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NUCLEAR SAFETY TEST REPORT
FOR THE SPACE VERSION OF THE
PRESENT SNAP III THERMOELECTRIC
GENERATOR

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I INTRODUCTION

This report has been prepared to present results and conclusions of an experimental program conducted to evaluate the nuclear safety for a space version of the present SNAP III thermoelectric generator

The report first defines a space safety design criterion on which the design changes and test development for the generator system is predicated. This criterion, general design changes and detailed test specimen specifications are presented in Section II. Test development is presented in Section III, procedures and results are given in Section IV. Finally, conclusions and recommendations, based on test results, are made in Section V.

In this program, two generator configurations and a re-entry burnup fuel core design are tested and evaluated in three experimental environments.

II TEST SPECIMEN DESIGN

The increasing requirements for electrical power in space has prompted the development of a space version of the existing SNAP III Isotopic powered thermoelectric generator. Although this generator has been proven nuclear safe for ground operations, studies of the system were made to determine what design changes, if any, are necessary to achieve a nuclear safe space version. This is accomplished by establishing a space safety design criteria, from which a design specification is deduced to meet all safety requirements under any conceivable condition.

Once these have been determined, design changes are incorporated into the system, and a series of test specimens are fabricated. These are utilized to investigate the safety integrity of the generator system when it is subjected to the most stringent framework of conditions, in terms of internal and external mechanical, thermal and chemical forces.

In this program, 24 test assemblies of two different generator configurations and one fuel containment capsule design are investigated for system safety.

This section presents the space safety design criteria, general design specifications, and detail test specimen specifications utilized for the safety test analysis of the SNAP III space generator.

A Space Safety Design Criteria

The main environmental hazard resulting from the use of isotopic powered generators is that posed by the radiological effects of the radionuclide fuel when released to the biosphere. Therefore, the design criteria for this structure are dependent on the fate of the radionuclide fuel under all conceivable conditions, operational or accidental.

Since the unit is to be utilized on a space mission, the fate of the fuel must be considered on two different environments; the biosphere and space.

In the biosphere, nuclear safety requirements dictate only one alternative for the fate of radionuclide fuel. That is, absolute fuel containment under any conceivable operational or

accidental condition. However, because of the active nature of the radionuclide fuel, this mandate is dependent upon time. Thus, design criteria for this structure in the biosphere is established as absolute fuel containment during its effective fuel lifetime.

In space, several alternatives may be presented for the fate of the fuel, including:

- (1) Dispersion as small particles at altitudes above 100,000 feet resulting from unit burnup by aerodynamic heating and oxidation.
- (2) Intact contained re-entry.
- (3) Dispersion at orbital altitude as a result of unit destruction in orbit.
- (4) Prolongation of orbital lifetime.

Of these, the present safety philosophy favors the first alternative; that of dispersion at altitudes above 100,000 feet, resulting from unit burnup by aerodynamic heating and oxidation. This establishes the design criteria for the structure in space.

Once the fate of the fuel is established in all possible environments, a safety design criteria for the generator system can be determined. For the space generator, these are:

- (1) Biological shielding of sufficient magnitude to permit handling the unit from shipment to launch.
- (2) Absolute fuel containment from the time of unit fabrication to fuel lifetime if the unit remains in the biosphere or to the time of ignition of the injection stage of the missile if the unit is flown.
- (3) Dispersion of fuel above 100,000 feet altitude by aerodynamic heating and oxidation of the unit upon re-entry from orbital altitude.

B General Design Specifications

The SNAP III space generator is to produce 3.5 watts of electrical power, in a space environment, by utilizing the heat

produced by the radioactive decay of Polonium-210. General Design specifications for this system are given below:

1 Mechanical

The spectrum of all destructive mechanical forces investigated to establish a nuclear safe and operative assembly, revealed that the maximum conditions would be:

- (a) Forces imposed when impacted on a rigid medium at terminal velocity
- (b) Shock forces imposed by exploding missile propellants
- (c) Acceleration forces of 12 g's in the longitudinal axes and 2 g's in the lateral axes, vibration forces of 400 - 3000 cps at 20 g's, and shock forces of 40 g's in all planes imposed by the space vehicle before injection into space

Therefore, the design mechanical specifications for developing a nuclear safe and operative assembly are to maintain structural integrity when subjected to the forces indicated above

2 Thermal

Thermal specifications for the SNAP III space generator are:

- (a) Complete burnup upon re-entry from orbital altitude above 100,000 feet by aerodynamic heating and oxidation.
- (b) Maintain structural integrity at operating temperature
- (c) Contain the radionuclide fuel when subjected to a thermal environment equivalent to that of a burning missile with a full fuel load
- (d) Contain the radionuclide fuel when subjected to thermal shock forces imposed to a thermally hot assembly immersed in cryogenic liquids

- (e) Transfer sufficient heat to thermo-electric elements so that the electrical output requirement is maintained.

3 Chemical

Design chemical specifications are:

- (a) Remain operative and structurally integrated when subjected to atmospheric elements such as those encountered in Continental United States
- (b) Contain the radionuclide fuel for a specific length of time, at operating temperatures, when subjected to the corrosive action of chemical agents listed below:

<u>Chemical Agent</u>	<u>Min. Containment Time</u>
Sea Water	1600 days (4.4 yrs)
Red Fuming Nitric Acid	1 day
Liquid Oxygen	1 day
Air Oxidation (Temperatures above 2000°F)	1 day
RPI	1 day
Radionuclide Fuel, Polonium	1600 days (4.4 yrs)
Lead	1600 days (4.4 yrs)

C Detail Test Specimen Specifications

SNAP III space generator test specimens of heterogeneous designs are fabricated to ascertain unit integrity. These include 24 test assemblies of two different generator configurations and one fuel containment capsule configuration.

The following is a description and discussion of the pertinent safety aspects of these various configurations. No

reference is made to operation of the system, since the test program being reported is principally concerned with nuclear safety.

1 Generator Configuration

The two designs for the space SNAP III generator utilized in this test program are:

- (1) Original SNAP III copper shell generator.
- (2) Original SNAP III configuration with an aluminum shell replacing the copper

The latter design is tested to ascertain unit integrity of an aluminum generator should it be required for better aerodynamic burnup characteristics.

Design specifications of these configurations are given in Table 1. Detailed test specimen specifications are in Table 2. The copper shell generator is referred to as design number A-AC and the aluminum as C-AA.

2 Containment Capsule

A single containment capsule design is utilized in this program. It is of the same configuration of the original molybdenum capsule; but it is fabricated from Haynes Alloy No. 25, and the original pin plug is replaced with a welded screw plug. The former change is made to assure aerodynamic burnup of the capsule, and the latter, to meet the more strenuous structural requirements of the space generator.

Design specifications of this design are given in Table 1. Detailed test specimen specifications are in Table 2. It is designated as design number B-CH.

3 Material Selection

Copper was originally chosen as the generator enclosure material because of its thermal conductivity characteristics. However, as the concept of post-orbital re-entry of fuel cores evolved to one of fuel burnup in the upper atmosphere, this material, requiring high heat inputs for meltdown, became less desirable. Therefore, aluminum is selected as a possible replacement of the original copper shell. The properties of these materials are given in Table 3.

Haynes Alloy No. 25 is selected as the fuel containment material because of its excellent impact strengths at elevated temperatures. Figure 3 shows a comparison of the impact strength as a function of temperature of this material and two others that were investigated as possible core materials. Figure 4 shows the relationship of tensile strength and temperature for Haynes 25. Table 3 summarizes the properties of this material.

TABLE 1

8.

DATA SUMMARY OF CONFIGURATIONS DEVELOPED FOR SNAP-III GENERATOR

Design Number	Configuration Material	Test Specimen Type (Ref. Table 2)	Diameter				Length		Surface		Area				Aerodynamic Drag	
			Ins.		Cm.		Ins.	Cm.	Ins. ²	Cm. ²	Maximum		Minimum			
			Ins.	Cm.	Ins.	Cm.	Ins. ²	Cm. ²	Ins. ²	Cm. ²	Ins. ²	Cm. ²	Ins. ²	Cm. ²		
A-AC	SNAP III gen. copper shell	5	4.830	12.27	5.328	13.53	81.78	527.6	28.43	183.43	16.62	107.23				
B-CH	SNAP III fuel core. Haynes "25"	6	Max. 1.000 Min. 0.750	Max. 2.54 Min. 1.91	2.063	5.24	7.63	49.23	2.036	13.14	0.785	5.065				
C-AA	SNAP III gen. Aluminum shell	11	4.830	12.27	5.328	13.53	81.78	527.6	28.43	183.43	16.62	107.23				

Design Number	Volume (Bulk)			Weight	Mass		Density (Bulk)			Terminal Velocity			
	In ³	Ft ³ x 10 ⁻³	cc x 10 ²	lbs.	Slugs x 10 ⁻²	Gms. x 10 ²	Slugs In ³	Slugs Ft ³	Gms. cc	Ft/Sec.		Cm/sec. x 10 ³	
										Max.	Min.	Max.	Min.
A-AC	67.149	38.86	11.006	3.24	10.1	14.7	1.50	2.60	1.34	166 Mean	105 135	5.06 Mean	3.20 4.12
B-CH	1.459	0.844	0.239	0.472	1.466	2.14	10.05	17.37	8.95	292 Mean	150 221	8.9 Mean	4.57 6.74
C-AA	67.149	38.86	11.006	2.69	8.35	12.20	1.24	2.15	1.11	152 Mean	96 124	4.63 Mean	2.93 3.78

Design Number	Impact Pressure (At terminal velocity, rigid medium)						Heat Requirements for Melt down (from operating cond)	
	P.S.I.		P.S.F.		Gms/cc ²		BTU	Calories x 10 ⁴
	Max.	Min.	Max.	Min.	Max.	Min.		
A-AC	497	200	7.16x10 ⁴	2.87x10 ⁴	3.45x10 ⁴	1.59x10 ⁴	1013	25.53
B-CH	1.05 x 10 ⁴	2.5 x 10 ³	1.5 x 10 ⁶	3.6 x 10 ⁵	7.4 x 10 ⁵	1.8 x 10 ⁵	66	1.67
C-AA	345	138	4.97x10 ⁴	1.98x10 ⁴	2.4 x 10 ⁴	9.7 x 10 ³	904	22.78

TABLE 2

DETAIL SPECIFICATIONS OF TEST SPECIMENS USED TO EVALUATE UNIT INTEGRITY - SNAP III

Specimen Type	Specimen Number	Shape	Diameter Inches		Length Inches	Weight Pounds	Mass Grams	Material	Test Environment	Remarks
			Max.	Min.						
5	1	Cylinder with Hemispherical ends	4.53	-	5.45	3.51	1590	Shell-copper Core-Haynes "25"	Impact	Basic SNAP III Generator with copper shell and no thermoelectric elements. See Figure 1
	2		4.52	-	5.43	3.2	1451		Impact	
	3		4.516	-	5.35	3.09	1402.5		Impact	
	4		4.50	-	5.35	3.06	1388.5		Impact	
	5		1.531	-	1.825	0.21	95.9		Shock	
	6		1.532	-	1.827	0.21	94.9		Shock	
	7		1.532	-	1.818	0.21	96.6		Shock	
	8		4.512	-	5.375	3.10	1407.1		Fire	
	9		4.513	-	5.425	3.15	1413.1		Fire	
	10		4.505	-	5.350	3.06	1392.1		Fire	
6	1	Truncated Cone	0.997	0.750	2.25	0.464	210.5	Haynes "25"	Impact	Basic SNAP III fuel core of Haynes alloy number "25" See Figure 2.
	2		0.993	0.750	2.25	0.459	208		Impact	
	3		0.994	0.750	2.25	0.466	211.25		Impact	
	4		0.995	0.750	2.25	0.463	210		Impact	
	5		0.997	0.750	2.254	0.50	227.6		Impact	
	6		1.003	0.750	2.253	0.54	229.0		Impact	
	7		0.333	0.250	0.75	0.08	37.6		Shock	
	8		0.333	0.250	0.75	0.08	37.1		Shock	
	9		0.333	0.250	0.75	0.08	38.1		Shock	
	10		1.007	0.750	2.256	0.51	229.6		Fire	
	11		1.003	0.750	2.253	0.52	235.6		Fire	
	12		1.007	0.750	2.253	0.52	229.1		Fire	
11	1	Cylinder with hemispherical ends.	4.530	-	5.565	2.63	1181.1	Shell-aluminum Core-Haynes "25"	Fire	Basic SNAP III gen. with aluminum shell and no thermoelec. elements. See Fig 1.
	2		4.531	-	5.565	2.65	1188.1		Fire	

TABLE 3
 PROPERTIES OF MATERIALS UTILIZED IN THE SNAP III SPACE TEST PROGRAM

	Material		
	Haynes Alloy No. 25	Copper	Aluminum
Composition (weight %)	Ni (9-12), Co (balance), Cr (19-21), W (14-16), Fe (3), C (0.05-0.15), Si (1), Mn (1-2)		
Density (gm/cc)	9.13	8.94	2.70
Melting Range (°C)	1329-1410	1083	660
Thermal Conductivity watt-cm/cm ² - °C (20°C) (500°C)	0.098 0.185	0.923	0.52
Specific heat (28-100°C) cal/gm °C	0.092	0.100	0.260
Tensile Strength Ultimate psi (room temp.)	150,000	50,000	64,000 (24 S-T sheet)
Tensile Strength Yield psi (room temp.)	70,000	30,000	42,000 (24 S-T sheet)
Modulus of Elasticity psi (room temp.)	-	15,000,000	10,000,000

FIGURE 1
SNAP III Generator, Specimen Types 5 and 11

FIGURE 2
SNAP III Fuel Core, Specimen Type 6

FIGURE 3
Charpy Impact Strength vs Temperature

FIGURE 4
Ultimate Tensile Strength of Haynes "25" as a Function of Temperature

III TEST DEVELOPMENT

Once design changes are established and test specimens are fabricated, an experimental development program must ensue in order to substantiate design criteria. Although many performance tests are required to produce a useful satellite generator system, the basic impetus for a test program involving a radioisotope power system utilized on any mission is nuclear safety. Therefore, the program developed and consummated in this report reflect only those tests which formulate a nuclear safety profile of the generator system.

It has been established that in the biosphere a nuclear safe unit is one which will contain the radioisotope when subjected to all operational and accidental conditions. A perusal of these conditions indicated the most stringent, in terms of internal and external mechanical, thermal, and chemical forces, result from the following:

- (1) Impact with a rigid medium at terminal velocity.
- (2) Shock overpressures generated by an exploding missile.
- (3) Missile fire on the launch pad.
- (4) Thermal shock induced into the thermally hot structure in the presence of cryogenic missile oxidizers.
- (5) Corrosive action of fuel forms, shield material, missile propellants and natural elements.

If the generator system can maintain structural integrity when subjected to this spectrum of forces and be capable of aerodynamic burnup above 100,000 feet upon re-entry from orbital decay, the unit would be acceptable for a space application. Therefore, the safety test program can be developed, based upon these maximum conditions.

Three test programs are developed to analyze nuclear safety in the SNAP III Space Generator System. These are:

- (1) High velocity impact
- (2) Mechanical shock
- (3) Missile fire

The following discusses the development of these tests. It is assumed that the specimens utilized in this program are functionally adequate, can be burned up upon re-entry under conditions previously stipulated, maintain integrity in the presence of cryogenic missile oxidizers and other corrosive materials previously listed.

A. High Velocity Impact Test

Since it is necessary to appraise integrity of the SNAP III space generator when subjected to impact forces, a high velocity impact test is developed. The primary purpose of this experiment is to determine the degree of damage and possible mode of failure of the test specimens. This is accomplished by actually impacting full scale specimens at a specific velocity into media of varying rigidity. Ten specimens are to be tested on four different impact media. Generalizations for the selection of test specimens, velocities, and impact media are given below:

1. Test Specimens

Theoretical calculations indicated that impact pressures on a fuel core are greater than those on a complete generator by a factor approximately nine at corresponding impact velocities. This is shown in Figure 5, which represents velocity-pressure relationships of the fuel capsule design and the two complete SNAP III generators.

Since the complete generator is a size that can be tested at terminal velocities, impact integrity is measured on both the bare core and the generator. The copper shelled generator is tested, for it represents the weaker structure of the two configurations being investigated. A demonstration of integrity of this unit, logically demonstrates integrity of the second. The test specimens are preheated before impact to simulate actual operating conditions.

Six bare cores and four complete generators, without thermoelectric elements, are tested.

2. Impact Velocities

Table 1 shows the terminal velocities of the various designs. The maximum terminal velocity of the complete generator,

FIGURE 5
Impact Velocity and Pressure Relationships of SNAP-III Configurations

if impacted as an integral unit is approximately 160 feet per second, for the bare core it is approximately 300 feet per second. Datum velocities of 350 and 500 feet per second are established for the purpose of test planning for the complete generator and bare core respectively. These velocities will be obtained by employing the supersonic Ballistic Research Track at the Aberdeen Proving Ground at Edgewood, Maryland.

3. Impact Media

Four impact media representative of the earth's surface fabric are to be utilized in this test. These are: granite, unconsolidated rock, water, and consolidated rock.

Granite characterizes a typical rigid material on which a generator might impact. Since little momentum is transferred to the granite from the impacting specimen, almost all energy is available to deform it. This creates the most stringent impact force possible. Figure 5 shows the pressures resulting from this type of impact. This medium is selected because it represents a rigid target from which damage of impacted specimens can be measured as a maximum.

The use of unconsolidated rock as an impact medium is twofold. First, since it is not rigid, some of the impact energy is transferred, and can be measured. This permits the determination of a degree of specimen deformation; which when compared to the maximum condition, could be used to establish configuration impact strength equations for future designs. Second, the burial depth can be measured. This information can be utilized to determine radiation shielding afforded to the system by the medium should an aborted fuel capsule meet with this fate.

Water typifies a non-rigid medium upon which the SNAP-III generators are most likely to impact in cases of missile failures. It is included in this test to determine structural deformation of the impacted specimens and to analyze the effects of cold water on a thermally hot core when it is instantaneously quenched upon impact. Since it is not possible to measure energy transfer, no comparison can be made to damage sustained during impact with the other media.

Consolidated rock characterizes a non-rigid medium from which momentum transfer can be measured. This information can be used to supplement future design work.

4 Summary

The High Velocity Impact Test is developed to determine structural integrity of a SNAP III generator system when impacted with the earth's surface during an aborted space mission. Structural damage is measured on 10 test specimens after impacting on four different target media at velocities of 350 and 500 feet per second.

The samples represent configurations of the SNAP III Generator System.

The four target media simulate the earth's surface fabric on which a unit may impact. Granite, unconsolidated rock, water, and consolidated rock are utilized as the target media because:

- (1) Granite typifies a substance of possible impact which is rigid in nature.
- (2) Unconsolidated and consolidated rock characterize non-rigid mediums in which impact energy transfer can be measured.
- (3) Unconsolidated rock affords a biological shield for the radioisotope.
- (4) Water depicts the medium most likely to be impacted by the aborted fuel core.

Impact velocities of 350 and 500 feet per second denotes the maximum terminal velocities of the complete generator and bare core respectively.

B Mechanical Shock Test

Shock forces originating from missile propellant explosions on the launch pad appeared to be of significant magnitude to warrant experimental verification of unit integrity to shock overpressures. Therefore, shock overpressures imposed on a generator, enclosed in the payload package of a satellite system, were studied and a fuel core shock integrity test was developed.

The primary predilection of this test is to determine structural deficiencies of generator designs subjected to an atmosphere of intense shock forces generated by missile fuels exploding on a launch pad. The lack of deficiencies will vindicate

theoretical design parameters. Generally, the test is devised to support design conjectures for configuration changes on basic SNAP III generator in a shock environment equivalent to that produced by a liquid oxygen and RP-1 fueled Atlas Missile explosion. Duplication of the shock environment, specimen function and justification of this shock integrity test are described below:

1 Shock Environment

Since it is not economically feasible to pointedly explode an Atlas missile, it becomes necessary to develop a simulated shock environment which, for all intents and purposes, can be utilized to determine structural integrity of isotopic fuel capsules. However, before this environment can be planned, the mechanics of a missile explosion must be understood. Recent work by Smalley and Anderson of The Space Technology Laboratory has yielded a reliable method of predicting the blast overpressures expected from a liquid oxygen-RP-1 missile explosion. Some of the relationships and limits resulting from this work are indicated below.

Assumptions made to derive equations for the expected overpressures from a liquid oxygen RP-1 explosions are as follows:

- (1) The missile tanks must be ruptured in a manner to permit a mass spill of the propellants.
- (2) The entire weight of propellants in the missile at the time of the spill is the effective weight.
- (3) An ignition source must be present at or prior to the time of tank rupture.
- (4) Once the blast wave forms a clean shock front, the resulting peak overpressure will decay with distance in the same manner as that from a TNT explosion.

Experience has shown that release of the propellants enmass will occur when the fuel tanks are ruptured by tank overpressurization prior to lift-off, and fallback after lift-off of the missile. Ignition sources are flame from the engine exhaust and/or impact of the missile structure. The empirical equations developed from 1/10 and 1/18 missile tests and full scale operational vehicle failures to theoretically calculate expected overpressures as a function of the weight and distance involved are:

$$P = \frac{593}{Z^3} - \frac{28.8}{Z^2} + \frac{20.7}{Z}$$

$$P = \frac{9862}{Z^3} - \frac{187.9}{Z^2} + \frac{52.8}{Z}$$

$$\text{where: } Z = \frac{R}{W^{1/4}}$$

P = average side on overpressure (psi)

R = distance from explosion (feet)

W = Total weight of propellants (pounds)

The first equation is the predicted average pressure and the second at the upper 98% confidence limit.

Since data is available to calculate overpressure, it was decided to simulate the test shock environment by employing TNT as the shock source. Dr. W. Baker of the Ballistic Research Laboratory at the Aberdeen Proving Ground compared maximum overpressure as a function of distance for the launching missile (Atlas booster) to compiled data on Pentolite explosives. This comparison indicated that an explosive weight of 22,400 pounds is required to produce the same peak overpressures over a large range of distances as the worst expected Atlas accident. This weight represents the weight of explosive detonated in free air, not near a reflecting surface such as the ground. However, the thermoelectric generator, in the launch configuration, might be subjected to both an initial shock wave from the fuel explosion and a relatively strong shock reflected from the ground. To compensate for this reflection, the maximum possible reinforcement of the incident shock is increased by doubling the effective explosive weight, giving a total weight of 44,800 pounds of TNT.

If it were feasible to detonate a TNT charge of 44,800 pounds, an equivalent shock environment to that of a maximum Atlas missile explosion containing 260,000 pounds of fuel could be created. However, test facilities and funds limited to this program would not permit the detonation of such a charge. Therefore, it became necessary to investigate the possibility of scaling down the charge weight to a reasonable quantity.

The maximum charge weight is dictated by facility requirements. Safety personnel at the Aberdeen Proving Ground, where the charge is to be detonated, agreed to a maximum of 2000 pounds of TNT, with one reservation. This limitation being time of detonation, which must be dependent on meteorological conditions.

Experiments by Dr. W. Baker and staff at BRL showed that dynamic response of structures to blast loading from explosive charges can be scaled. The scaling factor is a function of the structure's linear dimensions, distance from the blast, and the weight of explosive charge producing the blast. Tests showed that the dynamic response of structures to blast loadings are the same at scaled distances for any linear scale of the structure if the charge weight producing the blast is altered by the cube of that linear scale. That is to say, if the test specimen linear dimensions are scaled down by a factor of $1/3$, the charge weight required to produce the same dynamic response in the full scale specimen from a missile blast must be scaled down by a factor of $(1/3)^3$. Therefore, shock integrity of the generators can be determined by utilizing a TNT charge of $44,800 \times (1/3)^3$ or 1,650 pounds, if the test specimen and distance are scaled down by a factor of $1/3$. Now the charge weight is within test facility requirements and the test can be performed when meteorological conditions are favorable. Hence, the shock environment is generated by employing just 1,650 pounds of TNT.

2. Test Specimens

Three complete generator assemblies and three bare fuel cores are to be tested in the simulated shock environment. As in the impact experiment, the copper unit is tested. The specimens are preheated to simulate actual operating conditions.

Position of these test assemblies with respect to the blast center is determined by scaling down the distance of the generator in the satellite package to the missile area where an explosion is likely to originate. This information was obtained from STL. According to this group, a blast is more likely to originate in the area between the LOX Tank and RP-1 Tank, a distance of 36 feet from the satellite package. Therefore, using the scaling factor, the test specimens are located 12 feet from the blast center.

To determine the effects of a shock front on generator to missile attachments, the test specimens are secured in the test shock environment by incorporating two different fastening schemes. These are: (1) rigid attachment, and (2) loose attachment. The function of the rigid system is to contain the test specimen in the shock front for a time of sufficient duration to permit the shock wave to cycle at least once through the structural material of the assembly. On the other hand, the loose connection is to free the specimen so that the shock front can eject it without passing through the structure. Test specimens are analyzed after

the test to determine which connection is more effective against shock overpressures resulting from missile propellant explosions.

3 Test Justification

Since a theoretical approach for investigating blast effects on fuel cores is perplexed, a mechanical shock test is necessary to establish the safety of an isotopic generator system. It has been demonstrated by tests that blast effects resulting from a LOX-R₁-1 explosion can be duplicated by a TNT blast. Laws for elastic response and permanent deformation of model structures subjected to blast loadings have been developed and tested.

In estimating charge weight, conservative assumptions, and maximum possible blast effects are used. The scaled loading on the specimens is undoubtedly considerably greater than would be experienced in a launch accident. Therefore, the shock test described will surely augment data necessary for the development of a safe generator system.

4 Summary

The Mechanical Shock Test is developed to determine the effects of shock overpressures, generated by exploding missile propellants, on a SNAP III generator system. Effects are measured on six test specimens exposed to a shock blast induced by detonating 1,650 pounds of TNT.

The samples represent configuration changes to the basic SNAP III thermoelectric generator for space applications.

The TNT blast simulates a missile exploding on the launch pad. It generates shock overpressures equal in magnitude of those to which a generator system would be exposed if it was aboard a missile that exploded on the launch pad.

C MISSILE FIRE TEST

Most of the present day and future projected satellite launch vehicles employ hypergolic fuels for the second and third stage engines. Because of the propensity of these fuels, the contingency of a missile fire on the launch pad is perpetual.

Although the isotopic generator is a thermal device, it experiences maximum thermal retrogradation when subjected to this type of missile failure. Since it is difficult to calculate or predict the ability of any system to withstand a thermal encompassment of this magnitude any theoretical analysis should be justified by a test program. The missile fire test is developed to do just this.

The basic concepts of this test is to simulate a temperature profile equivalent to that of an Atlas missile burning on the launch pad. The thermal environment generated is utilized to expose test specimens; so that a thermal integrity evaluation can be established on the various generator configurations being developed for the SNAP III space system.

Mode of developing the simulated temperature profile, selection of test specimens, and justification of these selections are presented below.

1. Temperature Profile

As in the shock test, it is economically infeasible to intentionally set fire to an Atlas missile. Therefore, a simulated test environment must be developed. To accomplish this, theoretical calculations and data from previous missile fires were studied to determine temperature and heat profiles of a burning missile of the Atlas type. These investigations revealed the following: (1) the splatter of liquid propellants ensuing from the missile tanks are distributed over an area which forms a base for a fireball with a diameter of approximately 175 feet. (2) winds and the normal rise of the hot gases cause the entire fireball of combustion products to drift entirely clear of the launch point within five seconds. (3) about 6% of the available liquid oxygen enters into combustion. The remainder is either burned in the rocket motor or evaporated off. (4) the fire left burning consists of surface pools of fuels supported by combustion very similar to any surface oil fire. (5) about 16% of this missile structure is consumed.

In view of these facts a temperature profile is established. This profile is given in Table 4.

TABLE 4
THEORETICAL TEMPERATURE PROFILE OF A
BURNING ATLAS MISSILE

Temperature °F	Duration Seconds	Time	
		Sec	Min
6000	Few micro-seconds.	0	0
4500	4	4	0.067
3000	3	7	0.12
2000	490	497	8 3
1500	700	1197	20

Using this data, calculations indicate that a thermal environment equivalent to a burning Atlas missile would be approximated by completely burning the following:

- (1) 1500 pounds of aniline
- (2) 8500 pounds of RP-1
- (3) 4000 pounds of Magnesium

From this information, an environment for a generator thermal integrity test is developed. The test environment is generated by burning the materials indicated above. Red fuming nitric acid is utilized as the oxydizer for the aniline. Since these materials are hypergolic, the fire is ignited by releasing the two propellants from containers over a simulated missile structure.

The missile structure is simulated by utilizing scrap metal of various materials from which missile components are fabricated. This scrap metal consists of steel, aluminum and magnesium. These are zoned in layers to simulate distribution of materials in the missile. The zoning also simulates heat distribution through the burning missile structure.

2 Test Specimens

Thermal effects on eight test specimens representing two different generator configurations and the fuel capsule are evaluated. The aluminum generator structure is included in this experiment because thermal effects on it are greater in magnitude than on the copper structure. A comparison will be made between the two designs to determine integrity of each, since it may be more desirable to use the aluminum system on a space mission.

The test specimens are preheated to operating temperatures.

3 Summary

The Missile Fire Test is developed to determine the effects of thermal punishment imposed on the SNAP III space generator system. Effects are measured on eight test specimens exposed to a thermal environment generated by burning missile propellants and metals.

Specimens are various configurations of the SNAP III space generator system. The thermal environment duplicates heat generated by a burning missile on its launch pad.

IV TEST PROCEDURES AND RESULTS

This section presents a summary of procedures and results of all tests developed to optimize design configuration changes to the SNAP III space generator. Since these tests have been justified as to requirements, the procedure of each includes only details of facilities and set-up.

A. High Velocity Impact Test

These tests were conducted on the Supersonic Ballistic Research Track at the Army Chemical Center, Edgewood, Maryland. Ten specimens of the generator and fuel core configurations were preheated, propelled by rocket sleds and impacted against simulated earth media. Description of test equipment, procedures and results are presented.

1. Supersonic Ballistic Track

The ballistic track utilized in this test is a dual rail track, 2,443 feet long. The cold-rolled steel rails are 2 inches by 1 inch in cross-section with a two-inch separation between rails. Sleds are mounted by metal shoes designed to lock between the rails.

The track is designed to achieve varying velocities with a payload of from 1.5 to 590 pounds. Maximum acceleration is 110 g.

Sleds can be affixed to any position along the length of the track. The position is dependent upon impact velocity, sled weight and rocket thrust. See Figure 6.

2. Rocket Sled

To obtain desired impact velocities of 350 and 500 feet per second on each of the complete generators and bare fuel cores, two different rocket sled configurations were employed. Each sled was propelled by a rocket engine of the Type FFAR. Specifications for this engine are as follows:

(a) Engine weight	12.1 pounds
(b) Length	32 inches
(c) Diameter	2.75 inches
(d) Thrust	320 pounds
(e) Propellant Weight	6.4 pounds
(f) Burning Time	1.7 seconds
(g) Lot Number	ALN-RCHA-10C-52

On each sled, a specially designed insulated cradle was mounted in front of the engine cluster on a massive steel structure.

FIGURE 6

Supersonic Ballistic Track - High Velocity Impact Test

The cradle was used to contain the heated test specimen in the sled vehicle. The massive structure was used to restrict sled debris from impacting the target after specimen separation. Sled specifications and track distances are given in Table 5. Figures 7 and 8 show views of these two sleds.

3. Separation Technique

To separate the test specimen from the rocket sled, a unique impact system was employed. A large vertically mounted steel plate, 10 feet square and 8 inches thick, was located approximately 5 feet, 8 inches beyond the end of the track. An 8 inch diameter aperture was located in this plate directly in the path of the specimen bearing vehicle. Upon leaving the track, the sled vehicle impacted the steel plate. The test specimen entered the aperture separated from the sled and impacted the target medium. The vertically mounted steel plate restrained the rocket engine and sled debris from impacting the target. Figures 9 and 10 show views of this separation plate. Figure 11 shows a typical sequence of separation.

4. Test Specimens

Ten specimens were tested to evaluate impact integrity. Data for these specimens are given in tables as follows:

Detail design specifications	Table 1
Detail specimen specifications	Table 2
Detail Test Data	Table 5
Test Results	Table 6

The bare core specimens were preheated to temperatures indicated in Table 5 in an electric furnace. To assure good specimen temperatures, the cores were not removed from the furnace until furnace temperature remained stable for one-half hour. The fuel capsule in tested generators were preheated by utilizing pencil type electric heaters contained in the core.

Since it required between 10 to 40 seconds to remove the specimens from the furnace and impact it, the specimens were preheated to a temperature higher than that desired at impact. This allowed for the loss of heat due to radiation during this period of time. Furnace temperature was determined from the temperature decay of Haynes "25" shown in Figure 12.

After impact, specimen penetration was measured, when applicable, and photographs were taken to record specimen conditions.

FIGURE 7

Rocket Sled, SNAC III Generator, High Velocity Impact Test

FIGURE 8
Rocket Sled, SNAP III Fuel Core, High Velocity Impact Test

FIGURE 129

Vertical Separation Plate, Sled View

High Velocity Impact Test

FIGURE 10

Vertical Separation Plate, Side View

High Velocity Impact Test

(1.)

(1.) Sled leaves track

(2.)

(2.) Sled impacts separation plate

(3.)

(3.) Test specimen
in free flight

(4.)

(4.) Test specimen
impacting medium

FIGURE 14

Separation Sequence, Rocket Sled and Test Specimen

High Velocity Impact Test

824
012
7

35.

Time (seconds)

FIGURE 12

Temperature Decay by Radiation of Haynes "25" Fuel Core

5 Impact Media

Specifications and containment details of the four impact media are given in Table 7. All four media were positioned aft of the vehicle separation plate in the path of impacting specimen. These set-ups are shown in Figures 13, 14, 15, and 16. Table 5 gives position of each.

6 Data Recording

Physical data recorded during this test is summarized in Table 5. Also, documentary and Fastax 16mm films of the impacts were taken. These have been given a careful examination for purposes of verifying impact velocities and obtaining overall test results.

7 Test Results

Test results are shown in Table 6.

FIGURE 13

Granite Impact Medium, High Velocity Impact Test

FIGURE 17

Unconsolidated Rock Impact Medium

High Velocity Impact Test

FIGURE 15
Water Impact Medium, High Velocity Impact Test

FIGURE 16
Consolidated Rock Impact Medium, High Velocity Impact Test

TABLE 5

SUMMARY OF TEST DATA - HIGH VELOCITY IMPACT TEST

Date of Firing	Specimen Type	Specimen Number	Design Number	Vehicle Weight lbs.	Track Distance ft.	Free Flight Inches		Specimen Preheat Temperature °F	Time from Furnace to Impact Sec.	Impact Velocity ft/sec	Impact Medium	Penetration Depth Ins.
						Before Separation	After Separation					
11-30-59	5	1	A-AC	81.7	300	68	109	925	-	318	Granite	0
11-30-59	6	1	B-CH	58.8	425	68	109	1050	-	-	Granite	Missed Target
12-1-59	5	2	A-AC	82.71	300	68	168	1032	-	335	Unconsolidated Rock	24
12-1-59	6	2	B-CH	59.2	425	68	168	995	-	-	Unconsolidated Rock	Missed Target
12-3-59	5	3	A-AC	80.9	300	68	156	1100	-	341	Water	60
12-3-59	5	4	A-AC	81.5	300	68	168	850	-	342	Consolidated Rock	9
12-3-59	6	3	B-CH	59.6	425	68	156	1150	-	-	Water	Missed Target
12-3-59	6	4	B-CH	59.3	425	68	168	900	-	-	Consolidated Rock	Missed Target
3-9-60	6	5	B-CH	50.29	425	65	50	1010	30.5	468	Consolidated Rock	5
3-9-60	6	6	B-CH	50.55	425	65	50	1020	35	438	Granite	0

TABLE 6

SUMMARY OF TEST RESULTS HIGH VELOCITY IMPACT TEST

Spec Type	Spec No	Design No	Spec Impact Temp °F	Impact Press	Energy of Impact	Force of Impact	Energy Lost to Impactor	Force Acting on Specimen	Simulated Fuel Release	Dim of Impacted Fuel Cores		
				P S I	Ft-Lbs	Lbs	Ft-Lbs	Lbs		Max Dia	Length (Min)	Damaged g. (Ave)
				$\times 10^3$	$\times 10^3$	$\times 10^4$	$\times 10^3$	$\times 10^4$		Ins	ins	Ins
5	1	A-AC	925	1.82	5.1	3.2	0	3.2	None	1.01	2.18	0
6	1	B-CH										
5	2	A-AC	1032	2.03	5.67	3.38	~4.5	~1.53	None	No Chg	No Chg	
6	2	B-CH										
5	3	A-AC	1100	2.10	5.87	3.49			None	No Chg	No Chg	
5	4	A-AC	850	2.12	5.91	3.50	~4.3	~1.82	None	No Chg	No Chg	
6	3	B-CH										
6	4	B-CH										
6	5	B-CH	955	26.42	1.6	2.1	~0.27	~1.87	None	No Chg	No Chg	
6	6	B-CH	955	23.14	1.41	1.8	0	1.8	None	No Chg	No Chg	1.0
										(Min. 0.78)		

			Description of Impacted Target	Description of Impacted Specimens and Analysis of Its Mode of Failure
5	1	A-AC	No Change	Generator shell sidewall and weld ripped in tension. Aluminum cold junction ring split in one plane. Core had no fractures; however, impacted face was deformed slightly. See Figure 19. Theoretical calculations predict this result.
5	2	A-AC	~30 ins. of soil disarranged at impact face	Generator shell deformed on impacted surface, tension tear about 3 inches long resulted. See Figure 20. No damage to fuel core.
5	3	A-AC	See Figure 17	Generator shell dented by tank support. No fractures in shell. No damage to fuel core. See Figure 21.
5	4	A-AC	See Figure 18	Generator shell creased perpendicular to impacted surface. Aluminum ring split in 1 plane. See Figure 22. No damage to fuel core.
6	5	B-CH	Similar to Figure 18	Fuel core was not damaged. See Figures 23 and 24. Calculations on 6-5 and 6-6 indicate that structural deformation due to impact forces is primarily a function of impulse.
6	6	B-CH	No Change	Fuel core deformed in compression on edge of impacted face. See Figures 23 and 24. Figure 25 shows deformation of inner fuel capsules in this specimen. No fractures or pressure leaks were found.

TABLE 7

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SPECIFICATIONS AND CONTAINMENT OF HIGH VELOCITY IMPACT MEDIA

		Target Medium			Consolidated Rock
		Granite	Unconsolidated Rock (Tamped Earth)	Water	
Containment		Solid rectangular block backed up by 10 tons of earth.	Steel frame rectangular plywood box (1 inch thick) with open front and top.	Circular plastic tank with steel wire mesh reinforced sides.	Solid rectangular block backed up by 10 tons of earth.
Physical Dimensions	Length (ft)	4.5	20	2 (deep)	4
	Width (ft)	2	4	10 (diameter)	3
	Breadth (ft)	2	4		3
Volume (ft ³)		18	320	157	36
Density (lbs/ft ³)		168	80-50	62.4	109
Weight (lbs)		3024	24,320	9,800	4,250
Compressibility (psi)		30,000	300	-	655
Remarks		Abrasive hardness similar to that of steel (Rockwell hardness C-53)	Earth was partially frozen during first series of test	Wire mesh removed in area of impact.	A mixture of earth, 20% concrete and adequate water to insure proper mixing. Block cured for 30 days prior to test.

FIGURE 17
View of Water Medium After Impact, High Velocity Impact Test

FIGURE 18
View of Consolidated Rock Medium After Impact, High Velocity Impact Test

FIGURE 19
Tested Specimen Type 5 Number 1 Design A-AC Impacted on Granite,
High Velocity Impact Test

FIGURE 20
Tested Specimen Type 5 Number 2 Design A-AC Impacted on Unconsolidated Rock,
High Velocity Impact Test

FIGURE 21
Tested Specimen Type 5 Number 5 Design A-AC Impacted on Water,
High Velocity Impact Test

SP-1
012
1

FIGURE 22
Tested Specimen Type 5 Number 1 Design A-AC Impacted on Consolidated Rock,
High Velocity Impact Test

Type - 6
Number - 6
Design - B-CH
Impacted on Granite

Type - 6
Number - 5
Design - B-CH
Impacted on Consolidated Rock

FIGURE 23

View of Tested Specimens Type 6, Numbers 5 and 6 Design B-CH Impacted on Consolidated Rock and Granite Respectively, High Velocity Impact Test

Type - 6

Number - 5

Design - B-CH

Impacted on Consolidated Rock

Type - 6

Number - 6

Design - B-CH

Impacted on Granite

FIGURE 21

View of Tested Specimens Type 6, Numbers 5 and 6 Design B-CH Impacted on Consolidated Rock and Granite Respectively, High Velocity Impact Test

FIGURE 25

View of Tested Specimen Type 6 Number 6 Design B-CH, Sectioned to
Show Deformation of Inner Stainless Steel Containers, Impact Medium - Granite
High Velocity Impact Test

B. Mechanical Shock Test

This test was conducted March 23, 1960 on "M" Field at the Edgewood Chemical Center, Edgewood, Maryland. Six specimens were preheated and exposed to a shock wave produced by the detonation of 1650 pounds of TNT. Description of the test site, procedures and results are outlined.

1. Test Site

The site utilized for this test is a bomb test field located on a peninsula in the Chesapeake Bay at the entrances of the Bush and Gunpowder Rivers. This site was selected because it afforded a remote area with protection facilities for personnel and equipment. The coordinates of the blast area were $39^{\circ} 21' 15''$ latitude and $76^{\circ} 17' 30''$ longitude.

A massive concrete wall was used for protecting equipment. It is approximately 50 feet high, and 75 feet long. Thickness of the wall varied from 14 feet at the base to 5 feet at the top. The test blast was 200 feet from the wall in an east-northeast direction. A personnel bunker with an observation port was located approximately 1000 feet from the blast in a southeast direction. Figure 26 shows an aerial view of this site after conclusion of the test including the resultant crater.

2. Shock Energy Source

To obtain the desired shock overpressures, 1650 pounds of TNT was employed. This represents an energy release of 1.8×10^9 footpounds. This charge was contained in 25 wooden crates, each containing 66 one pound blocks of TNT. All 25 crates were positioned in a 5 layer pyramid on a wooden stand. This stand was leveled about 3 feet above the ground, and was resting on a steel plate 4 inches thick by 12 feet square.

The charge configuration was established in an effort to reproduce a geometric form as near to a hemisphere as possible. This geometry was required to obtain a symmetrical shock wave in all directions. The pyramid satisfied these conditions very effectively.

The TNT was primed and detonated by an experienced demolition engineer from the Aberdeen Proving Grounds. It was set off from the personnel bunker, 1000 feet from the charge.

FIGURE 26

Aerial View Of Mechanical Shock Test Site

3. Test Specimens

Six specimens, representing generator configurations and fuel capsules, were tested in this shock environment. Data for these specimens are given in tables as follows:

Detail design specifications	Table 1
Detail specimen specifications	Table 2
Detail test data	Table 8
Test results	Table 9

All specimens were preheated to temperatures given in Table 8. These temperatures represent the operating temperature of the core at the time when the generator might be exposed to a shock environment on the launch pad. Since the specimens are 1/3 scale, and preheating had to be accomplished remotely, electric pencil type heaters were employed. These were energized by a 110 volt 60 cycle single phase power source, which was located behind the concrete barrier, 200 feet from the specimens.

4. Specimen Set-Up

The six specimens were positioned 12 feet from the blast center on three posts 1 foot above the bottom layer of the TNT. These were anchored in the ground to a depth of 10 feet. The posts were 4-inch diameter steel tubing, located on the circumference of a 24 feet diameter circle. Specific positions of each post were as shown in Table 8.

Two types of specimen attachments were utilized. A rigid attachment was made by securing the specimens to 0.750 inch thick steel plates with over-size hardware. The steel plates are welded to the steel mounting posts. The non-rigid attachment was made by securing the specimens to the steel plates by means of pins. These pins were 0.064 inches in diameter and 1 inch long. Holes were provided in the plates and specimens to accommodate the pins. There are 2 specimens on each post, one was rigidly attached and the other, merely pinned. Figures 27, 28 and 29 show core attachments to these posts. Methods of attachment used on the test specimens are given in Table 8. The bare core specimens are covered with insulation to reduce heat losses during the preheating operation.

To recover the specimens after the test, 0.75 inch diameter nylon rope with 7500 pounds tensile strength was secured to each specimen by a lanyard ring. These ropes were anchored in the ground, 75 feet behind each set-up. They were

FIGURE 27
View of Specimen Attachment, Post 1. Mechanical Shock Test

FIGURE 28
View of Specimen Attachment, Post 2, Mechanical Shock Test

FIGURE 29
View of Specimen Attachment, Post 3, Mechanical Shock Test

covered with earth about 10 feet from each post all the way to the anchor stake. The function of the earth cover lines was to contain the test specimens within a 200 feet diameter circle. The earth was used to absorb specimen momentum resulting from breaking away from the mounting post during the test. See Figure 30 for the complete set-up.

Two beam type pressure gauges were positioned at 130 and 190 feet from the center of the charge. These were utilized to measure side-on over-pressures. These data are given in Table 8.

5. Data Recording

Physical data recorded during this test is given in Table 8. In addition, 4 cameras were covering the action of the test. Films have been screened in order to obtain visual test data. Data collected from these films are also given in Table 8.

6. Test Results

Test results are summarized in Table 9. A detailed analysis of the explosion, set-up and test specimens are presented below.

- (a) Explosion - The 1650 pound charge was detonated at time 14:04. A mushroom fire ball, 175 feet diameter by 100 feet high developed 0.1 seconds of detonation. It remained on the ground for 0.7 seconds then rose to a maximum altitude of 100 feet. At this point, and at a time of 2.7 seconds after detonation, the ball dispersed into a black cloud and moved down-wind.

As the fire ball moved off the ground, a cloud of dust and white smoke ensued from the blast area. This condition remained for a period of time of approximately 3 minutes, and prevented the cameras, focussed on the action, from recording specimen behavior in the blast. There were no indications on the film as to when or how the specimens left the test area. See Figure 31.

- (b) Set-Up - After the debris cleared, the surrounding area about the center of the blast was scrutinized to determine all possible effects of the explosion on the set-up. The area inspected was within a 3000 yard diameter circle. Field notes of this investigation revealed the following.

FIGURE 30

View Of Complete Test Set-up, Mechanical Shock Test

The wooden stand on which the charge was resting, and the wooden crates in which the TNT was packed, were completely obliterated. That is, not even a splinter of wood was found in the area inspected.

The three posts, which were located on a 24 feet diameter circle about the blast center, were sheared off at ground level. All posts were found approximately 2000 feet from and radially behind its original position. This indicated, assuming equal strengths and weights in each post structure, that the shock front was equivalent in magnitude at these points. All posts were permanently deformed structurally as indicated in Figure 32. Each had holes punctured through them perpendicular to the shock front. These holes showed indications of being burned through the metal rather than being sheared. Therefore, it was assumed that the impinging projectile was at a temperature higher than the melting point of the steel tubing, 2500°F.

The rigid specimen attaching hardware was sheared off of the posts in two of the three situations. On post 2, the hardware which contained specimen type 5, number 6 remained on the post structure. All others were not found.

At the blast site, a crater was formed. It was a spherical segment 26 feet in diameter and 6 feet deep. Calculations indicate that approximately 144,000 pounds of earth was moved out of the crater. The steel plate, on which the TNT charge was resting, was found at the bottom of the crater. There was no indication of damage to the plate by the blast.

(c) Test specimens- Of the six specimens tested, 2 were recovered. One was retained by the nylon rope and was found in a 200 feet diameter circle about the blast center. The other was recovered at a distance of 3000 feet from the blast site. Each was found directly behind the post on which it was originally attached. Assumptions of the behavior of each of the specimens in the blast, and a description of the condition of the tested specimens are given in Table 9.

FIGURE 39

View Of Blast Sequence - Mechanical Shock Test

FIGURE 32

View Of Post After Detonation

Mechanical Shock Test

TABLE 8

64.

SUMMARY OF TEST DATA - MECHANICAL SHOCK TEST

Specimen Data

Specimen Type	Specimen Number	Design Number	Post		Attachment	Specimen Preheat Temperature °F	Specimen Recovery Data
			Identification	Position (from true North)			
5	5	A-AC	3	288°	Rigid	1000	Not re-covered
5	6	A-AC	2	216°	Rigid	1000	Retained by nylon rope
5	7	A-AC	1	0	Loose	1000	Not re-covered
6	7	B-CH	3	288°	Loose	900	Not re-covered
6	8	B-CH	1	0	Rigid	900	Not re-covered
6	9	B-CH	2	216°	Loose	900	~3000 ft from blast center, in line with ori. posts

Fireball Data

Shape	Maximum Dimensions		Maximum Rise (feet)	Time Measurements (seconds)			Temperature Maximum (°F)
	Horizontal (feet)	Vertical (feet)		Develop Max. Ball	At Ground Level	Dispersal	
Mushroom	~175	~100	~100	~0.1	~0.71	~2.7	~7000

Crater and Pressure Data

Shape	Crater Dimensions (feet)		Volume (ft ³)	Weight of Earth Moved (Lbs.)	Pressure		
	Diameter	Depth			Detonation (psi)	Side on Overpressure (psi)	
						At 130 ft.	At 190 ft.
Spherical Segment See Figure 33	26	6	1600	144,000	9×10^5	5.02	2.95

Test over pressures compare to theoretical S.T.L. Data as follows:

- (1) At 130 ft., test overpressure was 25% higher.
- (2) At 190 ft., test overpressure was 28% higher.

FIGURE 33

View Of Ground Crater After Detonation

Mechanical Shock Test

TABLE 5
SUMMARY OF TEST RESULTS - MECHANICAL SHOCK TEST

Speci Type	Specimen Number	Design Number	Specimen Side-on Overpressure PSI	Shock Force lbs		Min Time for Shock Front to Traverse Specimen Micro-Sec	Ultimate Tensile Strength of Mat. PSI	Description of Tested Specimens
				Max	Min			
5	5	A-AC	1020	3220	1870			Not recovered
5	6	A-AC	1020	3220	1870	Shell - 14.9 Core 11.68	Shell - 40,000 Core 109,000	Copper shell was sheared off at assembly weld. Lower section of shell not found. No damage to core. See Figure 34
5	7	A-AC	1020	3220	1870			Not recovered
6	7	B-CH	1020	230	89			Not recovered
6	8	B-CH	1020	230	89			Not Recovered
6	9	B-CH	1020	230	89	11.68	109,000	Core surface was polished to a high luster by the shock front. No measurable or visible change in core. See Figure 34
Assumed Mode of Retention or Release of Test Specimens								
5	6	A-AC	1. Shock front sheared post with specimen attached. 2. Nylon rope pulled specimen out of its attaching hardware. 3. Force deformed lanyard ring. Since the specimen was retained by rope and the lanyard ring did not fail, this force must have been <800 lbs. and >than 500 lbs. 4. Therefore shell must have been ripped off when post and specimen was released. strength of asser weld - 2500 lbs					5. Conclusions, specimen retained by nylon rope since attachment was at core
6	9	B-CH	1. Because of the small area exposed to the shock front, force was not sufficient to release loose mounting. Therefore specimen and post were released as a unit. Force on post assem. ~700,000 lbs. 2. Nylon rope broke in tension, 7500 lbs, and loose attachment of specimen released from post assem. 3. Acceleration of specimen was greater than that of post assem. and carried about 3000 feet from blast center. post carried about 2000 feet. 4. Specimen found with about 2 feet of rope attached					
			General - The none recovered specimens must have been released with post assembly, sheared attaching hardware and carried beyond the 3000 feet radius search area

Type - 6
Number - 9
Design - B-CII

Type - 5
Number - 6
Design - A-AC

FIGURE 34
Tested Specimens - Mechanical Shock Test

C FIRE TEST

This test was conducted April 27, 1960, on "M" Field at the Edgewood Chemical Center, Edgewood Maryland. A thermal environment, typical of a missile fire on a launch pad, was generated to evaluate thermal integrity of three SNAP III fuel capsules and five SNAP III generators. Details and results are outlined below.

1. Test Site

The site utilized for this test is the same bomb test field described in the mechanical shock test. Approximate coordinates of the test set-up are 39° 21' 30" latitude and 76° 17' 45" longitude. Figure 35 shows an aerial view of this site.

2. Test Environment Set-up

A test environment, duplicating a missile fire was generated by burning aniline, RP-1, and magnesium metal in a simulated missile structure. Red fuming nitric oxide was used as the oxidizer and igniter, since it is hypergolic with aniline. The test set-up employed to produce this environment was as follows:

A 30 foot wooden tower was used to support the simulated missile structure. It was fabricated by bracing four creosote treated poles, 12 inches in diameter, with a wooden truss designed to support 25,000 pounds of metal. Scrap metal was contained in the tower by steel mesh wire. Horizontal dimensions of the tower were 11 feet squared at the base and 6 feet squared at the top. The entire structure was bolted to a 2 inch thick, 14 feet squared steel plate. See Figure 36.

The fuels, scrap metal, and test specimens were distributed throughout the tower from the bottom to the top and zoned as follows:

- (1) 8500 pounds of RP-1 in a plastic tank
- (2) 4000 pounds of scrap steel
- (3) 2000 pounds of magnesium metal
- (4) 6000 pounds of aluminum sheet
- (5) 2000 pounds of magnesium metal
- (6) 2000 pounds of aluminum metal fittings
- (7) 4000 pounds of magnesium metal
- (8) 10 Task 2 test specimens supported by 2 wooden beams
- (9) Aluminum sheets over the specimen support beams
- (10) 3500 pounds of red fuming nitric acid contained in 13 aluminum drums
- (11) 1500 pounds of aniline in 3 steel drums

FIGURE 36

View of Fire Tower, Fire Test

Items 1 through 9 were within the limits of the tower, while the last two were positioned atop of the tower on a portable steel and wooden pallet.

A semicircular retaining wall of earth was erected on the downhill side about 24 feet from the center of the tower. The mound; 2 feet high, was used to retain the fuel in the vicinity of the tower. This concentrated the heat of the burning fuels in the tower structure.

The aluminum metal sheets in the tower were positioned to permit maximum air flow through the tower structure; for, calculations indicated that 196,000 pounds of air were required for the complete burning of the fuels and metals, discounting the aniline.

The test specimens, eight in number, were positioned off of two wooden beams located diagonally across the tower's support legs at distances of 22 feet and 28 feet from the ground. The bottom beam was located in a northeast line, while the top beam was 90° to the bottom in a northwest direction. The specimens were supported by chain hoops rigidly fastened to the two beams. Specific positions of each specimen are given in Table 10.

The function of the aluminum sheets over the test specimens was for protection of the specimens against direct contact with the burning fuels. This simulates the condition of the SNAP III generator in a missile structure.

The nitric acid and aniline were secured to the pallet by 1/4-inch diameter steel cables and wooden blocking. Thirteen aluminum drums of nitric acid and one dummy drum were banded and blocked together on the pallet's floor panel, about a central lift column. The aniline, in three steel drums, was positioned on top of the nitric acid. These drums were wired to support braces which were welded to the lift column. Details and dimensions of the pallet were: (1) Floor panel, 7.5 feet squared by 1-inch thick steel plate, reinforced by steel angle iron and perforated to permit fuel flow to the tower structure; (2) Central lift column, steel tube 6 inches in diameter by 10 feet long, welded to the floor and support structure.

Two shaped charges were installed to each of the drums. These were wired to an electrical firing circuit designed to detonate individual charges. Total explosive weight, including squibs, was 15 pounds. The function of this setup was to rupture the fuel drums; so that the hypergolic fuels could mix and ignite the fire. Two charges on each drum were required to equalize forces on the drums, allowing them to remain in a relative position on the pallet when the fuel was released.

3. Instrumentation and Equipment Set-Up

Instrumentation and equipment utilized to measure and record data during this test included:

- (1) Temperature measurements in tower
- (2) Photographic coverage

Temperature measurements were recorded in the tower, to establish a temperature profile. Photographic coverage included the recording of specimen data in the fire, and temperature measurements by color comparison.

The following describes the set-up of this equipment in the tower and field.

(a) Tower Temperature Measurements

There were five thermocouples equally spaced in the vertical plane and approximately in the center of the tower in the horizontal plane. Figure 37 shows a diagram of the approximate locations of these couples.

The first 18 inches of each couple was protected by heat-resistant ceramic tubing. The tubing end opposite the junction was sealed into a 1-3/8 diameter steel pipe. This pipe terminated into a drum buried in the ground at the base of the tower. The drum served as a cold junction. The leads were continued, in a covered trench, to a recorder approximately 500 feet away. Wiring in the steel tubing was protected from the intense heat by water, surged through the tubes under pressure. The water was supplied from a reservoir and the pressure from a 1500 psi air tank, both of which were buried in the ground near the tower. The couples were of the types chromel-alumel and platinum-platinum 10% rhodium as indicated in Figure 37. Continuous temperature readings were recorded in millivolts on a visicorder for 58 minutes.

(b) Photographic Coverage

Camera set-up, film, film speed, location, function and other pertinent information utilized during this test are given in Table 12. There were 11 cameras strategically positioned to record maximum data previously indicated.

4. Test Specimens

Thermal effects were investigated on eight test specimens. These configurations included two generator designs and a fuel capsule of the SNAP III space system.

Figure 37

Tower Temperature Instrumentation, Fire Test

Data for these specimens are given in Tables as follows:

Detail design specifications	Table 1
Detail specimen specifications	Table 2
Detail Test Data	Table 10
Test results	Table 11

All specimens were preheated to core operating temperatures indicated in Table 10. This was accomplished by utilizing 110 volt electrical heaters encapsulated in the core structure. Power was supplied by a portable generator furnishing 220 volts, 60 cycle, single phase service. Temperature was controlled by regulating voltage through a control panel wired between the specimens and the power source. Temperatures were measured by utilizing chromel-alumel thermocouples welded to the test specimen. Temperatures were manually recorded to a time 10 seconds before ignition. In order to maintain temperatures in the cores, each was insulated with 4 inches of cerafelt material.

5. Test Procedures

Prior to the test date, the following set-up procedures were conducted and completed.

- (1) Tower and fuel pallet constructed and erected on test site.
- (2) Scrap metal placed in tower.
- (3) Test specimens positioned in tower.
- (4) Wiring for heating test specimens set-up and checked out.
- (5) Tower temperature instrumentation installed.
- (6) Camera positions and towers erected.
- (7) Fuel retaining wall around tower erected.
- (8) Two safety practice runs conducted on hypergolic fuel pallet.

On the test date, determined by meteorological conditions, a test countdown was initiated. This countdown began two hours prior to ignition. The work accomplished during this period was as follows:

Time: 0 minus 2 hours

- (1) Cameras positioned and checked out
- (2) Hypergolic fuels moved into test area (on separate vehicles)
- (3) Electrical heaters in test specimens energized.

Time: 0 minus 1 hour

- (1) Local meteorological conditions checked and recorded.
- (2) Radio silence established and maintained for the remainder of the test.
- (3) Road blocks in test area set up and maintained.
- (4) Demolition charges installed to fuel containers and firing wires extended to control center. They were shorted and grounded.

Time: 0 minus 20 minutes

- (1) Area within 20 feet of the tower cleared of all personnel except operating crew
- (2) RF-1 fuel tank under tower filled

Time: 0 minus 15 minutes

- (1) Crane operator, wearing high temperature suit, positioned fuel pallet atop of tower

Time: 0 minus 10 seconds

- (1) Time indicated by green flare
- (2) Final specimen temperature readings recorded
- (3) Cameras started
- (4) Instrumentation recorder turned on

Time: 0 - Demolition 14:04:00 hours April 27, 1960

- (1) Explosive charges energized.
- (2) Pertinent data recorded.

Time: 0 plus 30 minutes

- (1) Fire extinguishing operation begun.

Time: 0 plus 58 minutes.

- (1) All equipment turned -- off.

7 Data Recording

Data collected during this test are given in Figures and Tables as indicated below:

(1) Fireball	Figures 38 through 43
(2) Specimen Test Data	Tables 10 and 11
(3) Tower Temperature Measurements	Table 13, Figure 44
(4) Meteorological Data	Table 14, Figures 45 and 46

These data represent information recorded and observed with instruments and photographic equipment previously described. Detailed analysis of this data is given in the test results.

8 Test Results

Test results are summarized in Tables 10 through 14. A detailed results analysis of the fireball, specimens, tower temperature, meteorological data and set-up are presented below.

(a) Fireball

The hypergolic fuels were ignited at time 14:04. Two mushroom fireballs each approximately 150 feet in diameter developed in the following manner. At ignition, the original fireball was 50 feet in diameter and 30 feet off of the ground, as seen in Figure 38. One second after ignition the fireball proceeded to move in all directions. At this time the ball was approximately 90 feet in diameter, with its lower surface 12 feet above the ground. The

FIGURE 38

Fireball at Ignition

upper extremity was 72 feet from the ground. A color comparison temperature reading indicated temperatures as high as 5000°F. See Figure 39. At 2 seconds, the fireball rose to an altitude of 140 feet. Its diameter was about 100 feet, and it ejected a white cloud downward over an area of approximately 8000 square feet. See Figure 40. At 3 seconds after ignition, the original fireball reached its maximum diameter of 120 feet. At this point, it rose to an altitude of 200 feet and the downward cloud was over an area of 12,000 square feet. See Figure 41. The second fireball developed 5 seconds after ignition. As the first began to disperse into a dark yellow to black cloud at an altitude of 250 feet, the second fireball exploded about 30 feet and it encompassed the entire tower. Temperatures were as high as 5500°F. See Figure 42. At 8 seconds after ignition both fireballs were completely dissipated into a dark yellow to black cloud. This cloud proceeded to move down wind from an altitude of approximately 200 feet as shown in Figure 43.

(b) Specimens

The positions of each specimen before, during and after the test are given in Table 10. Conditions of the specimens are summarized in Table 11. All specimens were recovered. Six of these were found on the tower structure and recovered, when the tower was dismantled on May 2, 1960. The remaining two were found in the debris on May 3, 1960.

(c) Tower Temperatures

Temperature recordings as a function of time are given in Table 13. Average temperatures to which the test specimens were exposed during the test are plotted as a function of time in Figure 44.

(d) Meteorological Data

A portable meteorological trailer was located 400 meters downwind from the test tower. The trailer contained instruments to measure and record the wind velocity and direction before, during and after the test. These data are shown in Figures 45 and 46. These figures show data for the first 7 minutes of the test. Wind velocity varied between 10 and 16 miles per hour and wind direction shifted from 360 to 310° measured from 360° true north.

Three balloon runs, to record wind direction, velocity, temperature and density at altitudes up to 10,000 feet, were made at the Meteorological Station at Aberdeen Proving Ground. These runs were made at 12:14, 13:15 and 14:16 hours and the recorded data are contained in Table 14.

FIGURE 39

Fireball 1 Second After Ignition

FIGURE 4/

Fireball 3 Seconds After Ignition

FIGURE 43

Dispersal of Fireball 8 Seconds After Ignition

FIGURE 50

Wind Velocity As A Function Of Time - Fire XXXXXXXXXX Test

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81

Wind Direction As A Function Of Time - Fire Test

(e) Set-Up

After the fire had burned for 30 minutes, the A.P.G. Fire Department pumped water on the test area until 1600 hours. At this time, the fire was nearly extinguished. The mass was still smoking, however, and there was definite evidence of nitric acid fumes. The tower was still standing. See Figure 47. Two days after the test, the debris was still hot and there was still evidence of nitric acid fumes. More water was pumped on and around the test area. Five bags, 400 pounds, of lime were spread around the test area in order to neutralize the acid and decontaminate the area. During the next two days, the test area, including the specimens, was exposed to 0.38 inches of rain. On the fifth day after the test, 350 gallons of a 5% solution of soda ash was sprayed over the debris. On this day the tower was dismantled and 6 of the 8 specimens were recovered. The last 2 specimens were recovered by sifting the debris on the sixth day, May 3, 1960.

TABLE 10
SUMMARY OF SPECIMEN TEST DATA - FIRE TEST

Speci Type	Speci Number	Design Number	Position in Fire Tower (Distance and Direction from Center)	Preheat Temperature	Description of Action on Specimens During Test	Recovery of Specimen, Position and Date
5	8	A-AC	Upper layer, approximately 1 2 feet, S E	1008	Tower Structure and Specimen partially fell after 20 minutes.	On tower structure, recovered May 2, 1960.
5	9	A-AC	Lower layer, approximately 1 2 feet, N E	1008
5	10	A-AC	Lower layer, approximately 1 2 feet, S W	1124		
6	10	B-CH	Upper layer, approximately 2 feet, S E	1006		
6	11	B-CH	Upper layer, approximately 2 feet, N W	1006	Tower structure and specimen partially fell after 20 minutes	On tower structure, recovered May 2, 1960
6	12	B-CH	Lower layer, approximately 2 feet, N E	1002	Fell into burning debris during first 10 minutes	Core sifted from debris May 3, 1960
11	1	C-AA	Upper layer, approximately 1 2 feet, N W	999	Tower structure and specimen partially fell after 20 minutes.	On tower structure, recovered May 2, 1960
11	2	C-AA	Lower layer, approximately 2 feet, S W	1003	Fell into burning debris during first 10 minutes.	Core sifted from debris May 3, 1960. Aluminum shell not recovered.

Note: Specimen support beams were located diagonally across tower structure as follows;
(1) Upper - N W. to S E. direction, (2) Lower - N.E. to S.W. direction

TABLE 11

87.

SUMMARY OF SPECIMEN TEST RESULTS - FIRE TEST

Speci. Type	Speci. No.	Design No.	Exposure Temp. °F			Temp. Exposure Time-seconds		Description of Tested Specimens (Figures 48 and 49)
			Maximum		Ave (30min)	Fire ball	Burning Metals	
			Fire- ball	Burning Metals				
5	8	A-AC	5060	4000	1400	8	0	Copper shell showed indication of air oxidation. No other visible or measurable damage was observed on either the shell or the core.
5	9	A-AC	5060	4000	1400	8	0	Shell oxidized. Assembly weld melted off, releasing cover and exposing fuel core. No damage to core
5	10	A-AC	5060	4000	1400	8	0	Same as 5-9.
6	10	B-CH	5060	4000	1400	8	0	No damage.
6	11	B-CH	5060	4000	1400	8	0	No damage.
6	12	B-CH	5060	4000	2000	8	600	No damage to core; however, there was some indication of oxidation on the metal surface.
11	1	C-AA	5060	4000	1400	8	0	Surface of aluminum shell oxidized slightly. Shell remained intact. Core showed no damaging effects
11	2	C-AA	5060	4000	2000	8	600	Aluminum shell consumed by the environment; however, exposed core remained integral with slight indications of surface oxidation.

FIGURE 48
Tested Specimens - Fire Test

FIGURE 49
Tested Fuel Core Specimens - Fire Test

TABLE 12

CAMERA SET-UP - FIRE TEST

Camera No.	Camera Type	Film Type	Film Speed fps	Film Running Time min	Lens	Camera Location	Remarks
1	16mm Cine	Ektachrome Color	24	Manual Control	1 inch 3 inch wide angle		General documentary of test setup, test and post test including preparatio and damage. Also general site scenes
2	16mm Mitchell	Ektachrome Color	24	33	1 inch	1000 feet from fire tower on windward side of tower	Fixed camera position with target pole 20 ft. high, 2x2 foot target located 100 feet in front of camera. Positioned off center of subject tower to show cloud drift
3	16mm Bell and Howell	Ektachrome Color	24	30 for tacking	6 inch	On 150' tower 3000 feet from fire tower, leeward side	Tracking camera, to record fire test and secondary ignition.
4	Hulcher camera with frame rate sequence	Color	Intermittent	30	Tele photo	On 150' tower as above	For complete coverage of test data collections of cloud movements and size.
5	16mm Bell and Howell	Ektachrome	24	Manual Control	6 inch	Test Control Center	To record any unforeseen events at the fire tower
6	16mm Cine	Ektachrome	24	Manual Control	zoom lens	Test Control Center	General documentary of test. Target pole to be used to determine cloud rise and size

TABLE 12 (continued)

7	16mm Model K	Ektachrome 2 Color	33.3	1 inch	In marinite box on 20 ft tower 150 ft from fire tower	Field of view 19.37 feet in horizontal and 14.50 feet in vertical plans. To record action of test specimens in fire.
8	16mm Model	Ektachrome 2 Color	33.3	2 inch	In marinite box on 20 ft tower 100 ft from fire tower	Field of view 19.25 feet horizontal 14.42 feet in vertical plans. To record action of test specimens in fire.
9	16 mm Cine	Ektachrome 24	6.12 ran intermittently	1 inch	Same as #7	Same as #7
10	16mm Cine	Ektachrome 24	6.12 ran intermittently	6 inch	Same as #9	Field of view 6.33 feet in horizontal and 4.23 feet in vertical plans to record action of test specimens in fire
11	16mm	Ektachrome 1500 Color	5 sec.	Fastax	At control Center	To record first 5 seconds of fireball.

NOTE: All remotely operated cameras are started 10 seconds before start of test

TABLE 13
SUMMARY OF TOWER TEMPERATURE DATA - FIRE TEST

Time		Thermo-	T.C.	T.C.	T.C.	Highest	Time		T.C.	T.C.	T.C.	T.C.	Highest
Sec	Min	couple	No. 3	No. 4	No. 5	Temp.	Sec	Min	No. 1	No. 3	No. 4	No. 5	Temp.
		No. 1				Film							Film
0		Ambient	Ambient	Ambient	Ambient	Ambient	420	7	1543	1628	1519	1472	3970
10		Ambient	Ambient	Ambient	Ambient	3600	450		1510	1565	1455	1375	3960
20		230	1757	1578	165	5000	480	8	1418	1502	1389	1278	3940
25		340	4200	1610	1670	5100	510		1370	1460	1350	1240	3920
30		450	1700	1649	2592	5000	540	9	1332	1413	1312	1205	3900
40		824	2464	1442	831	4720	570		1325	1404	1306	1195	3860
50		1045	1874	1229	736	4540	600	10	1319	1395	1300	1186	3800
60	1	1198	1779	1133	1288	4200	660	11	1259	1327	1258	1123	3750
70		1124	1413	917	704	4000	720	12	1191	1260	1182	1060	3700
80		1144	1121	701	514	3200	780	13	1121	1186	1124	977	3650
90		1140	860	1473	374	1720	840	14	1054	1112	1062	904	3600
100		1150	670	1596	301	1960	900	15	1028	1060	926	863	3550
110		1182	707	458	920	2160	960	16	958	1014	710	809	3500
120	2	1054	590	350	444	2300	1020	17	917	977	673	587	3500
130		1067	584	747	501	2440	1080	18	835	937	527	533	3480
140		1102	559	1920	552	2500	1140	19	853	916	512	514	3460
150		1108	415	1735	650	2800	1200	20	837	906	530	533	3460
160		1131	1234	1589	777	3040	1260	21	645	436	340	577	3480
170		1204	1812	1272	806	3160	1320	22	645	452	343	634	3500
180	3	706	989	485	872	3240	1380	23	645	492	340	546	3520
190		965	1204	494	920	3400	1440	24	623	476	309	492	3560
200		1428	1275	299	964	3540	1500	25	613	485	290	470	3560

TABLE 13 (continued)

210		1322	1091	593	495	3620	1560	26	597	476	290	428	3600
220		1565	1597	932	1110	3660	1620	27	581	476	290	428	3600
230		1460	1511	1025	1117	3720	1680	28	572	492	266	444	3650
240	4	1418	1398	1327	634	3760	1740	29	454	504	269	444	3700
270		1428	1521	1287	1015	3860	1800	30	460	492	269	482	3900
300	5	1514	1628	1445	1364	3920	1920	32	454	492	272	666	4000
330		1565	1653	1544	1475	3940	2160	36	470	507	278	634	3980
360	6	1572	1674	1550	1513	3960	2400	40	480	492	278	508	3800
390		1555	1645	1535	1490	3980	3480	58	150	169	161	419	

- NOTES: 1. Thermocouple numbers 1 through 4 - chromel-alumel.
 2. Thermocouple number 5 - platinum-platinum 10% rhenium.
 3. Thermocouple number 2 was destroyed before test.
 4. Film temperatures were estimated by flame color comparison.
 5. Ambient temperature 67°F.

TABLE 14

SUMMARY OF METEOROLOGICAL DATA - FIRE TEST

Time HR: min	Altitude Feet	Wind Direction (To) Degree	Wind Velocity m.p.h.	Temperature °F	Relative Density
12:14	0	335	12.0	71.6	0.985
12:15	1110	342	13.0	63.2	0.997
12:16	2250	327	14.8	58.3	1.002
12:17	3390	325	15.5	54	1.006
12:18	4545	322	16.4	50	1.007
12:19	5775	306	13.4	46	1.011
12:20	6630	283	16.5	44.5	1.010
12:21	8070	272	21.4	39	1.014
12:22	9240	257	23.7	36	1.012
12:23	10,470	253	31.3	33	1.011
13:15	0	330	5.0	71.1	0.986
13:16	1140	338	15.9	64	0.997
13:17	2160	333	16.9	57.3	1.004
13:18	3210	322	17.5	54	1.008
13:19	4260	313	18.3	51	1.007
13:20	5430	307	15.0	49	1.008
13:21	6645	287	12.5	45	1.003
13:22	7830	278	13.9	41	1.011
13:23	8940	274	16.6	36	1.015
13:24	10,155	290	22.4	34	1.010
14:16	0	330	10 + 16	66.2	0.997
14:17	885	341	23	59.0	1.008
14:18	1800	337	17.9	56.0	1.008
14:19	2700	324	9.7	55	1.007
14:20	3705	301	9.8	53.5	1.004
14:21	4680	298	14.6	51	1.007
14:22	5625	301	14.7	48	1.007
14:23	6615	308	15.3	44	1.011
14:24	7590	307	15.6	39	1.013
14:25	8625	290	11.0	37	1.015
14:26	9660	245	14.2	33	1.015
14:27	10,680	237	26.3	33	1.011

Fire ignition time - 14:04

Surface Data (ignition time)

Sky - overcast Temperature - 67°F Relative Humidity - 78%
 Wind Direction (to) 320 Visibility - 6 miles - Haze S.L. Pressure - 29.86
 Relative Density - 0.994 Wind Speed 5 mph gusts to 16

V. CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions and recommendations, based on experimental results, for the two generator configurations and the re-entry burnup fuel core design being considered for the space version of the SNAP III Thermoelectric Generator.

Generally, the experimental program showed that all designs investigated would be a nuclear safe system; however, a single recommendation might be considered so as to enhance the already complete integrity. This recommendation is to replace the second steel capsule containing the two fuel containers, with a capsule fabricated from a material with chemical characteristics to resist corrosion by hot red fuming nitric acid. Preliminary investigations indicate that either tantalum or vanadium can be used. This change would provide an added degree of safety, especially in a missile launch pad fire, where test results indicated that hot red fuming nitric acid might be detrimental to the core material.

Since the test program described in this report has been justified as being the most stringent set of conditions in terms of mechanical thermal and chemical forces, imposed on the generator system during its life span, system safety conclusions can be verified by the results of these experiments.

Although the generator shell failed, structurally, in a few of the test situations, the fuel core remained structurally integrated under all conditions. Therefore, with the one recommendation included in the design, it can be concluded that the two generator systems tested can be utilized on space missions without endangering mankind.