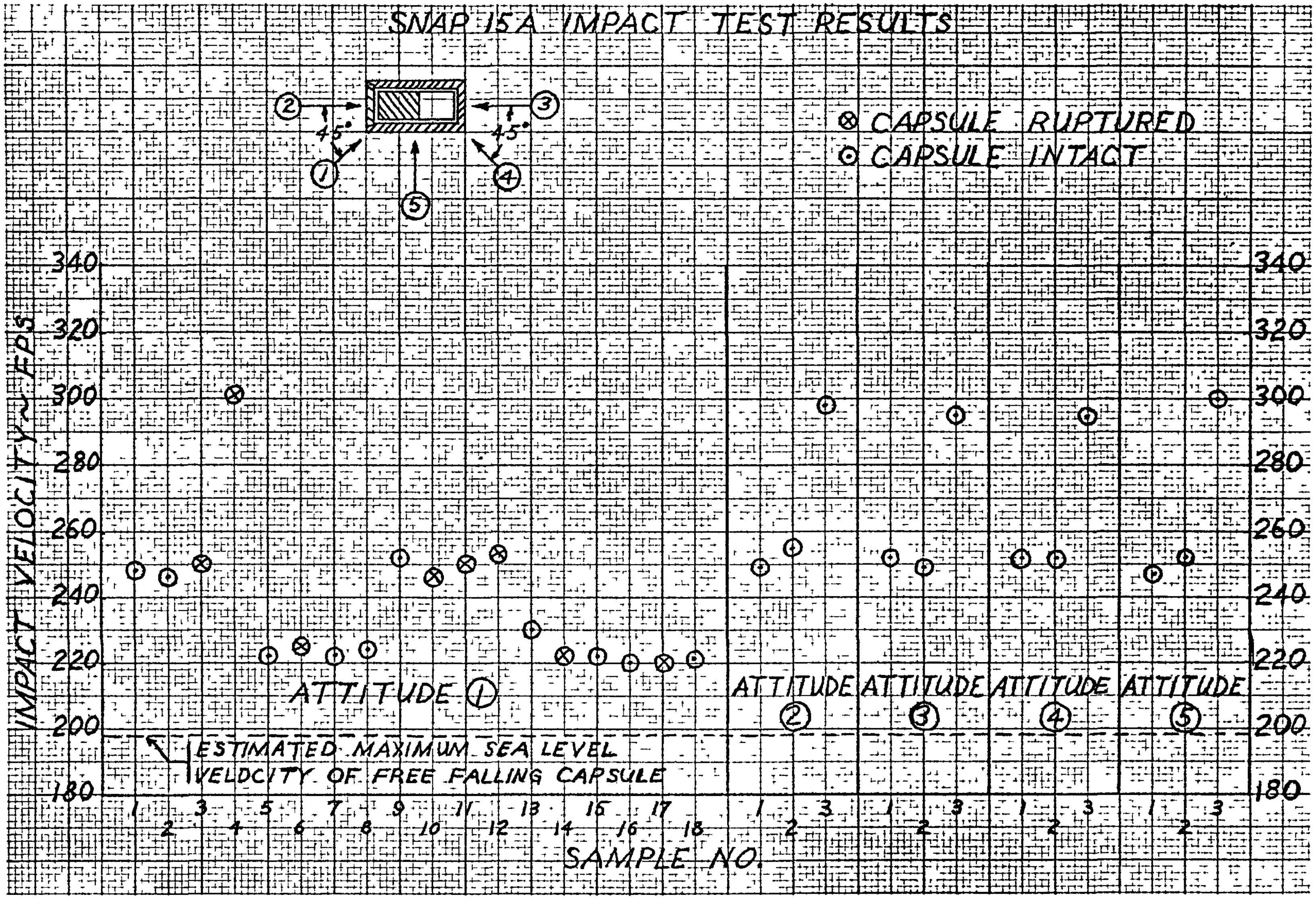

SNAP 15A IMPACT TEST RESULTS
② ③ ① ④ ⑤
45°
45°
⊗ CAPSULE RUPTURED
⊙ CAPSULE INTACT
IMPACT VELOCITY ~ FPS
340
320
300
280
260
240
220
200
180
ATTITUDE ①
ATTITUDE ②
ATTITUDE ③
ATTITUDE ④
ATTITUDE ⑤
ESTIMATED MAXIMUM SEA LEVEL
VELOCITY OF FREE FALLING CAPSULE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
1 2 3
1 2 3
1 2 3
1 2 3
SAMPLE NO.

Fig. [G.8]

SNAP 15 A FUEL CAPSULE
IMPACT TEST RESULTS

Number			Velocity	Temperature	
Test	Capsule	Attitude	(FPS)	(± 5, deg. F)	Results
1	119	45 deg, fuel end	248	230	intact
2	86	45 deg, fuel end	246	230	intact
3	96	end on fuel end	249	230	intact
4	104	end on, fuel end	255	230	intact
5	89	end on, void end	252	230	intact
6	91	end on, void end	249	230	intact
7	97	45 deg, void end	254	230	intact
8	90	45 deg, void end	253	230	intact
9	113	side on	247	230	intact
10	131	side on	252	230	intact
11	95	45 deg, fuel end	250	230	rupture
12	126	45 deg, fuel end	301	230	rupture
13	98	end on, fuel end	298	230	intact
14	120	end on, void end	295	230	intact
15	123	45 deg, void end	295	230	intact
16	109	side on	300	230	intact
17	106	45 deg, fuel end	222	230	intact
18	127	45 deg, fuel end	225	230	rupture
19	124	45 deg, fuel end	222	230	intact
20	82	45 deg, fuel end	225	230	intact
21	121	45 deg, fuel end	252	230	intact
22	114	45 deg, fuel end	247	230	rupture
23	130	45 deg, fuel end	250	230	rupture
24	110	45 deg, fuel end	253	230	rupture
25	85	45 deg, fuel end	225	230	intact
26	99	45 deg, fuel end	222	230	rupture
27	105	45 deg, fuel end	222	230	intact
28	122	45 deg, fuel end	220	230	intact
29	129	45 deg, fuel end	220	230	rupture
30	136	45 deg, fuel end	221	230	intact

Fig. [G.9]

SNAP 15 A FUEL CAPSULE
IMPACT TEST RESULTS

Number		Capsule Weight in grams				Acetone* Absorbed (in.^{3})
Test	Capsule	Before Impact	After Impact	After Soak	Change	
1	119	13.0462	13.0460	13.0460	.0000	.00000
2	86	13.1147	13.1144	13.1144	.0000	.00000
3	96	13.1883	13.1886	13.1886	.0000	.00000
4	104	13.0589	13.0591	13.0591	.0000	.00000
5	89	13.0614	13.0613	13.0613	.0000	.00000
6	91	12.9875	12.9872	12.9872	.0000	.00000
7	97	13.1893	13.1895	13.1895	.0000	.00000
8	90	13.0503	13.0502	13.0502	.0000	.00000
9	113	13.0385	13.0386	13.0386	.0000	.00000
10	131	13.1706	13.1705	13.1705	.0000	.00000
11	95	13.0792	13.0791	13.1065	.0274	.00212
12	126	13.0073	13.0068	13.0362	.0294	.00227
13	98	13.2013	13.2010	13.2010	.0000	.00000
14	120	13.0473	13.0467	13.0467	.0000	.00000
15	123	12.9608	12.9600	12.9613	.0013	.00011
16	109	13.0712	13.0715	13.0715	.0000	.00000
17	106	13.0850	13.0850	13.0850	.0000	.00000
18	127	13.2067	13.2037	13.2266	.0229	.00173
19	124	13.0223	13.0222	13.0222	.0000	.00000
20	82	13.2374	13.2372	13.2372	.0000	.00000
21	121	13.1265	13.1227	13.1227	.0000	.00000
22	114	13.1107	13.1102	13.1342	.0240	.00184
23	130	13.2874	13.2870	13.3085	.0215	.00167
24	110	13.1459	13.1450	13.1677	.0222	.00248
25	85	13.1187	13.1192	13.1192	.0000	.00000
26	99	13.1604	13.1602	13.1656	.0054	.00042
27	105	13.1396	13.1393	13.1393	.0000	.00000
28	122	13.0183	13.0180	13.0180	.0000	.00000
29	129	13.1708	13.1705	13.1940	.0235	.00181
30	136	12.9118	12.9100	12.9100	.0000	.00000

*The acetone temperature remained at 68 ±5 degrees F during the leak tests, and the specific gravity of the acetone was assumed constant at .79.

Fig. [G.10]

Appendix H

FUEL CAPSULE ENVIRONMENTAL TEST REPORT

The material below and on the following five pages is a reproduction of a report by Ryan Electronics on environmental tests of the SNAP-15A fuel capsules.

A. ADMINISTRATIVE DATA

1. Purpose of Test: Safety Program for Fuel Capsule when subjected to vibration test

2. Test Specimen Data:

Description: Fuel Capsule
Manufacturer: General Atomics
Quantity Tested: Twenty-Two (22) each
Disposition: Returned to General Atomics

3. Security Classification: Unclassified

4. Reference: Ryan Letter 455/4102 and verbal vibration instructions of Representatives of General Atomics.

5. Test Conducted by: Environmental Laboratories of Ryan Electronics on 12 November 1963. This test was conducted by Ryan Test Engineers and J. England.

6. Abstract: The Fuel Capsules were subjected to vibration test as described in paragraph B. of this report.

7. Appendix:

I Instrument List
II Factual Data
III Axes Orientation

B. Test Procedure and Requirements

1. The twenty-two Fuel Capsules were mounted in a suitable vibration fixture designed and furnished by General Atomics.

2. The vibration fixture was then securely mounted to the exciter head in the vertical axis of vibration. An accelerometer was mounted adjacent to the test specimen for vibration control. A second accelerometer was mounted in the "Y" or minor horizontal axis to measure the crosstalk. The test specimen was then subjected to a sinusoidal vibration level of 0.5 inch double amplitude from 10 to 34 CPS and ± 30 g peak from 34 to 2000 CPS at a sweep rate of 7 minutes per octave.

   This test procedure was repeated for vibration excitation in the "Y" or minor horizontal axis while measuring Z axis crosstalk levels. Vibration time was one hour per axis for a total of 2 hours.

C. Test Results

The test specimens were vibrated as indicated above with all test data recorded by General Atomics personnel. Vibration crosstalk was recorded in the minor or "Y" axis when vibrated in the "Z" of vertical axis and similarly in the "Z" axis when vibrated in the horizontal "Y" axis. This information is tabulated in Appendix II. Appendix III identifies Axis of Vibration.

D. Revisions

1. Revised Quantity of Samples Tested from Ten to Twenty-Two on Pages 1 and 2.

E. Signatures

Test conducted by Harlan K Good
Harlan K. Good
Test Engineer

State of California
County of San Diego

J. F. Schroepfer, being duly sworn, deposes and says: that the information contained in this report is the result of complete and carefully conducted tests and is to the best of his knowledge true and correct in all respects.

J. F. Schroepfer
J. F. Schroepfer,
Supervisor
Environmental Laboratory

Subscribed and sworn to before me this 7th day of April 1964.

Florence E. Hrvatin
Florence Hrvatin

Notary Public in and for the County of San Diego, State of California

My commission expires:

February 24, 1968

FLORENCE E. HRVATIN
NOTARY PUBLIC · CALIFORNIA
PRINCIPAL OFFICE IN
SAN DIEGO COUNTY

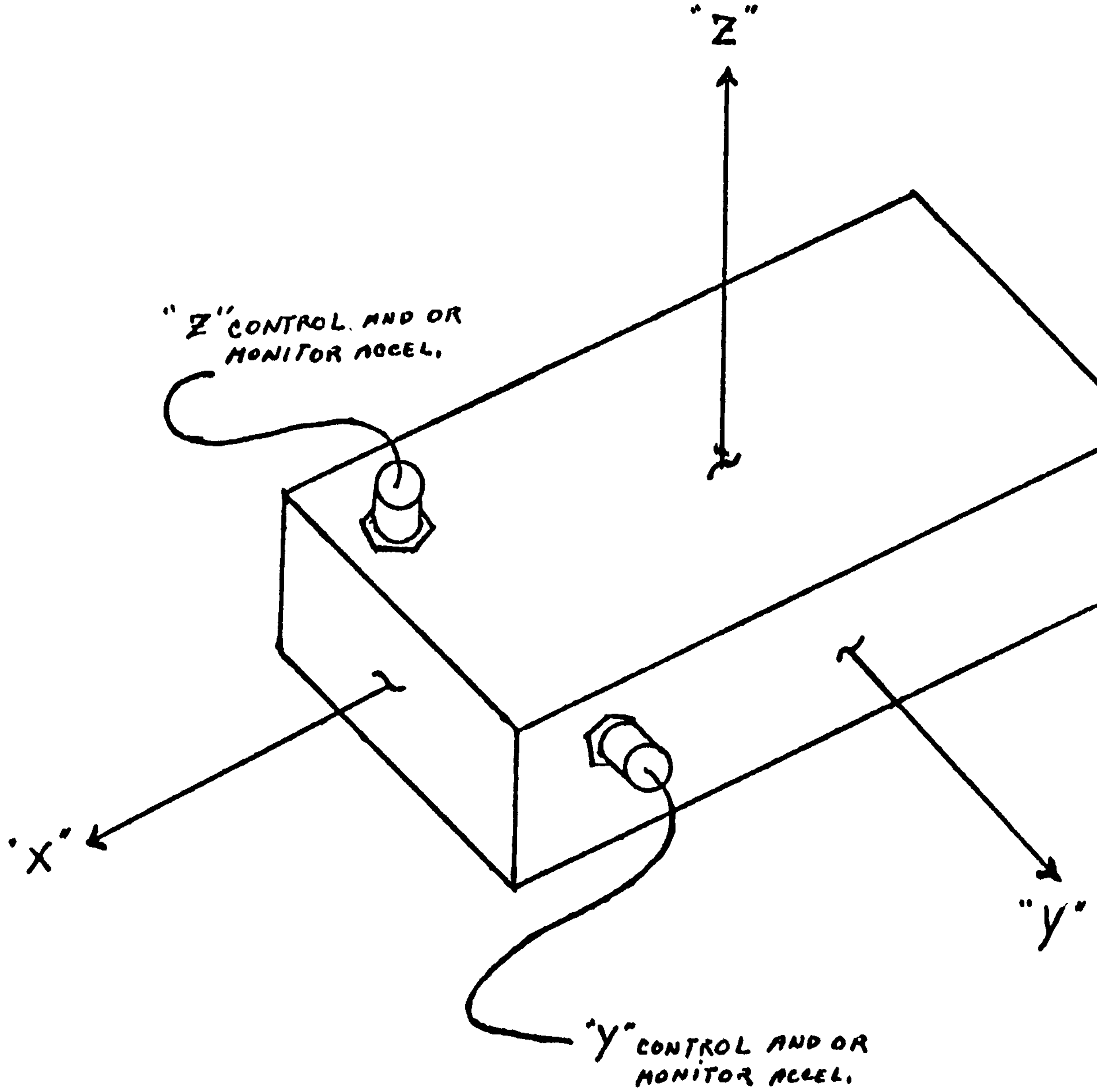
APPENDIX I

TYPE OF TEST	DESCRIPTION	MANUFACTURER	MODEL	RYAN ASSET NO. or SERIAL NO.	CALIBRATION DUE DATE
Vibration	Vibration System	M/B	EL-250	2-32301	3-8-64
Vibration	Transducer System	Endevco	2213	1960-173	3-27-64
Vibration	Amplifier	Endevco	2614	2-32937	1-2-64
Vibration	AC Volt Meter	Hewlett/Packard	400HR	2-31021-1	11-21-63
Vibration	Scope	Hewlett/Packard	120A	2-30777	1-23-64
Vibration	Servo Control	M/B	N-572-1	2-32301-2	3-8-64

APPENDIX II

FREQUENCY (CPS)	CROSSTALK - "g's" "Y" AXIS (Excitation in "Z" Axis)	"Z" AXIS (Excitation in "Y" Axis)
50	5.0	9.0
70	5.0	13.0
100	9.0	20.0
150	10.0	28.0
200	12.0	29.0
250	13.0	32.0
300	14.0	36.0
400	15.5	34.0
500	16.0	33.0
700	18.0	19.0
1 KC	18.0	12.0
1.5 KC	15.0	8.0
2.KC	13	3.0

APPENDIX III



Volume II

HANDLING OF SNAP-15A FUEL CAPSULES AND FUELED GENERATORS WITHIN GENERAL ATOMIC

by

F. Bold, R. W. Dexter, W. G. Homeyer, and W. E. Sargent

CONTENTS

I. INTRODUCTION

The SNAP-15A thermoelectric generator is being developed by General Atomic for the U.S. Atomic Energy Commission. It utilizes the nuclear heat produced by the α-decay of Pu^{238} sealed in a double capsule to provide about 1 mw of electrical power at a minimum of 4.5 v for a period of 5 yr.

The safe use of Pu^{238} requires special care in handling the fuel capsules and the fueled generators. The steps to be followed from the time the fuel capsules are received by General Atomic until they are sent out to the user in generators are set forth in this manual. Section II contains a description of the SNAP-15A generator and its fuel capsule. Section III describes the facilities and equipment used for the handling of fuel capsules and fueled generators. Section IV presents detailed step-by-step procedures for various phases of the handling of the capsules and generators.

II. DESCRIPTION OF GENERATOR

The SNAP-15A generator, shown in the frontispiece, is 2.5 in. in diameter and 5 in. long. The fuel capsule is surrounded by thermal insulation to reduce the loss of heat. The hot junctions of the thermocouples are next to the fuel capsule, while the cold junctions are held against the stainless steel disks, which serve as a thermal mass to reduce the effects of temperature transients.

The fuel capsule is in the form of a double capsule. The inner capsule is made of tantalum and the outer capsule of Haynes-25 alloy. The inner and outer capsules are independently sealed by fusion welds.

The dose rate from neutrons and gamma rays at the surface of the fueled generator has been measured to be about 10 mrem/hr, and that at 1 ft from the fuel to be less than 8.8 mrem/hr. The dose rate at the surface of the fuel capsule has been estimated to be about 1000 mrem/hr.

III. SPECIAL EQUIPMENT AND FACILITIES

A large amount of special equipment is used to assure safe handling of the SNAP-15A capsules and generators. Some of this equipment directly controls the hazards of inhalation or ingestion of the Pu^{238} or of over-exposure to ionizing radiation. Other equipment contributes indirectly to safety by increasing the ease and speed of performing the necessary handling operations.

RESTRICTED AREA

The restricted area for handling of the SNAP-15A capsules and generators is a room within a room as shown in Fig. 1. Doors of both the inner and outer rooms are equipped with locks.

The restricted area is a completely enclosed room with provisions for containment of radioactive material in the event of any accident. The room is maintained at a slightly negative pressure, and the hood and glove box is vented through a high-efficiency air filter.

The room contains the following equipment:

1. Hood
2. Dry box
3. Safe.

The hood, which contains the hot and cold chambers for the life test, is a standard chemistry-laboratory type with a vertical sliding glass door.

The dry box consists of a 2 ft × 2 ft × 3 ft glove box to be used for assembling fuel capsules into generators. The box is fitted with an air-lock type of entrance for inserting the capsules and generators.

The safe is a standard type with a capacity for holding at least 30 generators.

HEALTH PHYSICS EQUIPMENT

The Health Physics counting equipment has a sensitivity of 3 $\mu\mu$C of α and 15 $\mu\mu$C of $(\alpha+\beta)$. It consists of an Eberline SAC-3-alpha counting system,

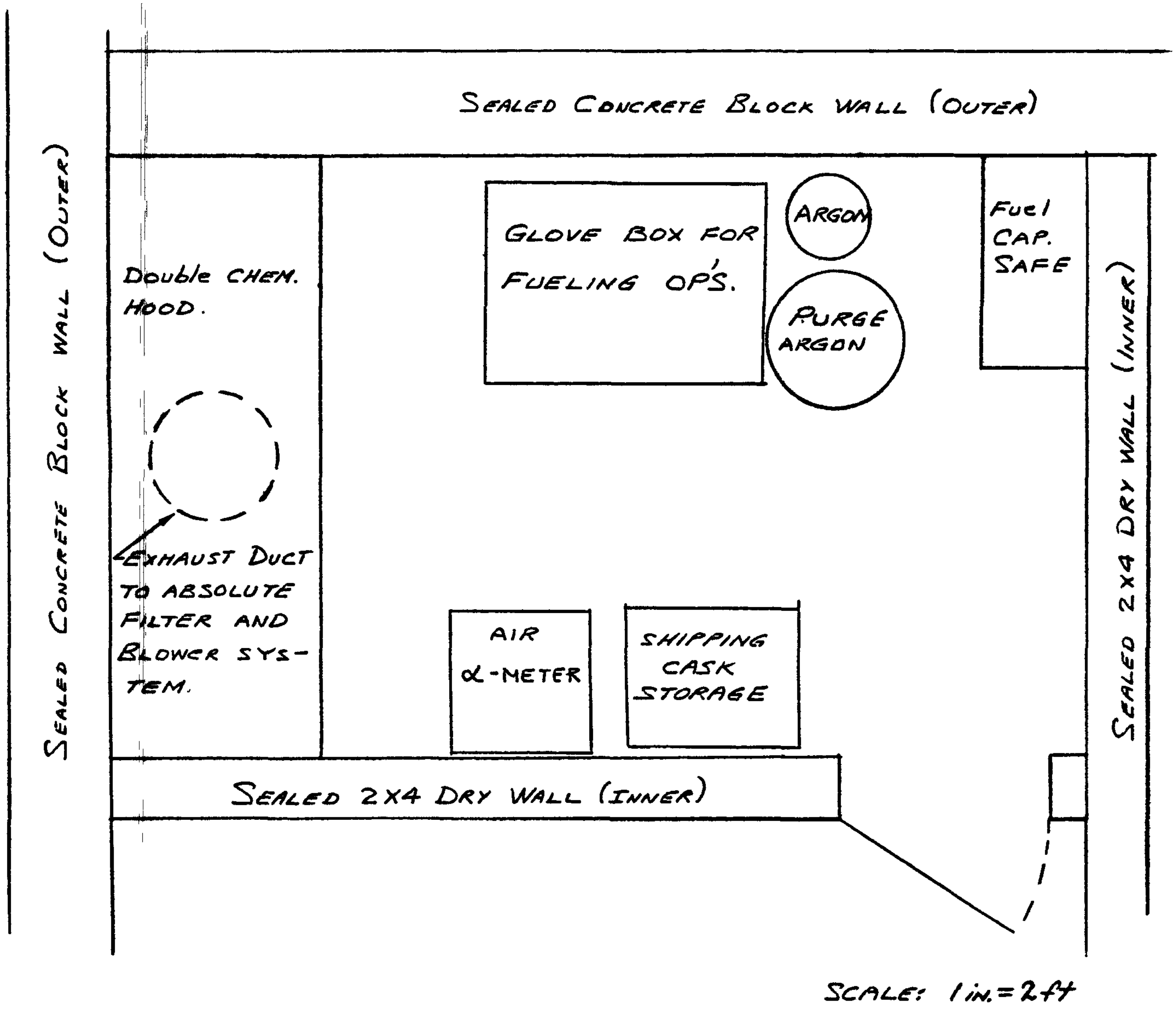


Fig. 1--Room for handling SNAP-15A generators

or equivalent, modified to be used with a ZnS alpha phosphor and a Pilot B plastic phosphor.

An Eberline PAC-1SA portable alpha scintillation counter, or equivalent, is used for surveying personnel and packing materials.

Air samples are collected and periodic wipe surveys are made by a Health Physics Surveyor.

CAPSULE SHIPPING CONTAINER

The shipping container for the fuel capsules, which has been approved under Bureau of Explosives Permit No. 1764, consists of a steel outer can, which can be locked, and a sealed aluminum inner can. Up to eight capsules can be contained in the inner can.

GENERATOR SHIPPING CONTAINER

The shipping container for the generator is shown in Fig. 2. The outer steel can is sealed by an O-ring and serves as an additional air-tight enclosure for the fuel under normal conditions and as a fire wall in the event of a serious fire. The inner steel can, which is separated from the outer can by thermal insulation, serves as a heat sink to limit temperature transients from a fire. A voltmeter is supplied in the lid of the inner can to allow the electrical output of the generator to be checked before the generator is completely unpacked. This meter measures the voltage output of the generator to a 20,000-Ω resistive load.

KIT FOR FUELING AND SEALING GENERATOR

The tools and parts that will be used to fuel and seal the generator are listed below. They are shown in Fig. 3.

1. Capsule diameter gauge.
2. Stand for capsule diameter gauge.
3. Capsule insertion tool.
4. Counter-torque plug driver.
5. Plug for capsule holder (Print No. 354-06-202).
6. Plug for fueling port (Print No. 354-06-001).
7. Plug for lower insulation (Print No. 354-06-405).
8. Epoxy kit.
9. Container for mixing epoxy and mixing stick.
10. Wiping cloths (e.g., Kimwipes).

Fig. 2--SNAP-15A generator and shipping container

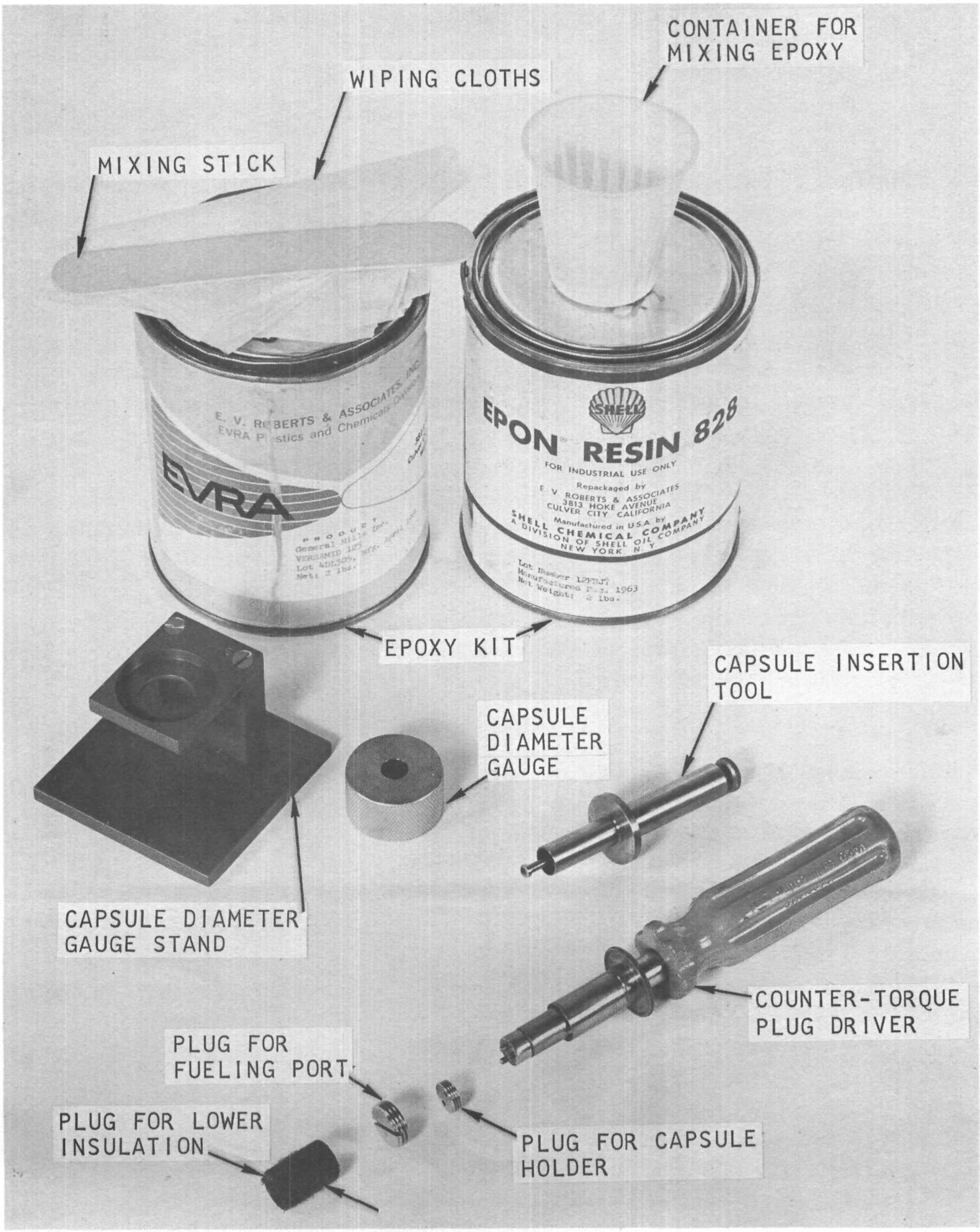


Fig. 3--Tools and materials for fueling and sealing SNAP-15A generators

IV. HANDLING PROCEDURES

The fuel capsules and fueled generators will always be kept in the safest environment consistent with their use at the time. Specifically, they will be stored in a shipping container and locked in the safe in the restricted area whenever they are not being used. They will be removed from their shipping containers only when necessary, and then only in the glove box or hood in the restricted area, in accordance with the procedures outlined below. A member of the General Atomic Health Physics Group will supervise all handling of capsules and generators outside of their shipping containers.

Capsules and generators will be wiped and monitored for α-activity as described below whenever their surfaces are exposed by unpacking and before they are repacked for storage or shipment; additional wipes will be taken during and after testing. The voltage of the generator will also be checked at these times according to the procedures outlined below in steps C and D. The results of all wipe and voltage checks will be recorded in the log. This log book will be a standard General Atomic log book, and will be retained by the Document Center as a permanent record.

If leaking of a source is confirmed, the capsule or generator in question will be packed in the appropriate shipping container and its ultimate disposition will be determined by the Atomic Energy Commission.

The detailed procedures for routine handling of the capsules and generators are outlined in steps A through E below. Checklists similar to those appended to this manual will be filled out as each operation is performed. Boxes will be checked after each step is performed, and the values of voltages and α-counts and other information will be recorded in the spaces provided. The completed checklists will be fastened into the log.

A. RECEIPT OF CAPSULES

1. A member of the Health Physics Group will be present.
2. A wipe will be made of the entire outside surface of the shipping container. If the α-activity is 6 $\mu\mu$C or less, the Health Physics Surveyor will release the delivery vehicle. If the α-count is higher than 6 $\mu\mu$C, a survey of the delivery vehicle will be made.
3. The shipping container will be placed into the glove box.

B. UNPACKING OF CAPSULES

1. A member of the Health Physics Group will be present.
2. The lid of the shipping container will be removed, and the packing material will be checked with a portable α scintillation counter.
3. If there is no detectable activity on the packing material, the inside shipping container will be opened and the inside of the lid will be wiped.
4. If the wipe of the inside of the lid over the capsule indicates α-activity of 6 $\mu\mu$C or less, the capsules will be removed one at a time, and a wipe will be made over the entire surface of each capsule. If the α-activity on the wipe is less than 10 $\mu\mu$C, the capsule will be considered not to be leaking.

C. PACKING OF GENERATORS

1. A member of the Health Physics Group will be present.
2. A wipe will be taken over the entire outside surface of the generator.
3. If the α-activity on the wipe is 6 $\mu\mu$C or less, the generator will be placed into the shipping container and the inner lid will be closed and the voltmeter attached.
4. The voltmeter reading will be recorded and the container will be sealed.
5. After the shipping container is sealed, a wipe will be taken over the entire outside surface of the container. If the α-count is 6 $\mu\mu$C or less, the container will be removed from the glove box.

D. UNPACKING OF GENERATORS

1. A member of the Health Physics Group will be present.
2. A wipe of the entire outside surface of the shipping container will be made as the container is removed from the safe. If the α-activity on the wipe is 6 $\mu\mu$C or less, the shipping container will be placed into the glove box.
3. The outer lid of the shipping container will be removed and the reading of the voltmeter will be recorded. If there is a voltage drop of more than 5%, additional wipes will be made as directed by the Health Physics Surveyor.

4. The inner lid of the shipping container will be removed, and a wipe will be taken of the exposed surface of the generator. If the α-activity on the wipe is 6 $\mu\mu$C or less, the generator will be removed from the shipping container.
5. After removal from the shipping container, a wipe will be taken over the entire surface of the generator. If the α-activity on the wipe is 6 $\mu\mu$C or less, the source will be considered to be intact.

E. FUELING OF GENERATORS

The generator will be fueled and sealed while it is in the glove box. The procedures for unpacking capsules (step B) and packing generators (step C) will be followed, and the check lists for these procedures will be filled out along with the check list for fueling the generator.

1. A Health Physics Surveyor will be present.
2. All necessary equipment will be placed in the glove box, including:
   a. The generator;
   b. The kit for fueling the generator;
   c. The capsule shipping container;
   d. A No. 20 Allen wrench;
   e. The generator shipping container; and
   f. A socket wrench.
3. The capsule handling tool will be inserted into the fuel opening in the generator. If it does not pass freely until the shoulder on the tool seats on the end of the generator, no further steps will be performed until the generator is removed and tested.
4. The glove box will be sealed and the fuel capsules unpacked following the steps outlined in step B.
5. The capsule will be picked up with the capsule tongs and its serial number will be noted.
6. The capsule will be passed through the check bushing on the capsule diameter gauge. If it does not fall through freely, it will be returned to the shipping container and steps E5 and E6 will be repeated with another capsule.
7. The capsule will be placed in the cup end of the insertion tool with the weld facing out. It will be pressed lightly into place with the handling tongs.
8. The capsule insertion tool will be held in one hand, with the capsule held vertical and facing up. The capsule will be inserted upward into the fuel opening in the generator until the shoulder of the insertion tool is seated against the end of the generator.

9. The generator will be turned over so that the insertion tool is on top.
10. The capsule will be ejected from the insertion tool by pressing down the knockout pin on the capsule holder until it is flush with the handle.
11. The capsule handling tool will be withdrawn.
12. The capsule retaining plug will be inserted and tightened with the special tool for this purpose.
13. The plug of insulation will be inserted.
14. The lid will be fastened in place.
15. The capsule shipping container will be repacked and sealed.
16. The generator will be packed in its shipping container according to the procedure described in step C.

Appendix

CHECKLISTS FOR HANDLING CAPSULES AND GENERATORS

Checklist for Receipt of Capsules

1. Member of Health Physics Group - Name (Print) ____________________

   Signature ______________________.

2. α-Count _____________

3. ☐

   Remarks:

Checklist for Unpacking of Capsules

1. Member of Health Physics Group - Name (Print) ____________________

   Signature ____________________.

2. α-Count ____________

3. α-Count ____________

4. Capsule No. ________, α-Count ____________.

   Capsule No. ________, α-Count ____________.

   Capsule No. ________, α-Count ____________.

   Capsule No. ________, α-Count ____________.

   Capsule No. ________, α-Count ____________.

   Capsule No. ________, α-Count ____________.

   Capsule No. ________, α-Count ____________.

   Capsule No. ________, α-Count ____________.

   Remarks:

Checklist for Packing of Generators

1. Member of Health Physics Group - Name (Print) ____________________

   Signature ____________________
2. α-Count ____________.
3. ☐
4. Voltmeter reading ______________. Sealed? ☐
5. α-Count ____________.

   Remarks:

Checklist for Unpacking of Generators

1. Member of Health Physics Group - Name (Print) ____________________

   Signature ____________________

2. α-Count ____________. In glove box? ☐
3. Voltmeter reading ______________.
4. α-Count ____________.
5. α-Count ____________.

   Remarks:

Checklist for Fueling of Generators

1. Member of Health Physics Group - Name (Print) ____________________

   Signature ____________________.

2. Equipment Present - a. ☐, b. ☐, c. ☐, d. ☐,

   e. ☐, f. ☐

3. Pass: ☐

4. Is Checklist for Unpacking of Capsule attached? ☐

5. Serial number ____________.

6. Clear? ☐ Numbers of rejected capsules ____________.

7. ☐

8. ☐

9. ☐

10. ☐

11. ☐

12. ☐

13. ☐

14. ☐

15. Sealed? ☐

16. Is Checklist for Packing of Generators attached? ☐

    Generator Number ____________.

Remarks:

VOLUME III

SNAP-15A USER'S HANDLING MANUAL

by

R. J. Campana, F. Bold, R. W. Dexter,
W. G. Homeyer, and W. E. Sargent

CONTENTS

Appendix

I. INTRODUCTION

The SNAP-15A thermoelectric generator was developed by General Atomic Division of General Dynamics Corporation for the USAEC to provide about one milliwatt of electrical power at a minimum of 4.5 volts for a period of 5 yr. It derives its power from the thermal energy released in the decay of the artifically produced radioistope, Pu^{238}.

The principal components of the generator can be seen in the cutaway view in the frontispiece. The view shows the isotopic heat source of the fuel capsule, capsule holder, insulation, thermopile (with its associated output leads), and electrical connector. These are the components essential to the electrical power production under static conditions. A block of stainless steel designated the thermal capacitor and connected to the cold end of the thermopiles is an additional feature which prevents load voltage fluctuations to large environmental thermal transients.

The converter utilizes metallic thermocouples to transform heat into electrical energy. Thirteen hundred thermocouple wires, each 2 mils in diameter and 1-1/2 in. long are arranged into a bundle, or thermopile. The end of the thermopile to be heated is joined to the isotope-containing capsule. The heat is produced by the decay of Pu^{238}, maintaining one end of the thermopile at an elevated temperature. The opposite end of the thermopile is held at a lower temperature, since it is in close thermal contact with the outer shell of the device. The temperature difference impressed on the thermopile is the driving force that produces electrical output.

Thermal insulation is of exceptional importance to efficient operation. Heat which flows directly to the walls of the device escapes the conversion process. A thick blanket of Min-K insulation surrounds the isotope source to minimize heat leakage.

Approximately 3 g of Pu^{238} supply the normal thermal power input of 1.65 thermal watts. The plutonium is contained in a double-walled fuel capsule. The inner liner or inner capsule is composed of tantalum metal hermetically sealed by welding. The tantalum capsule in turn is contained within a Haynes-25 alloy capsule. The fuel capsule is mechanically held in place in the generator by an aluminum capsule holder. Finally, the generator is enclosed by an aluminum canister hermetically sealed with epoxy resin.

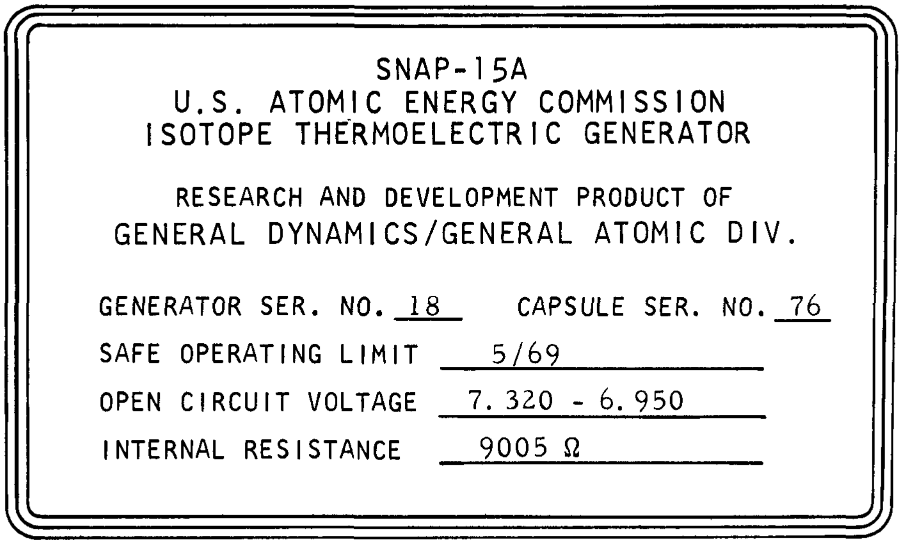
The name plate as it appears on the generator is shown in Fig. 1 and contains vital information about the generator. The generator serial number references the complete history of the generator, including all aspects of materials and fabrication. Similar information is provided with respect to the fuel capsule and may be traced through the capsule number. In addition, the fuel capsule loading, date of sealing, and life limit information are available through the capsule serial number. Information is stored in permanent records maintained at General Atomic. The safe life limit indicated on the name tag indicates 5 yr from the date on which the capsule was sealed and calorimetered with its plutonium fuel. This is considered to be the safe design life of the fuel capsule. The open-circuit voltage indicated on the name plate was measured at the beginning of the generator life. The lower limit to the open-circuit voltage range given is the open-circuit voltage expected at the end of the generator life as a result of decay of the plutonium heat source. If the open-circuit voltage, as measured, at any time during the life of the generator falls outside of this range, then either (1) the internal resistance of the generator has changed from short or open circuiting or (2) the fuel is leaking from the fuel capsule. The internal resistance of the generator is marked on the name plate and may be compared at any time with measured values to determine whether open or short circuiting has occurred in the thermopile. If loss of fuel from the fuel capsule is suspected for any reason, the procedures for safe handling given below should be followed.

There are two potential hazards, both related to the fuel capsule: (1) the decaying Pu^{238} emits gamma and fast neutron radiations that escape the generator, and (2) Pu^{238} may escape the fuel capsule and become a hazard if inhaled or ingested. Therefore, the fuel capsules in generators have been subjected to a series of tests designed to prove their inherent safety features. Dose rates measured at the surface of a generator are given in Table 1. The generators have been subjected to the environmental qualification tests listed in Table 2, and the fuel capsules have been subjected to the tests enumerated in Table 3. While the generators have been designed to be safe and have been proof-tested under severe conditions, the ultimate safety and the use of these generators depends upon the proper handling and constant checking to ensure their continuation in the safe condition. It is the purpose of this manual to set down the basic handling and shipping procedures to be followed to ensure safe use.

The basic safety rules to be followed are discussed in Section II. The control procedures required to prevent loss or mishandling of the generators are described, andthe tests designed to detect the presence of a leaking source are discussed.

Section III describes radiation-measuring equipment and the shipping container.

Section IV gives the detailed procedures for performing certain routine operations in handling of the generators. The procedures for packing and unpacking the generator are described, as well as the methods of performing the wipe tests for contamination and voltage tests to detect malfunctioning of the generator.



SNAP-15A
U.S. ATOMIC ENERGY COMMISSION
ISOTOPE THERMOELECTRIC GENERATOR

RESEARCH AND DEVELOPMENT PRODUCT OF
GENERAL DYNAMICS/GENERAL ATOMIC DIV.

GENERATOR SER. NO. 18 CAPSULE SER. NO. 76
SAFE OPERATING LIMIT 5/69
OPEN CIRCUIT VOLTAGE 7.320 - 6.950
INTERNAL RESISTANCE 9005 Ω

Fig. 1--Example of SNAP-15A generator name plate

Table 1

DOSE RATE MEASUREMENT OF SNAP-15A GENERATOR
(Fuel Capsule 76)

Position	Distance From Fuel Center (cm)	Dose Rate		
		Gamma (mr/hr)	Neutron (mrem/hr)	Total (mrem/hr)
Top	4.1	3.3	3.2	6.5
Side (0°)	3.3	6.4	3.9	10.3
Side (180°)	3.3	6.3	4.2	10.5
Bottom	8.6	0.37	0.21	0.58

Table 2

ENVIRONMENTAL QUALIFICATION TESTS

Thermal shock	-65° to +165°F in <5 min.: 6 cycles.
Mechanical shock	11-msec pulse of 100 *g*: 3 shocks in 2 directions along orthogonal axes.
Vibration	32 to 2000 cps at 10 *g* for 60 min.
Constant acceleration	60 *g* for 5 min.
Irradiation	100 R in <160 μsec.
Humidity	93% relative humidity at 149°F, 10 48-hr cycles.

Table 3

FUEL CAPSULE SAFETY TESTS

Fire	Heated to 2000°F and quenched in tap water: 2 cycles.
Thermal Shock	+500° to -100°F in 10 sec: 2 cycles.
~~Burst~~	~~1700°F at 7000 psi, 2000°F at 3000 psi.~~
Impact	200 fps (136 mph) onto granite.
Vibration	10 to 2000 to 10 cps for 3 hr at 30 *g*.
Hammer	10 ft-lb blow.
Salt Water Corrosion	Ocean water exposure for 3 months.
Fresh Water Corrosion	Tap water exposure for 1 week.
Air Corrosion	Humid air exposure for 1 week.

II. BASIC SAFETY RULES

The SNAP-15A generator can be used safely only if all phases of handling and shipping are carefully controlled. Close control is necessary to prevent mishandling or loss of the generator and to eliminate, as far as possible, the danger of an accident which could damage the generator and its fuel capsule. An additional precaution that must be taken is the perfomance of certain tests designed to detect a leaking fuel capsule. If these precautions are taken, the SNAP-15A generator can be used with negligible risk.

A. CONTROL OF HANDLING AND SHIPPING

All handling and shipping of the generators should be supervised by a competent individual who is fully aware of the hazards involved and the procedures that must be followed. This person will be responsible for enforcing adherence to the detailed procedures outlined in Section IV of this manual and for developing and implementing a program to provide both convenience and safety in the use of the generators. This program should include confinement of the generator to restricted areas with limited personnel access. It should also provide for the maintenance of complete records of each generator to protect against overuse of the generator (5-yr design life), and to detect the start of malfunctioning (reduced voltage and power output) that might indicate the leaking of a capsule. The program should also enforce compliance with the detailed procedures contained in Section IV and with all pertinent regulations of the Interstate Commerce Commission and Bureau of Explosives.

B. TEST FOR LEAKING CAPSULE

There are two tests for the effects of a leaking fuel capsule that should be performed at certain times. The voltage test is the simplest to perform, and will probably indicate generator malfunction from a leaking source long before there is any detectable α contamination external to the generator. The wipe test for α contamination, while it is less likely to give the first indication of a leaking source, is nevertheless important, since it is certain to detect α contamination on the outside of the generator where it may represent a health hazard. These two tests should be performed at the times specified in Section IV and periodically while the generator is in use. The frequency at which the tests should be performed must be determined for each application by a qualified health physicist on the basis of exposure of personnel to the generator and its surroundings.

III. EQUIPMENT FOR MONITORING AND SHIPPING

A. HEALTH PHYSICS EQUIPMENT

The health physics counting equipment will have a sensitivity of 3 $\mu\mu$C of α and 15 $\mu\mu$C of $(\alpha+\beta)$. It will consist of an Eberline SAC-3 α-counting system, or equivalent, modified to be used with a ZnS α phosphor and a Pilot B plastic phosphor. An Eberline PAC-1SA portable α scintillation counter, or equivalent, will be used for surveying personnel and packing materials. Air samples will be collected and periodic wipe surveys will be made by a Health Physics Surveyor.

B. GENERATOR SHIPPING CONTAINER

The shipping container for the generator is shown in Fig. 2. The outer steel can is sealed by an O-ring and serves as an additional air-tight enclosure for the fuel under normal conditions and as a fire wall in the event of a serious fire. The inner steel can, which is separated from the outer can by thermal insulation, serves as a heat sink to limit temperature transients from a fire. A voltmeter is supplied in the lid of the inner can to allow the electrical output of the generator to be checked before the generator is completely unpacked. This meter measures the voltage of the generator to a 20,000-Ω resistive load.

Fig. 2--SNAP-15A generator and shipping container

IV. DETAILED PROCEDURES

The generators will always be kept in the safest environment consistent with their use at the time. Specifically, they will be stored in a shipping container and locked in a safe in a restricted area whenever they are not being used. They will be removed from the shipping container only when necessary to be placed in operation. One person will be assigned and will supervise all handling of generators outside of their shipping containers. Generators will be wiped and monitored for α-activity as described below whenever their surfaces are exposed by packing and unpacking for storage or shipment; additional wipes will be taken during and after use. The voltage of the generator will also be checked at these times according to the procedures outlined below. The results of all wipe and voltage checks will be recorded in a log book. The log book will be maintained as a permanent record. If leaking of a capsule is confirmed, the generator in question will be packed in the appropriate shipping container and its ultimate disposition will be determined by the Atomic Energy Commission. The detailed procedures for routine handling of generators are outlined in steps A through D below. Checklists similar to those appended to this manual will be filled out as each operation is performed. Boxes will be checked after each step is performed, and the values of voltages and α-counts and other information will be recorded in the spaces provided. The completed checklists will be fastened into the log book.

A. RECEIPT OF GENERATOR

1. A Health Physics Surveyor will be present.

2. A wipe of the entire outside surface of the shipping container will be made. If the α-activity on the wipe is 6 $\mu\mu$C or less, the generator may be unpacked.

B. UNPACKING GENERATOR

1. A Health Physics Surveyor will be present.

2. The outer lid of the shipping container will be removed and the reading of the voltmeter will be recorded. If there is a voltage loss of more than 5%, additional wipes will be made as directed by the Health Physics Surveyor.

3. The inner lid of the shipping container will be removed, and a wipe will be taken of the exposed surface of the generator. If the α-activity on the wipe is 6 $\mu\mu$C or less, the generator will be removed from the shipping container. After removal of the generator from the shipping container, a wipe will be taken over the entire surface of the generator. If the α-activity on the wipe is 6 $\mu\mu$C or less, the source will be considered to be intact.

C. MAINTENANCE OF GENERATOR

The generator is designed to operate 5 yr continuously without maintenance. However, during the life of the generator, a wipe will be taken over the entire surface of the generator at intervals specified by a competent health physicist. If the α-activity on the wipe is 6 $\mu\mu$C or less, the generator will be regarded as safe for continued use.

D. PACKING GENERATOR

1. A Health Physics Surveyor will be present.

2. A wipe will be taken of the entire surface of the generator.

3. If the α-activity on the wipe is 6 $\mu\mu$C or less, the generator will be placed into the shipping container and the inner lid will be closed and the voltmeter attached.

4. The voltmeter reading will be recorded and the container will be sealed.

5. After the shipping container is sealed, a wipe will be taken over the entire surface of the container. If the α-count is 6 $\mu\mu$C or less, the container and generator may be stored or shipped. The generator may be shipped within its shipping container via all commercial or military carriers.

Appendix

CHECKLISTS FOR HANDLING GENERATORS

Checklist for Receipt of Generators

1. Health Physics Surveyor - Name (Print) ______________________________
   Signature ____ .
2. α-Count ________________
3. ☐

Remarks:

Checklist for Unpacking of Generators

1. Health Physics Surveyor - Name (Print) ______________________________

   Signature ___________________________________.

2. α-Count _________________. In glove box? ☐

3. Voltmeter reading _________________.

4. α-Count _________________.

5. α-Count _________________.

   Remarks:

Checklist for Packing of Generators

1. Health Physics Suveryor - Name (Print) ____________________
   Signature ____________________.
2. α-Count ____________.
3. ☐
4. Voltmeter reading ____________. Sealed? ☐
5. α-Count ____________.

Remarks: